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A pathway to Europe's Competitiveness: The clean transition

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A pathway to Europe's Competitiveness: The clean transition

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Abstract

This report provides a comprehensive overview of the European Union's clean transition as a pathway towards competitiveness. Adopting a systems-thinking perspective, it examines how coordinated action across climate, energy, circular economy, mobility, agri-food systems, biodiversity and ecosystems protection can contribute to a more resilient and resource-secure Europe.

The report identifies evidence-informed enablers to strengthen long-term competitiveness while delivering on the EU's climate and environmental ambitions. In doing so, the report further emphasises the enabling role of innovation, research and technological development in accelerating the uptake of clean technologies and enabling the transformation of production and consumption systems. In parallel, it examines the implications of global supply-chain vulnerabilities and critical raw materials dependencies, highlighting geopolitical pressures on the EU's strategic autonomy.

Finally, the report identifies a set of cross-cutting enabling conditions necessary to support transformative change across sectors and governance levels. These include the mobilisation of private and public investments, strengthened research and innovation ecosystems, education and skills development, improved monitoring and data systems, enhanced policy coherence across domains and governance levels, climate adaptation and resilience, a regenerative economy, and the advancement of a fair and inclusive clean transition. Together, these horizontal dimensions are presented as foundational conditions for enabling coordinated implementation of sustainable competitiveness, towards a prosperous and climate-neutral economy.

Foreword

Bernard Magenhann
Director-General, Joint Research Centre

The European Union stands at a decisive crossroad, where the urgency of supporting economic prosperity and competitiveness while strengthening energy security and strategic autonomy must align with the need to ensure citizens' wellbeing, build a climate-neutral economy, protect the environment and achieve the EU's One Health ambitions.
To address these multifaceted challenges, we must be guided by scientific evidence and translate European innovations into scalable solutions. It is my pleasure to introduce this flagship report on the clean transition as a pathway for EU competitiveness. It highlights the role of the clean transition as a pivotal driving force of a resilient and prosperous Europe. This study is the result of collective efforts and extensive multi-disciplinary collaboration among many scientists of the European Commission's Joint Research Centre.

Decarbonising our economies will reduce the EU's long-standing dependence on imported fossil fuels, enhancing energy security and reducing the risk of energy supplies being used as geopolitical leverage. The clean transition is pivotal in accelerating domestic clean-energy technologies, circular business models, and sustainable industrial practices. This is projected to result in creating high-quality jobs, stimulating innovation and opening new global markets while leaving no region or community behind. The report demonstrates that coordinated action across key sectors such as energy, industry, mobility, agri-food, as well as circular and bioeconomy, can deliver the triple ambitions of competitiveness, security and autonomy.

The pathways outlined in the report bridge the divides between priorities across different sectors with a focus on enabling conditions for sustainable competitiveness: implementing a fair and just clean transition; financing the transition; boosting innovation and knowledge infrastructure through education, skills and data; promoting a regenerative economy; mainstreaming adaptation and resilience; enforcing coherence across policies and governance scales.
I would like to invite policymakers, industry leaders, academia and civil society to engage with this evidence-based study and to seize the opportunity to shape a clean, innovative, and secure future for Europe. I hope this report will serve as a catalyst for a truly transformative effort, moving our collective ambition into concrete, lasting actions that benefit both current and future generations.

Bernard Magenhann
Director-General of the Joint Research Centre (JRC),
the European Commission's in-house science and knowledge service

Authors & Acknowledgements

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Executive Summary

Staying the course on the clean transition, while accelerating investment in decarbonisation, digitalisation and strategic technologies, is essential to safeguarding and boosting Europe's competitiveness in a sustainable and resilient way. This is a key message of Mario Draghi's flagship report, *The future of European competitiveness*, and is reflected in President von der Leyen's Political Guidelines for the European Commission of 2024-2029, as well as in her 2025 State of the Union address to the European Parliament.
In her mission letters to the Commissioners, the President further emphasised that "*Proposals must be evidence-based" and that "the Joint Research Centre, our internal scientific service, can support [...] you in that work*". In this context, the JRC has analysed **key challenges** and proposed **evidence-informed enablers** to accelerate the implementation of the clean transition, viewing it as central to EU competitiveness and its three pillars: **decarbonisation**, **innovation**, and **strategic autonomy**.

This report, together with the accompanying "*Essential brief*" (JRC147034) builds on a collaborative effort among JRC scientists, integrating and managing knowledge from both within and outside the JRC. The report identifies challenges hampering the implementation of a range of clean transition ambitions across multiple domains (climate, energy, circular economy, mobility, food systems, biodiversity and ecosystems). Building on this analysis, it goes a step further by seeking to convert those challenges into **opportunities** for Europe's competitiveness by proposing evidence-informed enablers that support **a smart, coherent and forward-looking implementation** of the clean transition. Finally, it distils the enabling cross-cutting conditions required for success (including finance, policy coherence, R&I, education and skills, better data and monitoring, regenerative approaches to the economy and enhanced adaptation to climate change) as the fundamental building blocks of the clean transition.

This report explores the *nexus* between the clean transition and EU competitiveness from an integrated perspective, emphasising how **environmental sustainability, economic resilience and social wellbeing are mutually reinforcing.** In doing so, the report pinpoints **where further action is needed to advance the transition while strengthening competitiveness**, securing access to clean energy and resources, and supporting citizens' wellbeing.
By **operationalising** the concept of competitiveness within the clean transition, the study translates scientific evidence into **actionable insights**, strategic priorities and **implementation checkpoints** for policy and investors, thereby supporting 2030 and 2050 policy objectives. Additionally, it breaks down sectoral silos to identify systemic challenges and common enablers, paving the way for a more integrated approach to implementation.

We are firmly on track to achieve our 2030 target to cut emissions by at least 55%. This is the power of the European Green Deal. And we must stay the course on our climate and environmental goals.

President von der Leyen, SOTEU 2025

Overall, **the analysis demonstrates that the clean transition is one of the strongest foundations for Europe's competitiveness**, requiring a coherent and transformative policy and investment effort to secure Europe's sustainable prosperity. While short-term measures are important to support households and firms, lasting competitiveness depends on sustained investments that strengthen resilience – such as securing access to critical resources, including water, energy, and raw materials, and **reducing dependence on fossil fuels**. At the same time, the transition is reshaping global markets: the rapid scale-up of clean technologies, with countries like China already accounting for a significant share, illustrates how leadership in clean industries is becoming a key determinant of future economic strength.

Background

Building on the JRC 2025 flagship report "*Delivering the EU Green Deal: Progress towards targets*", this study provides an extensive, evidence-based overview of the conditions for enhancing competitiveness in the EU's pathway towards the clean transition with a focus on the areas where implementation is more urgent and requires acceleration. It maintains the structure adopted in the previous report, focusing on the key areas of climate ambitions, clean energy, circular economy, mobility, food systems, biodiversity protection and zero-pollution objectives.
Adopting a systems-thinking perspective, it also discusses the costs of not taking measures to address climate change and environmental degradation, and a range of cross-cutting enabling conditions underpinning the transition.

The analysis is framed around the ***Competitiveness Compass***, which links clean-transition policies to three pillars: *A joint roadmap for decarbonisation and competitiveness; Reducing excessive dependencies and increasing security;* and *Closing the innovation gap*. Each pillar is supported by flagship actions and horizontal enablers (with a focus on Financing, Better coordination, and Skills and quality jobs). Overall, this work advances the identification of evidence-based enablers for the clean transition, **bridging** the previous European Commission's headline priority, the EU Green Deal (2019-2024) and the current Commission's competitiveness agenda (2024-2029).

Key messages

Previous JRC analysis shows **mixed progress** on the Green Deal targets: 21% of targets are "on track", whereas 41% have to accelerate to meet the EU's ambitions, highlighting the need for increased implementation efforts to achieve the EU's environmental and climate goals. Existing progress suggests that **food and housing** offer the greatest potential, whereas mobility, household goods and appliances are expected to remain a challenge even when targets are reached, because **consumption levels** are expected to rise.

Since the pace of implementation remains uneven, the consequences of delaying action become increasingly severe. Evidence suggests that the **costs of inaction** are rising across health, ecosystems, and the economy. Recent events illustrate the toll already being paid: the October 2024 flash floods in Valencia claimed around 237 lives (accounting for 70% of all flood-related deaths in Europe that year) while wildfires across Southern Europe caused an estimated €13–21 billion in annual production losses on average. By 2100, heat-related deaths could rise by tens of thousands annually, and flood and drought damages could amount to hundreds of billions of euros per year.

The **economic cost of biodiversity loss** is already estimated at around 3% of EU GDP annually, with global losses of key ecosystem services approaching US $480 billion per year. The degradation of natural capital, biodiversity and ecosystem services therefore creates substantial economic risks that far outweigh the costs of preventive action. Nevertheless, the same evidence also shows that timely conservation and restoration generate benefits that exceed their costs, reinforcing the economic case for immediate action. The most recent energy crisis and geopolitical challenges with regard to fossil fuel supply further stress the role of climate-policy instruments – in particular carbon pricing – for the EU's energy security and economic resilience.

A **cost-effective decarbonisation** of the EU's economy therefore requires a combination of measures: carbon pricing, social safeguards and strengthening carbon sinks. The *Emissions Trading System* (ETS) and carbon credits mechanisms are key drivers of emissions reduction. By internalising the true cost of carbon, the ETS also curbs demand for imported fossil fuels, thereby reducing the Union's vulnerability to supply interruptions and to the strategic weaponisation of energy resources. Strategic deployment of key enablers, including ETS revenues and EU funds, can support the transition and drive sustainable growth. Although carbon pricing creates a strong price signal, several sectors still face structural constraints that the price alone cannot resolve.

The **food and land sectors** remain constrained by the limited abatement options in agriculture and by the decline of land carbon sinks. Climate-smart agriculture, carbon farming and sustainable forestry, together with incentives for agroecological approaches such as agroforestry, can further shift the food system toward greater sustainability and resilience while restoring natural carbon sinks. Implementing these nature-based measures will require substantial investment, an area in which the private sector can play a decisive role.

Dedicated funds and policy measures are essential to support the **private sector** towards GHG reduction goals. Further, socioeconomic and health benefits can be achieved in tandem with emissions reductions, for example through reduced morbidity and mortality due to exposure to pollution and toxic environments, thereby optimising both health outcomes and public spending. These private-sector investments will be critical to finance the large-scale deployment of renewable generation and deep-retrofit programmes.

Achieving a 42.5% share of renewable energies by 2030 is fundamental to meeting EU climate targets. Scaling renewables such as solar and wind, alongside deep retrofitting of buildings, is necessary to deliver **cleaner, affordable energy**, accelerate the transition, reduce dependence on imports by producing more affordable domestic energy, and improve health outcomes.
However, progress is hindered by fragmented markets, slow permitting, material supply risks, and shortages of skilled workers. Deployment of renewable hydrogen and the retrofitting of buildings also face obstacles, including high costs and outdated energy standards. Yet, the speed of deployment is also shaped by social-equity factors that must be addressed in parallel.
Addressing these aspects calls for **coordinated** policy efforts, targeted **investment**, dedicated funding and a skilled **workforce**. Growing inequality, in particular the difficulty that lower-income households face in securing adequate housing, constitutes another challenge to the deployment of decentralised energy systems (solar rooftops, energy communities) and for improving **energy efficiency** in buildings.

Supply chain dependencies and vulnerabilities undermine the EU competitiveness and impede the twin transition towards a greener, more digital economy. This is especially true for the production of **Critical Raw Materials** and components for strategic value chains, where extraction must be balanced with biodiversity protection, ecosystem services and the rights of local populations, all within an increasingly complex geopolitical context and tighter trade restrictions. Reducing these external dependencies therefore calls for a stronger circular-economy approach.
Redirecting existing fiscal support for linear models towards **circular economy** practices, while ensuring externalities are accounted for in prices, could strengthen the competitiveness of circular practices. Alongside the *Ecodesign for Sustainable Products Regulation* (ESPR) for repair, preparing for re-use and remanufacture, **economic instruments** to facilitate trade in these products and reforms to labour-oriented tax system are essential.
Leveraging public-private initiatives to stimulate investments in waste management infrastructure, strengthening economic incentives to deter landfilling, and exploring measures to foster long-term demand for secondary raw materials can support continuous development and functioning of **secondary raw materials markets**.

A **shift to low-emission mobility** offers market and health benefits but requires rapid rollout of charging and refuelling infrastructure, targeted incentives for vehicle electrification and renewable hydrogen deployment, and real-world emission benchmarks for vehicle performance and certification. Transport, energy and food systems all depend on coherent, system-wide governance.

A **sustainable EU food system** requires integrated, cross-sectoral governance that links agriculture, fisheries, waste management, trade and health policies. Such a system must adopt a whole-value-chain perspective, from production to consumption, avoid food waste and ensure coordination across EU, national and local levels. **Sustainable production** and **healthier diets** can be advanced through fiscal incentives, public procurement, and education that foster behavioural change and make sustainable choices easy and affordable, while promoting nature-based and circular solutions – including waste prevention. Redirecting subsidies towards low-impact and climate-resilient farming can strengthen farmers' position in value chains, securing fair income and market access. Closing data gaps on soil, land, biomass and carbon is essential for monitoring ecosystem condition, assessing pressures and improving accountability. Better data underpin resilience and long-term sustainability across the food system.

Delivering on policy targets that support the clean transition can boost EU competitiveness by reducing **environmental externalities**, resource dependencies, and the degradation of natural capital. **Demand-side** and **lifestyle** changes, particularly through more sustainable and healthy consumption patterns, such as reduced energy consumption and low-emission mobility through greater use of zero-emission vehicles, public transport, and active mobility (like walking and cycling), hold significant potential for reducing environmental impacts.

Beyond sector-specific insights, the report stresses several **horizontal enabling conditions** for transformative change. These are: the adequate mobilisation of financial resources; innovation and knowledge infrastructure alongside the necessary education and skills development; regenerative economy uptake; mainstreamed adaptation and resilience; improved monitoring, data systems, and communication; a fair and inclusive clean transition; increased horizontal (cross-domain) and vertical (among governance levels) policy coherence.

Report rationale and link with Competitiveness

Chapter 1
Introduction. The clean transition as a pathway for a sustainable future

Introduction

SECTION A

Focus on clean transition **targets** for which **more efforts are needed** to achieve the ambitions across 7 thematic areas: (1) *Climate action*, (2) *Clean, affordable and secure energy*, (3) *Circular Economy*, (4) *Sustainable and Smart Mobility*, (5) *Sustainable and Resilient Food Systems*, (6) *Preserving and protecting biodiversity*, (7) *Zero-pollution ambition* ✶

Pillar 2 ✶

A joint roadmap for decarbonisation and competitiveness

SECTION B

Chapter 2 ✶
Towards sustainable competitiveness: challenges and enablers

Chapter 3
Environmental impacts of future scenarios

Competitiveness compass'

Horizontal enablers

SECTION E

Chapter 6
Financing the clean transition

Chapter 7
Ensuring a fair and just transition

Chapter 8
Horizontal enablers

✶ Marelli, L., Trane, M., Barbero Vignola, G., Gastaldi, C., Guerreiro Miguel, M. et al., ***Delivering the EU Green Deal - Progress towards targets***, Publications Office of the European Union, Luxembourg, 2025, JRC140372.

✶ As presented in COM(2025) 30 *A Competitiveness Compass for the EU* and related Factsheet.

✶ The chapters are accompanied by thematic navigators with a graphic synthesis of challenges and evidence-informed enablers' mixes, covering Critical Raw Materials and the 7 European Green Deal thematic areas.

This report is organised around **8 interconnected chapters**, as illustrated below and accompanied by a summary document (***The Essential brief***, JRC147034). Together, they propose a structured **journey towards the EU's clean transition and competitiveness**. The report begins with a review of the progress achieved to date, then analyses the challenges and **evidence-informed enablers** to accelerate the transition and provides scenario-based insights on environmental impacts. Thematic **graphic navigators** capture the findings in a snapshot and offer a broad overview on desirable pathways towards the policy ambitions. Knowledge is organised around the three ***Competitiveness Compass*** pillars, their horizontal enablers and key flagship actions, including raw materials and resource security, the role of the bioeconomy and R&I, climate adaptation under a fair and just transition. The final three chapters focus on the **horizontal enabling conditions** needed to deliver the transition.

Pillar 3 ✶

Reducing dependencies and increasing security

SECTION C

Chapter 4 ✶
Reducing dependencies and increasing resilience

- Critical Raw Materials for the clean / digital transition
- Sustainable use of biomass
- A sustainable and regenerative environment
- Climate adaptation and resilience
- International collaboration on the global challenges

Pillar 1 ✶

Closing the innovation gap

SECTION D

Chapter 5
Closing innovation gap

- The role of R&I
- Innovation in the clean energy sector
- Innovation in the bioeconomy
- Biotechnologies
- The blue economy
- The digital transition

Conclusions

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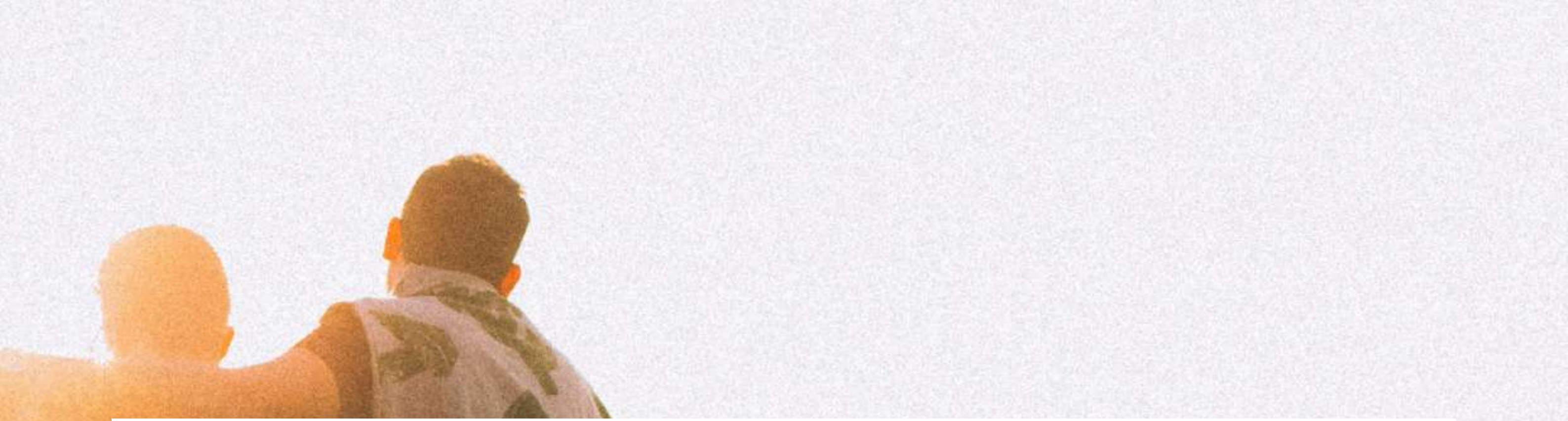
Enabling a clean transition supporting EU competitiveness

- An integrated transition
- Enabling conditions for a sustainable competitiveness
- Looking ahead

01

Section A
Introduction

Introduction: The Clean Transition as a pathway for a sustainable future



Key messages

The clean transition is a strategic pillar of the European Commission's 2024-2029 priorities and can provide key support to the **EU's competitiveness and security agenda,** linking climate neutrality with economic resilience and strategic autonomy; and advancing progress towards the **Sustainable Development Goals** (SDGs) by 2030.

The costs of not achieving climate and biodiversity goals are expected to be substantial, with significant economic, social, and environmental consequences, including thousands of additional deaths, widespread flooding, water scarcity, and severe impacts on ecosystems and the economy.

The clean transition simultaneously drives decarbonisation and strengthens EU energy security by reducing dependence on imported fossil fuels, limiting exposure to price volatility, and curbing the risk of energy being used as a geopolitical weapon.

The clean transition offers **substantial economic opportunities**. Environmental protection, conservation and restoration are **worthwhile investments** with significant long-term benefits.
Failing to act will result in significant economic and social costs, including loss of ecosystem services, increased prices of basic commodities, and disruption of supply chains, which may compromise the EU's strategic autonomy. Climate risk assessments show EU GDP losses of up to 0.7% by 2050 if the 2 °C pathway is missed, underscoring the competitiveness case for urgent delivery.

Climate change poses significant and growing **risks to human health**. These impacts are expected to worsen existing health inequalities, with disproportionate consequences for vulnerable groups and far-reaching implications for social stability, labour productivity, and public systems.

Public support for the clean transition is strong, but acceptance hinges on visible delivery and concrete benefits for citizens and firms. Public reactions to specific policies vary with perceived near-term socio-economic impacts and costs.
Effective communication is key to maintaining public trust. Transparent, inclusive and adaptive communication strategies emphasise the benefits of environmental policies and address sector-specific concerns.

Previous JRC analysis has shown that **progress towards EU Green Deal targets is mixed**, with 21% of targets currently "on track" and 41% requiring accelerated progress, highlighting the need for increased implementation efforts to achieve the EU's environmental and climate goals.

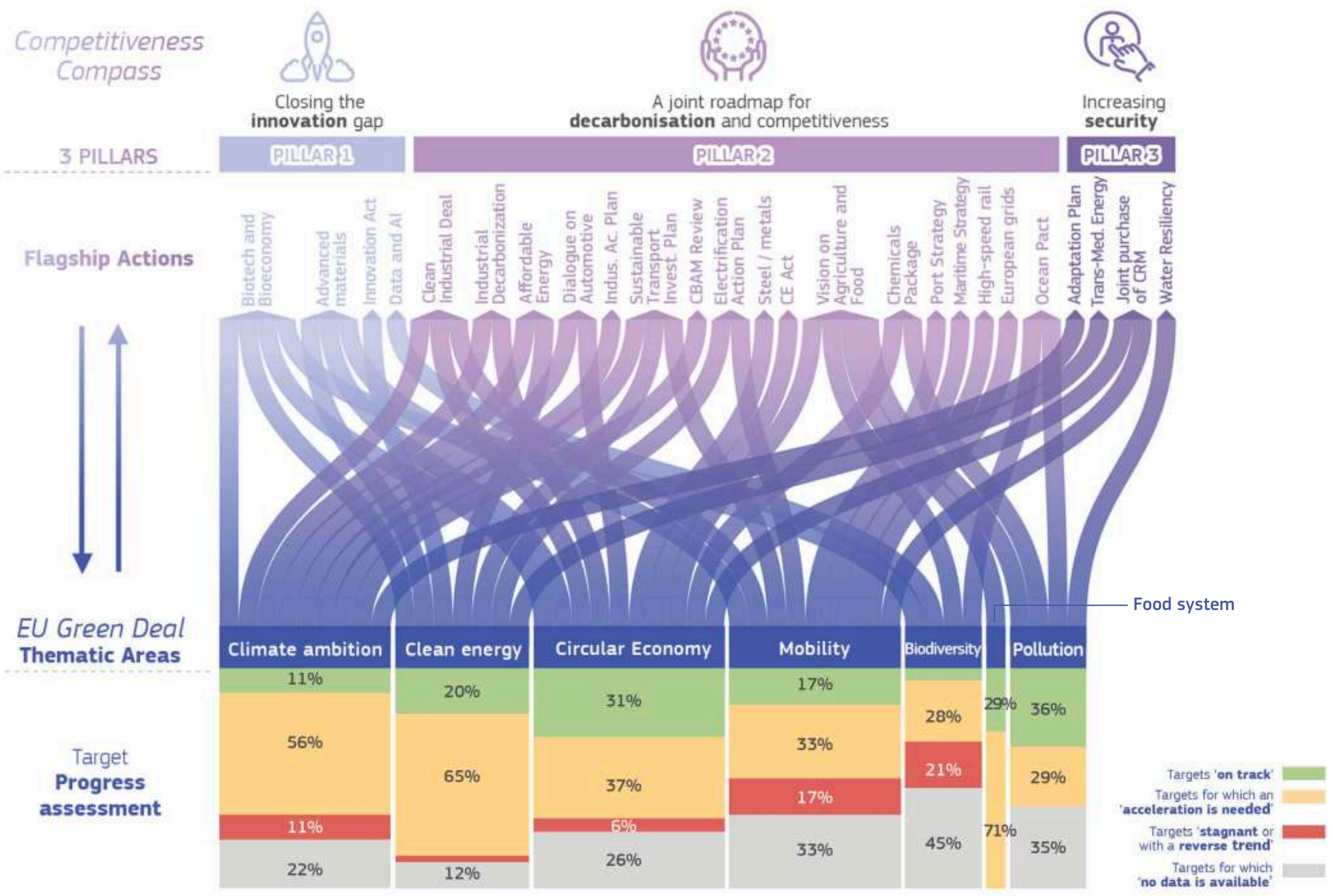
1.1 The clean transition AS a catalyst for the EU's political priorities

The EU's *Strategic Agenda 2024-2029 on Competitiveness* [1] underscores the central role of the clean and digital transition in steering Europe towards sustainable development and economic resilience. Amidst evolving global challenges, including geopolitical tensions and shifting economic power dynamics, this renewed focus on sustainable clean transition is primarily driven by the pressing need to address the triple planetary crisis (climate change, biodiversity loss and pollution) fueled by resource depletion.

In this context, the objectives of the clean transition continue to be central to the EU's 2050 climate neutrality ambitions, integrating climate action with citizen and environmental health, while decoupling economic growth from environment degradation and ensuring intergenerational fairness.

At the start of her second mandate, the European Commission's President von der Leyen reaffirmed her commitment to the goals of fostering economic resilience, social cohesion, and global leadership on climate and environmental action [2]. Since 2019, the EU has made **significant progress** in driving the EU's transition to a low-carbon, zero pollution and biodiversity-friendly economy. However, the implementation of clean transition policies has been slowed down by multiple interconnected challenges. The EU's competitiveness in the global market is shaped by both external pressures, such as rising geopolitical conflicts and unprecedented trade tensions, and internal structural factors, such as excessive fragmentation and territorial asymmetries [3]. External pressures can reinforce existing weaknesses, including historically lower levels of private investment in R&I compared with competitors.

Figure 1. The role of the EU Green Deal policy thematic areas in relation to the Competitiveness compass pillars and selected underlying flagship actions.



Source: Authors' elaboration.

Aligning **climate neutrality and a nature-positive economy** (i.e., an economic system that aims to stop and revert biodiversity loss, while also minimizing environmental damages) with **competitiveness** is essential to the EU's success and is reflected in the political priorities of the 2024-2029 European Commission mandate. The *Competitiveness Compass* [4] is composed of three pillars with related flagship actions (Figure 1), focusing on: a joint roadmap for decarbonisation and enhanced competitiveness; closing the innovation gap; reducing energy dependencies and increasing security. Failing to implement EU's clean transition policies could seriously undermine these new political priorities and compromise EU's strategic autonomy. In turn, the success of the clean transition depends not only on **environmental progress,** but also on economic resilience combined with ensuring fair opportunities for all – a balance necessary to meet rising global tensions and competition [2], [5]. Addressing this challenge calls for a **comprehensive approach** that integrates *sustainability* into the EU's socioeconomic framework (Focus 1).

The fourth *Global Trends Report*, produced by the European Strategy and Policy Analysis System (ESPAS) [6], identifies global challenges affecting the EU in the medium-to-long term. These include the aggravation of the environmental and climate crisis, the need to accelerate the clean energy transition, and the reliance on new technology development to reach the EU's climate and environmental targets, all of which call for **urgent action to boost the clean transition.** This is the necessary response and vital opportunity to face such challenges, to be pursued in a way that balances environmental protection and climate action with social justice and economic resilience.

Further, recent analysis by the World Economic Forum [7] underscores that the clean transition offers substantial **economic opportunities**. This 2026 report highlights that a shift towards a nature-positive economy could generate up to $10.1 trillion in annual business revenues and cost savings by 2030, and potentially create 395 million jobs, driven by emerging sectors such as regenerative agriculture, ecosystem restoration, and nature-based solutions. Therefore, investing in these areas represents a major opportunity for innovation, new markets, and job creation, reinforcing the case for a proactive and opportunity-oriented approach to the clean transition.

The clean transition is not a costly burden. It is a **catalyst for EU competitiveness**, driving innovation and growth while ensuring a sustainable and equitable future (Focus 1). It offers **responses to many EU and global challenges,** securing the biosphere and EU citizens' health, and meeting overarching global sustainability objectives such as the 2030 Agenda **Sustainable development Goals (SDGs).**
Furthermore, the clean transition is a strategic pillar for **energy security**. Structural dependence on imported fossil fuels has historically exposed the EU to geopolitical risks. Climate policy instruments discourage fossil fuel use and incentivise domestic clean energy investments, reducing exposure to global price volatility. Reducing reliance on imported oil and gas is also crucial to limit the scope for the "weaponisation" of energy trade, as seen during the gas disputes in Russia's invasion of Ukraine [8].
In this sense, climate policy, industrial policy, and security policy increasingly converge: the clean transition and decarbonisation strengthen not only environmental outcomes, but also economic resilience and strategic autonomy.

The 2025 JRC report **"Delivering the EU Green Deal - Progress towards targets"** [8] notes that while progress has been made in aligning policies to implement the transition towards enhanced sustainability of the economy, implementation gaps still persist. This work is an important piece in the puzzle of understanding where the EU stands, and underlines the need for enhanced coordination, targeted investment, and policy cohesion (Section 1.5). Achieving these targets is key to boosting EU competitiveness.
Building on these considerations, the present report aims to identify the leverage points to bridge the remaining gaps and accelerate progress towards policy achievement and enhanced competitiveness. This report is organised along the three Competitiveness pillars on decarbonisation, security and innovation, unveiling evidence-informed enablers to foster progress towards the EU's clean transition goals while securing EU's competitiveness agenda.

Focus 1 A macro-economic picture

The **European Green Deal** aims to transform the EU into a resource-efficient and **competitive economy**, ensuring **no net emissions** of GHGs by 2050. To achieve this ambitious target, it is essential to consider the **macroeconomic context** across different sectors and trends with the help of key indicators. This analysis is based on datasets provided by **Eurostat**, with a detailed **breakdown of macroeconomic variables** across time in EU27. This focus extends the broad analysis proposed in the ***Statistics for the European Green Deal*** [9]. Table 1 quantifies the distribution of **key indicators** – Gross Added Value (GVA), employment in terms of jobs per thousand persons, GHG emissions, and investments for the EU27, by sector of activity. It presents both the relative shares and absolute values of these indicators, providing a comprehensive view of the economic and environmental metrics of these sectors.

Table 1. Quantification (shares and absolute numbers) of main indicators (GVA, jobs, emissions, investments) by macro-sector, for EU27, 2023.

	Gross Value Added (GVA)		Employment		GHG Emissions[1]		Investments	
	%	million €	%	1,000 pp.	%	Mt CO_2eq.	%	Million €
Industry	14%	2,249,914	12%	25,856	24%	640	26%	924,876
Energy & mining	3%	484,801	1%	1,644	24%	630	0%	2,094
Trade	11%	1,748,805	14%	29,969	3%	74	5%	179,788
Transport & storage	5%	743,326	5%	11,410	17%	460	1%	22,209
Construction	6%	871,563	7%	14,549	2%	55	43%	1,505,768
Services	56%	8,689,507	53%	115,488	11%	285	25%	896,893
Food system	5%	757,564	9%	18,793	19%	517	0%	7,220

***Source**: Authors' compilation, based on Eurostat statistics.*

[1] GHG emission by economic activity (production side)

GVA

€ 2,249,914

The **Industry sector** is the largest contributor to GVA after **services**, with a 14% share. Following, the **Trade sector** contributes 11% (€ 1,748,805 million), and the **Construction** sector adds 6% (€ 871,563 million).

Employment

53% people

are employed in the **Service sector** (115,488 thousand persons), followed by **Trade**

7% people

are employed in the **Construction**, 9% are employed in the **Food system** sector

Investment

Investments are concentrated in the **Construction** sector:

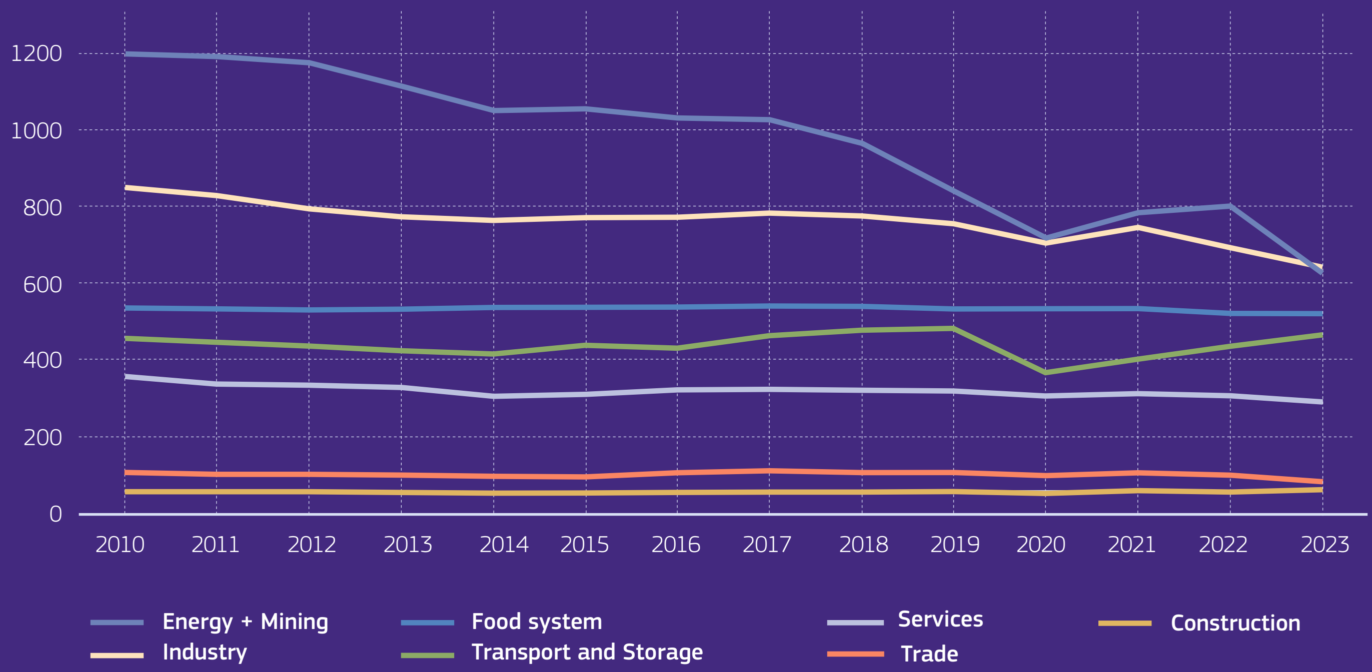
€ 1,505,768

millions

Services follows with 25% (€ 896,893 millions), while the **Industry** sectors contribute for 26%

Figure 2, illustrates greenhouse gas emissions from production activities by various economic sectors (2010-2023). It shows how emissions generated by production activities differ across sectors and how these patterns have changed over time. The data indicate a broad decline in emissions across most production activities. The most significant reduction is observed in **Energy & Mining**, which fell sharply in 2023, reaching its lowest level in the period. **Industry** also continued its downward trend, while **Trade and Services** recorded further decreases. The **Food system** remained relatively stable, with only a slight reduction over time. In contrast, Transport and Storage increased in 2023 compared with 2022, suggesting a rebound in mobility and logistics-related production activity. The trend provide a comprehensive view of the environmental impacts of production-based economic activities and highlight the importance of targeted policies to reduce emissions in high-impact sectors, improve carbon efficiency, and support the transition to a low-carbon economy.

Figure 2. Trend in greenhouse gas emissions in million tonnes of CO_2 equivalent.



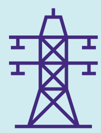
***Source**: Authors' elaboration based on Eurostat data "Air emissions accounts by NACE Rev. 2 activity".*

GHG emissions

The **Food System** contributes 19% of GHG emissions (517 Mt CO_2 eq.), despite its smaller share in GVA and employment

Industry and **Energy and Mining** sectors are the largest GHG emitters, account for 24% GHG emissions each

The **Transport and storage** sector contributes with 17% GHG emissions (460 Mt CO_2 eq.)



Energy and mining sector has the highest emissions intensity because it generates only 3% of GVA and employs 1% of workers.

383 tonnes GHG

emissions per employed person in the **energy and mining** sector. This makes it the most emissions-intensive sector in **employment terms**. It also emits about 1,300 tonnes of GHG per million EUR of GVA, far above transport, food system, and industry.
In contrast, **services** generate 56% of GVA and employ 53% of workers, but account for only 11% of GHG emissions, indicating a much lower emissions intensity.

1.2 The clean transition as a driver for the Sustainable Development Goals

The first **EU Voluntary Review of the 2030 Agenda** highlighted how major EU policies, particularly those in the frame of the EU Green Deal (EGD), are integral to the Commission's strategy for achieving the Sustainable Development Goals (SDGs) [10], [11], [12], [13], [14]. In fact, the EU clean transition policies and UN 2030 Agenda for Sustainable Development share common ambitions, notably addressing the **triple planetary crisis** (climate change, pollution and biodiversity loss). Recent global shocks – including the COVID-19 pandemic, Russia's war of aggression against Ukraine, and the ongoing conflict in the Middle East – have further underscored the need for stronger alignment of policies with the SDG's systemic framework. The 2025 Eurostat report on SDG progress confirmed that while many goals show moderate improvement, some are regressing, highlighting the **urgent need for accelerated and coordinated action** [15], [16], [17], [18].

The JRC assessment of the status of implementation of EGD policy targets [9] also explored the alignment between EGD targets and the SDGs, showing that the EGD not only advances climate and biodiversity goals but also serves as a system-wide accelerator of the UN 2030 Agenda. The analysis confirmed that **all assessed EGD targets directly contribute to at least one SDG**, highlighting the deeply interconnected nature of these frameworks (Annex II). Figure 3 displays these connections, illustrating thematic links between EGD priorities and specific SDGs, particularly in areas such as waste reduction, renewable energy expansion, energy efficiency, sustainable infrastructure, resilient food systems and ecosystem restoration.
The implementation of specific initiatives for the clean transition has the potential to trigger cascading positive effects across multiple SDGs, thereby amplifying progress within both frameworks. For instance, achieving the climate policy objectives or the *Renewable Energy Directive*'s target of 42.5% renewables in the EU's energy mix by 2030 directly advances clean energy goals and climate action. This also potentially improves public health by reducing air pollution (particularly when renewables are not based on combustion of biomass) and fosters economic growth through job creation in emerging green energy sectors. However, these benefits vary across renewable pathways, as some sources, such as bioenergy may also contribute to air pollution.

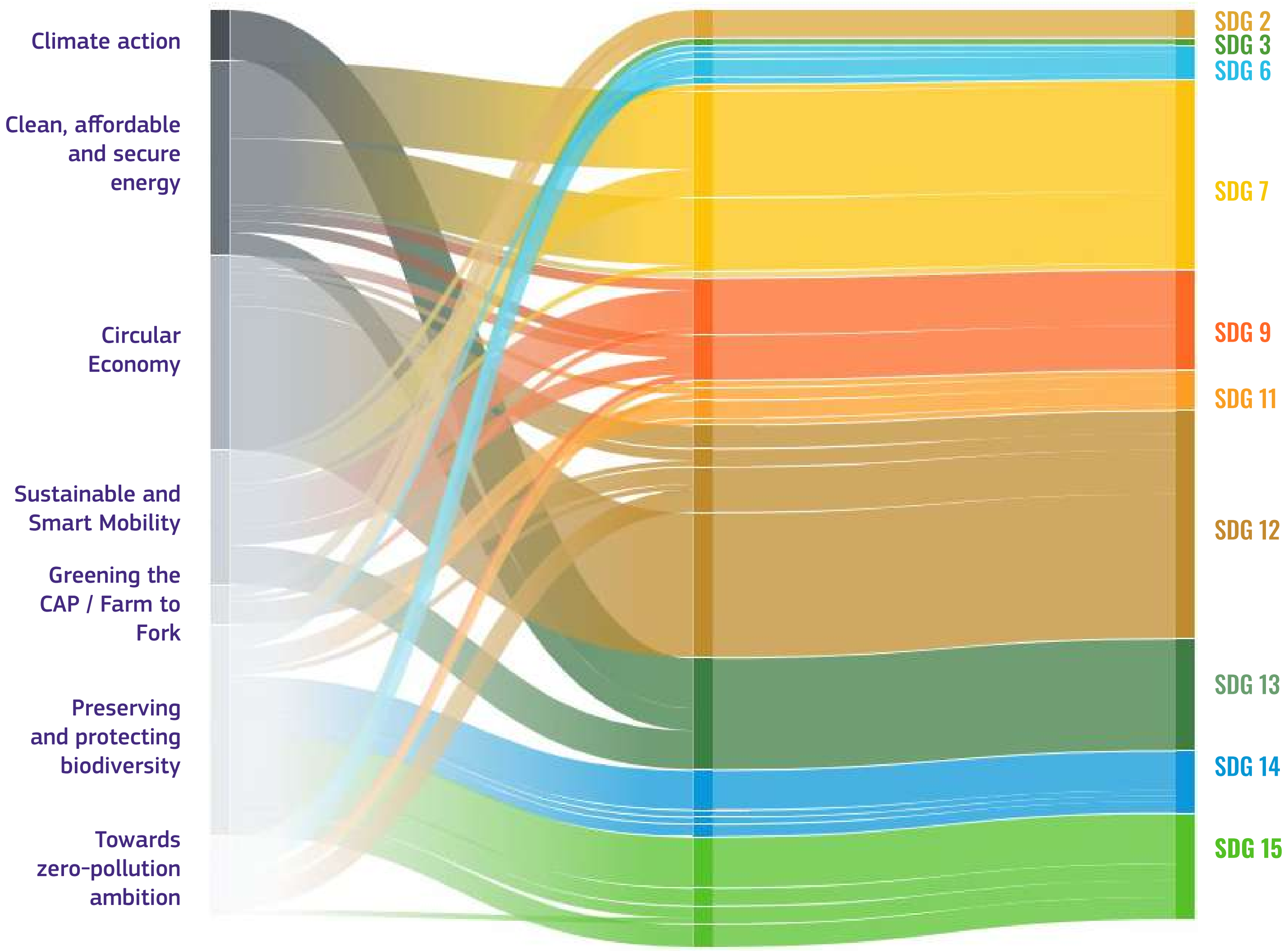
Similarly, initiatives related to the reduction of pesticide use and the expansion of organic farming, not only promote sustainable agriculture and biodiversity conservation but also strengthens water management and soil health - both essential to long-term food security. Furthermore, initiatives under the *Circular Economy Action Plan* encourage resource efficiency and waste reduction, stimulating technological innovation beneficial to environmental and economic sustainability. Efforts to maintain water quality and protect ecosystems also bolster climate resilience and broader environmental sustainability objectives.

While clean transition objectives have substantial potential to deliver positive outcomes, careful consideration and management of trade-offs are essential (Focus 2). For example, expanding bioenergy production can trigger land-use conflicts, potentially affecting food production and biodiversity due to increased demand for energy crops. Bioenergy also contributes to air pollution, and it is a driver of deforestation and forest degradation. Similarly, scaling renewable hydrogen to decarbonise industry might intensify water use, placing additional pressure on already constrained water resources. Circular economy practices, although aimed at reducing waste, could involve energy-intensive recycling processes, thus offsetting energy efficiency gains and complicating emission reductions (if not combined with a decarbonised grid). Moreover, transitioning to a low-carbon economy entails progressive socioeconomic transformations, including in terms of employment, away from fossil fuel related activities towards the electrification of the economy, underscoring the critical importance of instruments like the Just Transition Mechanism to accompany the adaptation of more vulnerable communities and the diversification of the economy (Chapter 7 on a **Fair and Just Transition**). Additionally, expanding renewable energy infrastructure, such as offshore wind farms or large-scale solar installations, may negatively impact marine and terrestrial ecosystems, emphasizing the need for balanced ecosystem management.

Leveraging the clean transition to support the 2030 Agenda while also contributing to broader EU priorities such as competitiveness and strategic autonomy, requires a recognition of both the **synergies and trade-offs that arise when aligning EGD targets with the SDGs**. While many clean transition measures have the potential to advance multiple goals simultaneously, certain actions may generate tensions between environmental, social, and economic objectives. To harness the full potential of EGD measures (and beyond) these must be addressed through coherent and integrated policy design that supports a transition that is sustainable, fair, competitive, and secure.

Figure 3 summarises progress towards the SDGs most closely linked to the EGD and displays how **interlinkages** between SDG targets further reflect interconnections between key clean transition policies. **Annex II** provides more detail with the entire list of 154 EGD targets associated with SDGs and their implementation level, based on the JRC assessment [8].

Figure 3. Interconnections of EGD targets with the SDGs, by thematic area.



Source: Authors' elaboration.

Note: The thickness of the lines represents the number of EGD targets by thematic area and SDGs. SDG 2: Zero hunger, SDG 3: Good health and well-being, SDG 6: Clean water and sanitation, SDG 7: Affordable and clean energy, SDG 9: Industry, innovation and infrastructure, SDG 11: Sustainable cities and communities, SDG 12: Responsible consumption and production, SDG 13: Climate action, SDG 14: Life below water, SDG 15: Life on Land.

Focus 2

The EU Green Deal's contribution to the SDGs

2 ZERO HUNGER

- Reduced sales of antimicrobials for farmed animals and aquaculture
- Moderate progress rate in agricultural land under organic farming management
- Decline of carbon stocks in EU agricultural soils, with adverse consequences for the agricultural ecosystem

3 GOOD HEALTH AND WELLBEING

- Improvement in air quality and decline in related deaths and illness

7 AFFORDABLE AND CLEAN ENERGY

- Positive achievements in EU electricity sector, especially in solar energy
- Acceleration needed in heating and transport
- Major challenges for renewable fuels of non-biological origin, not yet available for the market
- Acceleration needed in energy efficiency (in primary energy consumption, zero-energy buildings, buildings' final energy consumption)

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

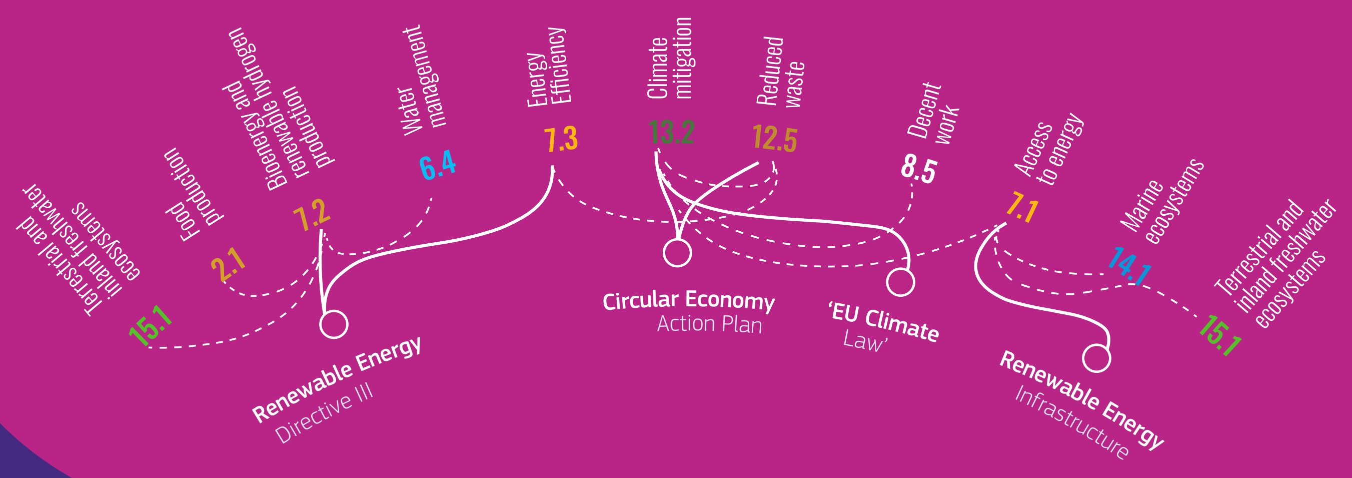
- Challenges for hydrogen electrolysers, production of renewable hydrogen, hydrogen refuelling stations, recharging pools for light and heavy-duty vehicles
- Good progress to develop interconnections between countries, but better electricity infrastructure is needed in some EU regions
- Positive progress made in power output of electric vehicles

11 SUSTAINABLE CITIES AND COMMUNITIES

- Reduced transport noise in cities and the share of people disturbed
- Increase in the amount of residual (non-recycled) municipal waste
- Reduced emissions of air pollutants

Examples of potential **trade-offs**

Achieving EGD targets may trigger cascading effects across other SDGs, thereby amplifying progress in both frameworks. Potential key synergies and trade-offs examples are shown based on the **JRC Interlinkages Tool**.



The outcomes of the 2025 JRC assessment of progress towards EGD targets [8] can also be looked through the lens of the SDGs to better capture how two frameworks are **mutually reinforcing** and where challenges persist. The results of this analysis are aligned with the 2025 Eurostat monitoring on progress towards the SDGs. Some key examples are shown here, and are complemented by Annex II.

Progress towards the EU Green Deal

- *Improvement and targets on track* (green)
- *Progress but insufficient to meet the targets* (yellow)
- *No progress or moving away from the targets* (red)

Progress towards SDGs based on EGD ambitions

- *Improvement* ↗
- *Policies in place but acceleration is needed* →
- *Coexisting improvements and challenges* ↗ ↘

12 RESPONSIBLE CONSUMPTION AND PRODUCTION ↗ ↘

- (yellow) EU extraction capacity for strategic raw materials has reached the target for some resources, but not for others, as well as for the Union processing capacity, recycling and imports of strategic raw materials
- (yellow) Challenges still exist in the generation of food waste in processing and manufacturing, in retail and consumer levels
- (yellow) Significant reduction in the use of chemical pesticides, but not enough for the more hazardous ones
- (green) Targets on track for recycling efficiency of batteries, recovery of materials (except lithium), lightweight plastic carrier bags, reuse and recycle of materials in vehicles
- (yellow) More efforts needed to reduce the packaging waste generated
- (red) Stagnation in the circular material use rate (no progress)

13 CLIMATE ACTION ↗ ↘

- (green) Positive results for the EU Emission Trading System (ETS) and energy neutrality in the wastewater treatment sector
- (green) The EU is on track to achieve the interim 2030 climate target
- (red) Increasing gap in EU net greenhouse gas removal for LULUCF
- (red) Major technological and economic challenges for Sustainable Aviation Fuel, synthetic fuels are not available on the market yet

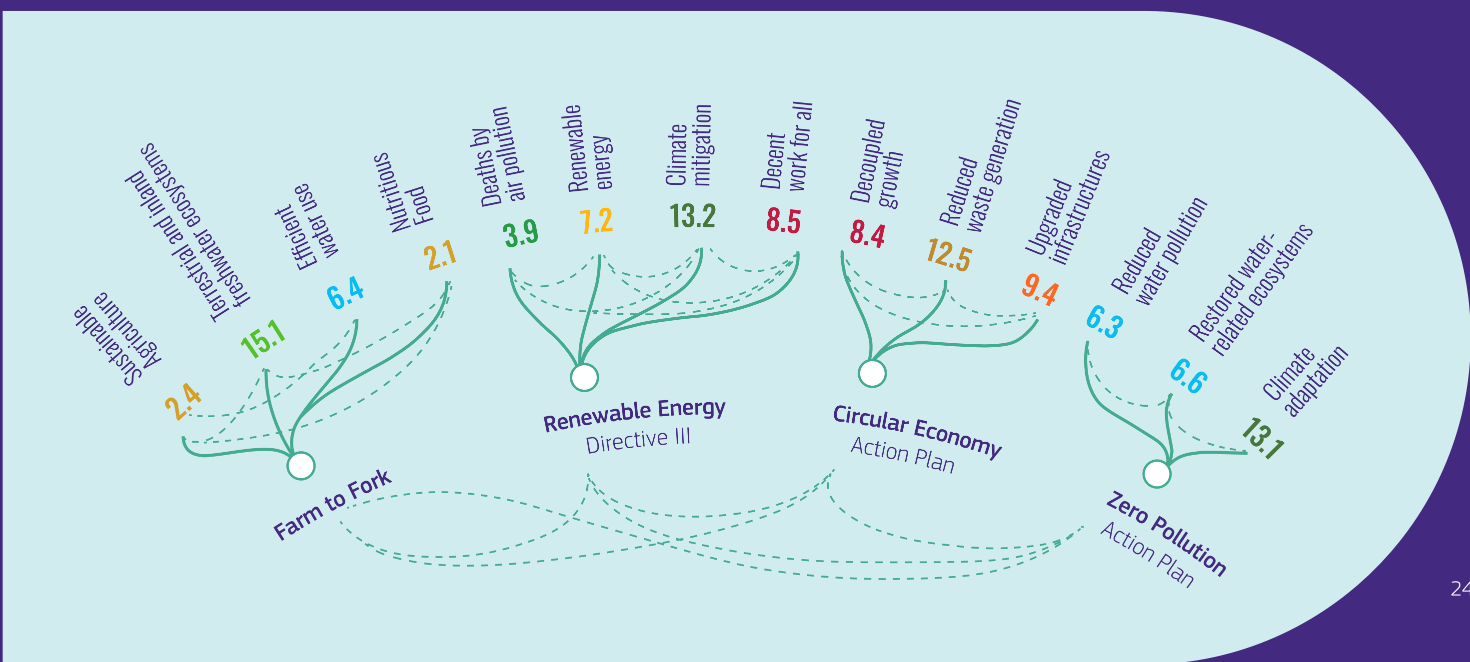
→ ↘ LIFE BELOW WATER 14

- (yellow) Restoration necessary to re-establish the habitat types in marine ecosystem
- (red) Regarding fishing practices, stock status improved but more efforts are needed to keep the fish stocks above Maximum Sustainable Yield levels

15 LIFE ON LAND ↗ ↘

- (green) The common forest bird index show a positive increasing trend
- (yellow) EU soils are not in healthy condition and soil erosion is expected to worsen
- (red) 'No net land take' is still far to be reached
- (red) Decrease of the common farmland bird index and decline of pollinator populations

Examples of potential **synergies**



1.3 The clean transition to prevent the costs of inaction

While the clean transition has emerged as a vital pathway to achieving a sustainable future, its upfront costs may seem economically daunting. However, the **economic, social, and environmental consequences of not taking measures to address climate change** and **environmental degradation** would be far greater: science indicates that the consequences of failing to meet clean transition targets can result in impacts that will substantially outweigh the costs of implementing sustainable solutions. Therefore, when assessing climate change and environmental policies, a comprehensive approach that accounts for both the **costs and benefits of action and inaction** is necessary. Such an approach allows for better informed decision-making, helps prioritise actions that minimise the risks and consequences of climate change, and can serve as a powerful additional motivator for individuals, organisations, and governments to urge collective climate and environmental action. Moreover, considering the costs of inaction can also help to identify opportunities for cost savings and economic benefits associated with taking action [19].

1.3.1 Climate-related costs of inaction

To better understand the costs of inaction, the JRC regularly publishes the pan-European climate risk assessment PESETA [20], covering a wide range of climate impact categories. The methodology integrates a combination of state-of-the-art process-based and empirical models that translate high-resolution projections of climate conditions into biophysical and economic impacts. In this study, the cost of inaction refers to the simulated climate damages without any policy action, i.e. without adaptation or mitigation policies [21].

The risks (and inherent costs) of not achieving the climate targets are also well evidenced in the *European Climate Risk Assessment* report by the European Environment Agency (EEA) [22]. The report notes that several climate risks pose severe threats to energy and food security, ecosystems and water resources, our health and the overall economy and finance. It provides estimates of the high monetary costs of extreme climate events, also in terms of reductions in EU GDP and of the number of people exposed to severe damages, with consequences on EU competitiveness, social inequalities and geopolitical tensions.

Preliminary results of the **JRC PESETA V** project (presented in Figure 4 and synthesised in Focus 3) estimate additional economic costs of up to 0.7% of EU GDP by 2050 under the 2 °C scenario, across the following impact areas: coastal floods, droughts, labour productivity, river floods, transport infrastructure, windstorms, and energy demand [21]. The burden of climate change shows a clear north-south divide, with southern regions in Europe impacted relatively more, particularly, southern-eastern regions. This spatial pattern is driven primarily by changes in high-end temperatures and shifts in the spatial and temporal availability of water.

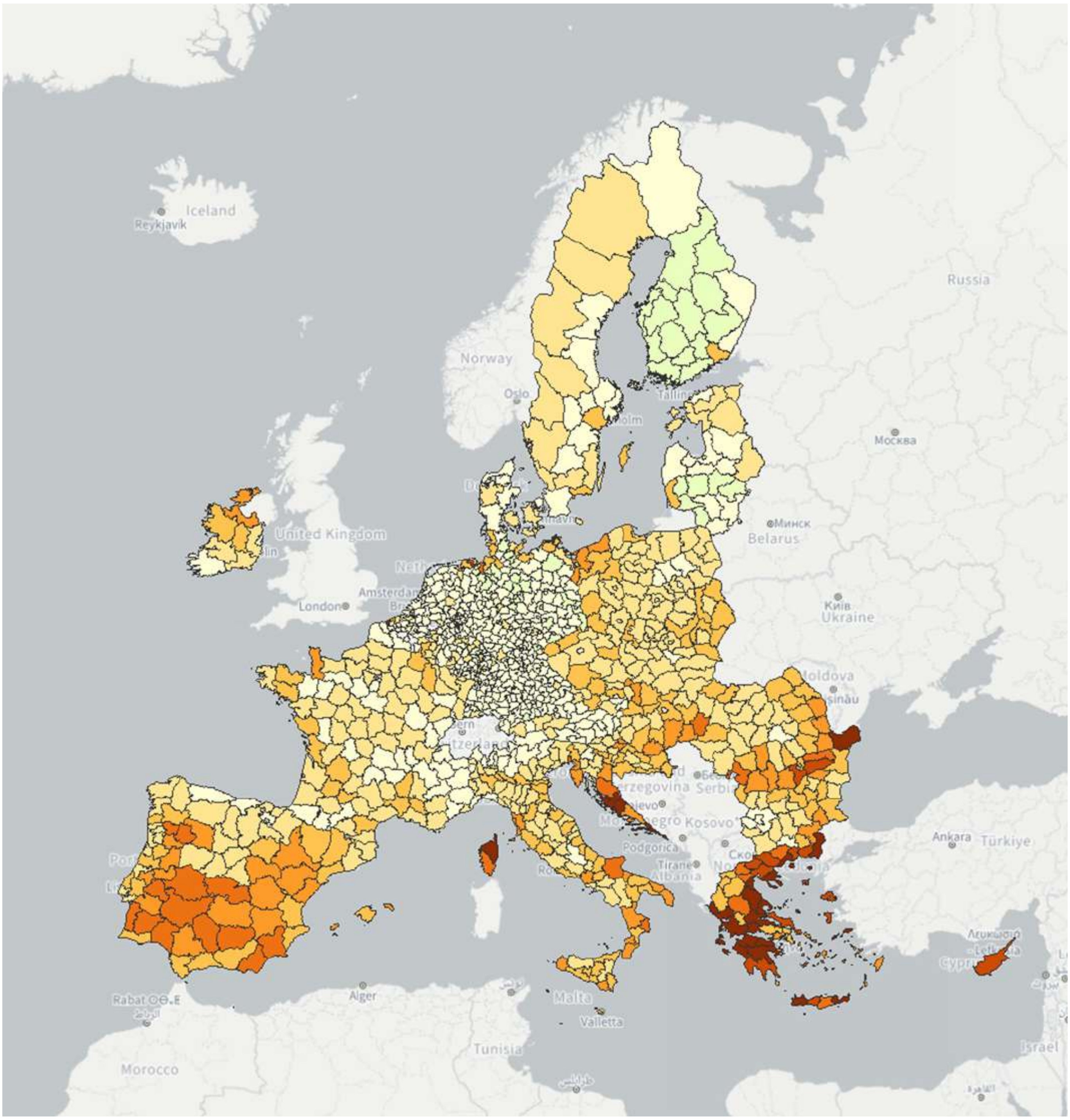
Key impacts not considered in the JRC PESETA assessment include those related to the **irreversible damage to nature** and species losses, aquatic and marine ecosystems, (including the impact on the agricultural sector) water- and vector-borne **diseases**, air quality, **displacement of people**, **conflicts and security**, and the consequences of passing climate tipping points. The extent of extreme events is also not fully captured, such as those of heat stress on crop yields and droughts on energy production. Cascading climate effects across sectors and from the rest of the world are also poorly understood.

This means that the biophysical and economic impacts reported in PESETA represent a **lower bound of the cost of inaction for Europe**. Furthermore, the assessment does not consider other fundamental cost categories indirectly associated with climate inaction: high energy supply vulnerability (notably higher energy import bill and the associated macro-economic costs in terms of growth, inflation and employment), more air pollution and security issues (e.g. migration).

1.3.2 Biodiversity-related costs of inaction

On top of the cost associated with a delay in preparing the EU for climate change, there is a considerable cost of inaction when it comes to protecting and restoring biodiversity. In fact, **nature provides benefits to people and economy through 'ecosystem services'** – such as the pollination of crops, protection of coasts from flooding and erosion, supply of freshwater, wood production, marine fisheries and carbon sink and storage. As the natural assets (such as forests, wetlands, coral reefs and seas) that provide these services decline, the economic burden on societies

Figure 4. Additional economic costs for 2°C scenario by 2050, as a share of GDP (coastal floods, droughts, labour productivity, river floods, transport infrastructure, wind storms and energy demand).



Source: 9th Cohesion Report, European Commission (2024) [23].

increases (including GDP, trade, and production and commodity prices).

Acting to restore and conserve the natural environment is a worthwhile investment and should not be thought of as a "cost." Failure to act would, however, come with a significant price tag for the economy and society. For example, managing the Natura 2000 network requires an investment of around EUR 5.8 billion per year, but it generates EUR 200-300 billion per year in economic benefits, according to European Commission figures.

Ensuring more effective implementation of EU Nature Directives at national and regional levels and placing greater importance on the value of the natural capital, as intended by the EU ***Regulation on Nature Restoration***, would have considerable benefits for biodiversity, sustainable economic development and Europe's prosperity.

Focus 3 Climate impacts. People, environment, economy

Taking stock from the **JRC PESETA** study [20], this focus identifies projected **damages** under a **3°C global warming scenario** as the "cost of inaction". For few impact areas, 4°C scenario damages are also reported. Economic damage estimates consist of climate impacts that would occur by the year 2100. The JRC study provides results regarding climate impacts on ***people***, ***environment*** and ***economy***, with both biophysical and economic metrics. The consistent results summarised below refer to the eleven JRC PESETA IV project **impact areas** [20] (human mortality from heat and cold waves, windstorms, water resources, droughts, river flooding, coastal flooding, wildfires, habitat loss, forest ecosystems, agriculture and energy supply) and the follow-up studies (e.g. labour productivity).

Wildfire and pest outbreaks will become more frequent and severe, increasing biomass loss and additional carbon release (and warming)

An additional **15 million Europeans** living in the proximity of wildland would be exposed to high-to extreme **fire danger** for at least 10 days/year.

Widen disparities in **regional mortality**, particularly impacting EU southern regions [24].

People

Temperature-related deaths could increase by around 55,000 additional deaths by 2100, driven by rising heat-related deaths and an ageing population

1.4 million people would be exposed per year to **coastal inundation** compared to around 70,000 at present, i.e. a 20-fold increase.

Water resources availability would **drop by up to 40%** in Southern regions of Europe

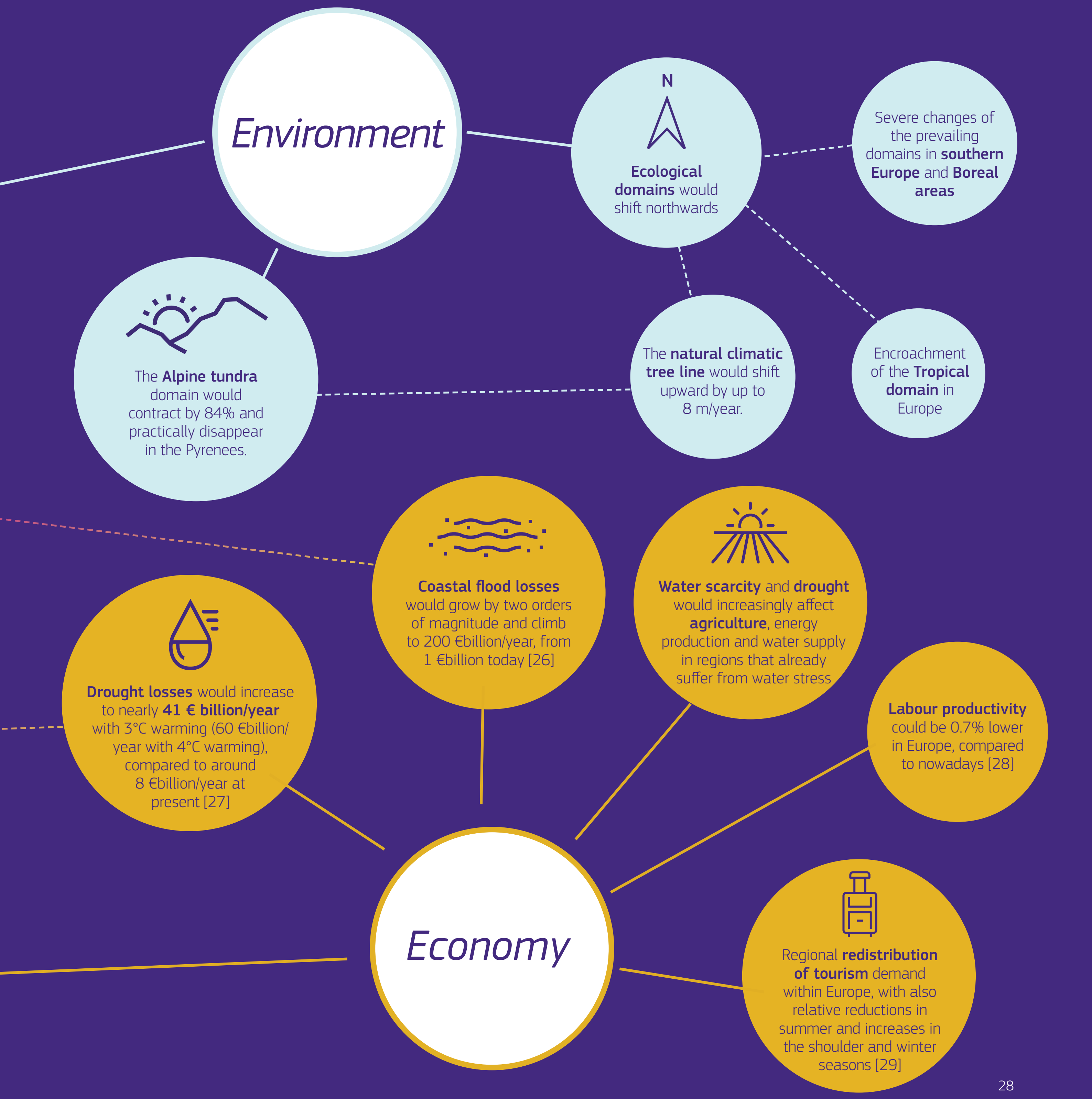
Particularly impacting EU southern regions [24].

Around 450,000 people would be exposed to **river flooding** each year, or nearly three times the number at present.

River flood losses would rise 6-fold in magnitude, reaching 43 €billion/year with 3°C [25].

Biodiversity-related cost of inaction

Financial resources needed to protect and restore **world natural resources** currently amounts to $166 billion per year (*for comparison, less than one-sixth of the annual investment in the greening of the energy system [30]*), but it will need to **increase to about $1 trillion** globally by 2030 [31]. While this is a sizable sum, it pales in comparison to the economic **cost of biodiversity loss** by the end of the decade. Even by the **World Bank**'s conservative estimates, the deterioration of natural processes could see global GDP come in $2.7 trillion a year lower than projected levels by 2030. Similarly, a detailed report by **WWF** [32] calculated the reduction of supply of **six ecosystem services** (therefore, highly conservative) in a '*Business-as-Usual*' scenario, which would lead to an annual loss of US$ 479 billion. Over the period between 2011 and 2050, the total cumulative loss would be US$ 9.87 trillion (3% discount rate). In **Europe**, biodiversity is in rapid decline and the economic picture is aligned with the global one. Economists estimate the loss of biodiversity in Europe costs the EU around 3% of GDP per year [33]. Crop pollination alone is worth more than €14bn annually, while wetlands provide an estimated €6bn in ecosystem services each year [34]. The INCA project implemented at JRC delivered an estimate of the monetary value of a subset of 9 ecosystem services in Europe at about € 321bn in 2021, while unmet demand for ecosystem services creates a €106 billion annual gap [35].



1.4 The clean transition to secure people's and planet's health

Climate change is a major stress on the environment, and hence to the living forms it hosts. The consequences of climate change are global, multifaceted, and far-reaching (Focus 4). It is already modifying the behaviour of living organisms and pushing them beyond their physiological limits, with major and long-lasting impacts on all living organisms. In 2015, the WHO stated that "*Climate change is the greatest threat to global health in the 21st century*". While, in July 2023, for the first time in history, **climate crisis and related extreme weather events** were **declared a public health emergency** by the WHO Regional Office for Europe. According to the World Economic Forum (WEF), by 2050 climate change is likely to cause an additional 14.5 million deaths and USD 12.5 trillion in economic losses worldwide, including USD 1.1 trillion in extra costs to healthcare systems [36], [37]. When tackling the causes and mitigating the impacts of climate change, it is crucial to adopt an integrative strategy, as the environment, animals and humans are tightly connected (i.e. the **One Health approach**).
Looking ahead, the EU's "Choose Europe for life sciences" strategy [38] highlights the critical importance of investing in research linking climate change and health. The Commission recognises that addressing the Climate-One Health nexus through innovative surveillance tools, prevention technologies, and climate-resilient healthcare solutions is essential for achieving the clean transition ambitious environmental and public health objectives by 2030, with a special focus on persons at risk, such as young children, elderly, and people with disabilities.
The EU's new strategic research and innovation agenda on health and climate change, mobilising EUR 170 million from Horizon Europe, is designed to incentivise Member States and industry to contribute to research in this area.

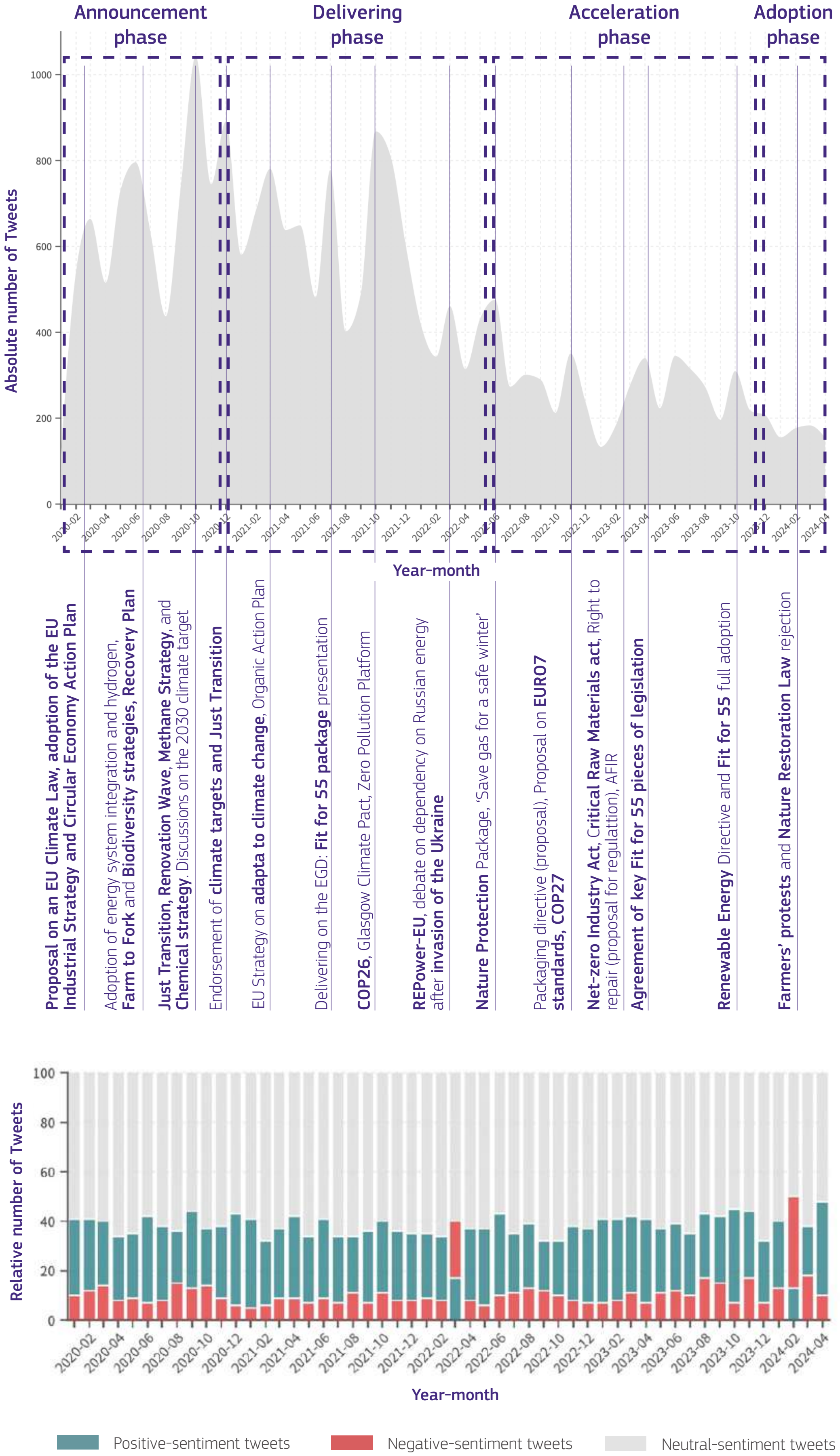
1.5 Public sentiment on Europe's clean transition: survey and social-media evidence

The latest Eurobarometer published by the European Commission (June 2025) confirms the trend in public opinion registered over the years: **85% of Europeans believe climate change is a serious problem** and tackling it to improve public health and quality of life should be a priority. Furthermore, in nearly all EU Member States, more than **half of respondents** support the **EU objective of becoming climate-neutral by 2050**.
While half of EU citizens find it hard to identify disinformation about climate change on social media, 52% also think that traditional media from their country does not provide clear information on the causes and impacts of climate change.

In general, public sentiment plays a critical role in shaping the success of the clean transition. To better understand perceptions of the EGD on social media the JRC has analysed 582.156 English-language Twitter/X posts from January 2020 to March 2024. While not representative of the general population, this analysis provides timely insights into public discourse among engaged and vocal users, complementing broader environmental attitudes captured by Eurobarometer surveys.
The study uncovers clear patterns in how different stakeholders engage with various stages of the EGD's implementation [40] (Figure 5).

Public perception of the EGD has evolved significantly through distinct implementation phases, shaped by policy developments across multiple sectors and by external events. Analysis reveals that while general support for environmental and economic transformation remains strong, specific policy measures often face resistance when their immediate socioeconomic impacts become apparent. The predominance of neutral sentiment (62%) in public discourse, compared to positive (28%) and negative (10%) reactions, indicates a crucial window of opportunity for policy communication and stakeholder engagement.
Temporal trends reveal four distinct phases in public perception. During the *announcement phase* (2020), cautious optimism prevailed, with positive sentiment reaching 29% following the launch of the European

Figure 5. EGD-related tweets over time concerning key policies and major international events (top). All tweets' sentiment evolution over time in relative terms (bottom).



Source: [40]

Focus 4

Direct and indirect impacts of climate change on health

Effects of climate change on health are numerous, and include direct and indirect impacts (Figure 6). Globally, climate change is likely to exacerbate existing health inequities by affecting the social determinants of health, such as access to clean water, sanitation, and healthcare. Economic losses, and decreased productivity will obviously affect agriculture, food prices, and availability, thus challenging global food systems that will be more likely to be disrupted. This may lead to social instabilities, and in some countries, to malnutrition and food insecurity. Consequently, more migration and displacement are expected. This, in turn, can lead to more social, economic, and health problems, including higher stress levels among populations of Member States, increased (re)emergence and circulation of pathogens, higher vulnerability to disease, while society at large is expected to exhibit a decreased access to healthcare.

Floods are the highest risk of acute **climate-induced mortality**, potentially accounting by 2050 worldwide for

8.5 mln deaths

by 2050 worldwide [27] [28]

Poor Water Quality

degraded by **temperature rise**, **extreme weather**, and **saltwater intrusion**, directly increasing waterborne diseases, chemical contamination, and health risks

Thawing of Permafrost

can also impact human health through [48] **release of trace elements** into water (with the subsequent health consequences) or **previously contained pathogens**, including unknown viruses [49].

Extreme weather events

Such as **hurricanes**, **wildfires**, and **floods**, typically result in **displacement**, physical **injuries**, and loss of **lives**. These events can also have long-term effects on mental health, including **anxiety**, depression, and **Post-Traumatic Stress Disorder** (PTSD).

Food, feed and water scarcity

caused by **changes in temperature** and precipitation patterns can lead to **malnutrition and micro-nutrient** deficiencies for all living organisms, with a greater impact on **vulnerable** populations

Heat Stress

due to **temperatures rise** becomes a major concern for all living organisms (eg: bacteria, animals). As humans are concerned, **heat stress** can lead to heat exhaustion, heat stroke, and death especially for vulnerable populations [30] [31] [32]

77-129,000

excess deaths between 1980 and 2020 estimated to be caused by heat waves [30] [31] [32]

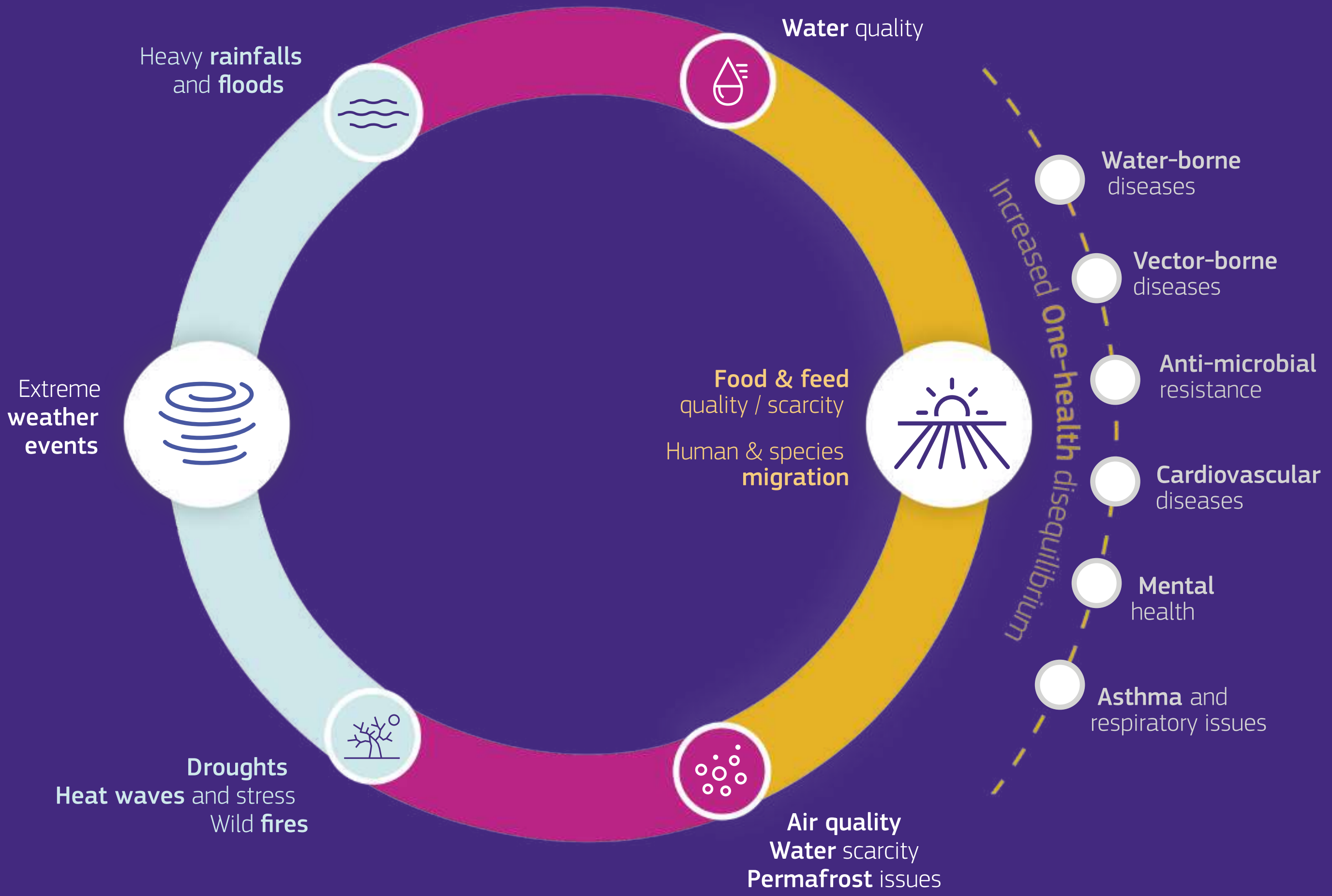
Poor Air Quality

(Pollutants such as PM2.5, PM10, O_3, NO_2, SO_2) can exacerbate respiratory conditions like **asthma** and **Chronic Obstructive Pulmonary Disease** (COPD), but also **cardiovascular** disease, particularly for those with pre-existing conditions and lung cancer

300,000 deaths

prematurely due to **air pollution** yearly in the EU [33]. The average life expectancy is estimated to be reduced by **8.6 months** due to the PM2.5 exposure [31]

Figure 6. Effects of climate change on health



***Source**: Authors' elaboration.*

Increased **One-health disequilibrium**

Water-born diseases

Changes in **precipitation patterns**, **sea-level rise**, and **increased flooding** can contaminate water sources, spreading water-borne diseases like cholera and diarrhea.

Vector-born diseases

Climate change is altering the distribution and prevalence of disease vectors like mosquitoes, ticks, and fleas. These vectors carry also zoonotic diseases, meaning they can be transmitted between animals and humans [27] [37].

Mental health

ranging from **anxiety** and **depression** to **PTSD** and suicidal ideation. The **stress** of living in a rapidly changing environment can be overwhelming, particularly for those who have experienced **traumatic events** [44]. These effects pose threats particularly for vulnerable groups with limited **coping capacities** and pre-existing **mental disorders** [27], [45], [46], [47]

Anti-Microbial Resistance

is one of the **top ten global public health threats** humanity is facing [39]. Climate change can exacerbate it as: it facilitates **bacteria growth** [40]; **flooding** can cause **wastewater and sewage** to overwhelm treatment plants and contaminate surrounding areas [41], [42] [43]; **biodiversity loss** diminishes the richness of plant species that might hold the key to **new treatments** against resistant bacteria [41], [43].

Asthma and respiratory issues

affects over **30 million people** in Europe, and it can be exacerbated by climate change and higher CO_2 levels which link to **increased pollen** production [31]. Pollutants such as PM2.5, PM10, O_3, NO_2, SO_2 have been shown to have an **inflammatory effects** on the airways of susceptible subjects, facilitating the interaction with cells of the immune system [31] [35].

Climate Law and key strategies such as *Farm to Fork* and *Biodiversity*. In the *delivery phase* (2020–2022), positive sentiment climbed further to 32%, bolstered by comprehensive packages like "*Fit for 55*", which demonstrated the impact of concrete, well-communicated policies. However, the *acceleration phase* (2022–2023) exposed vulnerabilities, with geopolitical events such as Russia's war of aggression against Ukraine, shifting the discourse. Negative sentiment rose to 18%, driven by energy security concerns and uncertainties surrounding systemic transitions. Most recently, the *adoption phase* (2023–2024) underscored progress as initiatives like COP28 elevated positive sentiment to 33%, even if sectoral disruptions, including the farmers' protests in early 2024, drove negative sentiment spikes up to 22%.
Thematic analysis underscores specific **drivers of public sentiment**. *Positive sentiment* often aligns with policies demonstrating tangible environmental and health benefits, such as improved air quality or biodiversity restoration, and those fostering economic opportunities through renewable energy and green innovation, notably under initiatives like *REPowerEU*. In contrast, *negative sentiment* tends to focus on perceived costs of economic transition, concerns in the agricultural sector regarding pesticide regulations, excessively complex reporting requirements, and immediate consumer impacts associated with product lifecycle and repair policies.
A notable divergence between institutional and public sentiment highlights a **communication gap**. EU-affiliated accounts[1] demonstrate consistently higher positive sentiment (36%) than non-EU accounts (28%), suggesting that public messaging often fails to resonate with broader audiences. Policies that lack visible implementation pathways or adequate support mechanisms provoke heightened scepticism, with negative responses increasing.
The findings underscore the need for transparent, inclusive, and adaptive **communication strategies to maintain public trust and engagement**, and to address simplified narratives that may contribute to polarisation. The successful implementation of the clean transition depends on maintaining and building public support while managing the inevitable transition challenges effectively. With 62% of sentiment remaining neutral, a significant opportunity exists to build stronger support through tailored communication and engagement measures that address specific stakeholder concerns while maintaining focus on the EGD's transformative vision. By emphasizing the immediate and localised benefits of EGD policies while addressing sector-specific concerns, policymakers can bridge existing gaps and foster wider acceptance. The integration of diverse stakeholder feedback and continuous sentiment monitoring will ensure that the ambitious goals of the *Clean Industrial Deal* align with public expectations, enabling a smoother and more inclusive transition.

1 The study explores potential differences in sentiment between EU-affiliated accounts, of EU institutions or officials (including Members of the European Parliament (MEPs) and those of the broader public. It should be noted that, while tweets from EU-affiliated accounts may provide valuable insights, they do not necessarily represent official EU communications.

1.6 Where we stand: progress towards targets

In January 2025, the JRC published a comprehensive **assessment of the implementation status** and trends of policy targets across all domains of the EGD [8]. The analysis examined **154 quantifiable** targets (legally binding and non-binding) from 44 key policy documents. As of mid-2024, 32 targets (**21%**) were evaluated to be "**on track**" and 64 targets (41%) required accelerated progress. Furthermore, 15 targets (10%) showed no progress or regression, and 43 targets (28%) lacked sufficient data for an evaluation.
One reason for the mixed progress is because many EGD legislative initiatives, such as the *Nature Restoration Regulation*, has only recently been adopted and was yet to be implemented or required long lead times before delivering significant results. Nevertheless, tracking progress is crucial to identifying areas where further action is needed to achieve the clean transition.

The **climate action** promising but requires continuous efforts, as current reductions are falling short, particularly in sectors covered by the '*LULUCF Regulation*' (land use, land use change, and forestry). Accelerated action is especially critical in agriculture and carbon removal strategies. Methane emissions also require intensified abatement efforts.
The **transition to clean energy** requires an increased share of renewable energy sources, energy infrastructure, including renewable power generation, hydrogen production facilities, energy storage systems, and modernised electricity grids. Additionally,

current trends in energy consumption and efficiency must be reversed.

In the **buildings and energy efficiency sector**, progress towards EU energy and climate targets is mixed. Deployment of solutions like heat pumps is accelerating and overall energy consumption is decreasing, but improvements remain uneven and are too slow in many areas. Buildings still consume a large share of energy and emissions reductions are not on track, with renovation rates and efficiency gains lagging behind what is needed. Overall, while some indicators are moving in the right direction, a significant acceleration of efforts is required to meet the 2030 targets.

Conversely, the EU is progressing to meet its ambitions in the **circular economy**, where about 30% of targets are on track to be met. However, trends must be reversed in the circular material use rate, and urgent acceleration is needed in recycling and preparation for the reuse of waste. Initiatives could therefore prioritise waste reduction and material recovery, while addressing existing challenges related to data availability and the adoption of circular practices.

In **sustainable mobility**, the decarbonisation of road transport requires a robust infrastructure for alternative fuels, with significant acceleration in deploying renewable hydrogen and electric charging stations. Advanced biofuels, biogas and Renewable Fuels of Non-Biological Origin (RFNBOs) will be vital for decarbonising hard-to-electrify sectors like aviation and maritime transport. While urban transport is moving towards electrification, more rapid reductions in CO_2 emissions from heavy-duty vehicles are still needed.

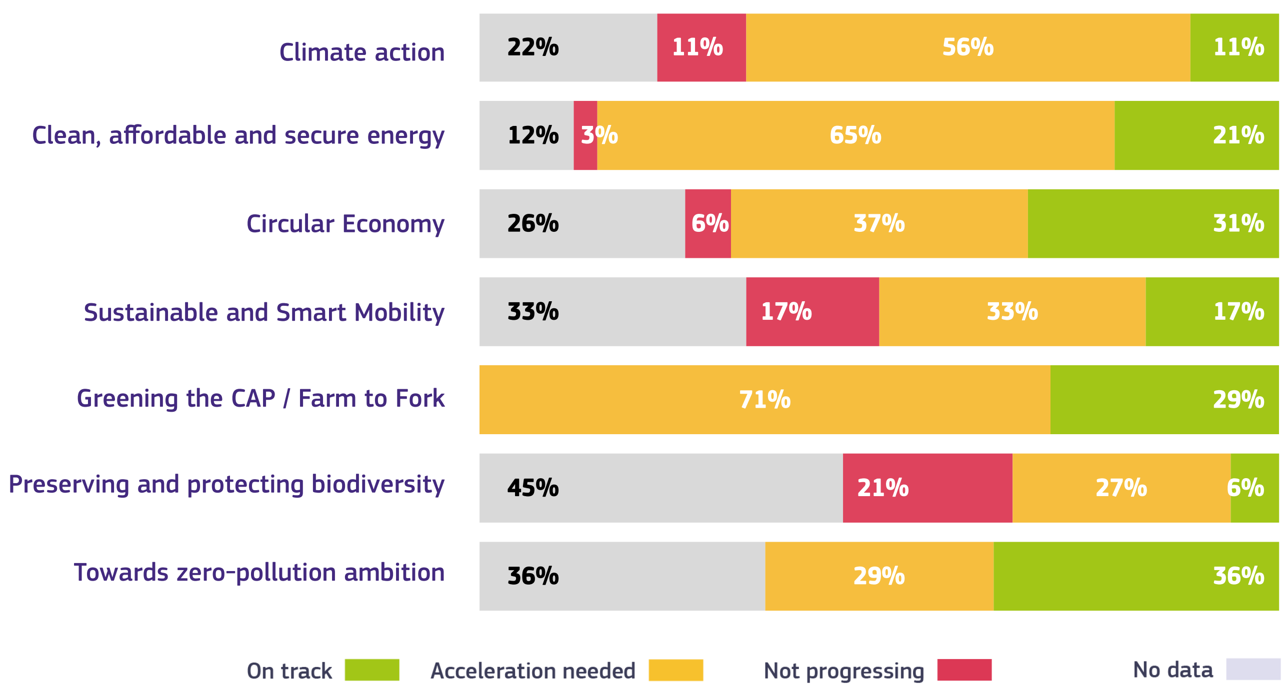
In the **food system**, trends need to be reversed in unhealthy dietary patterns and negative health outcomes, employment quality, food affordability, consumption footprint, energy consumption, and waste generation. It is also essential to address challenges such as reducing greenhouse gas emissions, promoting sustainable agriculture practices, and reducing food waste.

The **biodiversity** thematic area presents particular challenges: 45% of the targets cannot currently be evaluated due to the lack of defined parameters and indicators for comprehensive biodiversity monitoring. In general, biodiversity and ecosystem restoration efforts should be accelerated, accompanied by improved data collection and monitoring to better assess progress towards targets.

Progress has been made towards **zero pollution** in the areas of air pollution, chemical pesticides, and antimicrobial sales. However, challenges remain in the areas of noise pollution, water quality, waste generation and emerging concerns such as microplastics.

Figure 7 provides a synthesis of the progress made towards the EGD targets, as fully captured in the JRC study [8]. The "distance to target" analysis serves as a basis for the present report, which, capitalising on the findings of the first study, dives deeper into the challenges to implementation and the potential enablers, to gain a better understanding of the state of the clean transition in the EU.

Figure 7. Progress towards the EU Green Deal targets.



Source: Authors' elaboration based on [8].

02

Section B
Compass Pillar: Joint Decarbonization and Competitiveness

Towards sustainable competitiveness: challenges and enablers

A sustainable clean transition plays a crucial role in advancing EU competitiveness while promoting climate action, environment and people health. Policies under all its thematic areas are crucial for reducing the EU's environmental footprint, increasing strategic autonomy (for example, in the field of clean energy), but also to stay competitive in innovation and emerging sectors. In turn, a transition to carbon neutral and resource-efficient economy would enhance EU competitiveness, drive economic growth and create new market and job opportunities. **Nevertheless, the success of the clean transition relies on a comprehensive understanding of the challenges hampering policy implementation and leveraging of enablers' mixes across sectors.** Building on the findings of the 2025 flagship JRC report "Delivering the EU Green Deal - Progress towards targets" [8], this chapter explores existing challenges and potential enablers that would shape the implementation of the clean transition policies, with specific reference to targets for which more efforts are needed to meet the ambitions.

This approach positions this report at the nexus between the two headline priorities of President von der Leyen's European Commissions, proposing actionable inputs to support the implementation of the clean transition and competitiveness agendas as a unicum. In particular, this chapter addresses the second pillar of the *Competitiveness Compass*, seeking at accelerated decarbonisation of the EU economy. Within each policy domain, this chapter identifies key challenges and enablers that influence the pace and extent of the clean transition. While not exhaustive, these factors highlight **critical considerations for policymakers at all governance levels, stakeholders, and practitioners in designing and implementing effective strategies for a successful transition**. Each policy domain is accompanied by key messages and a visual Navigator, which gives a snapshot on the major issues discussed and ambitions to achieve, making also reference to cross-cutting enablers discussed in greater details in chapters 4 to 8 (e.g. financial aspects, innovation, skills development, critical raw materials, fair and just transition, and enhanced monitoring systems).

This analysis draws on extensive literature review and expert judgment informed by the latest science for policy analysis conducted by the JRC.

Key messages (Climate action)

A **cost-effective decarbonisation** of the EU's economy requires an integrated mix of measures, including carbon pricing, accelerated deployment of clean technologies, social safeguards to ensure fairness, and strengthened natural carbon sinks.

The **Emissions Trading System** (ETS) remains the cornerstone of EU climate policy. Its expansion to buildings and transport (ETS2) reinforces the carbon price signal, incentivising electrification and reducing dependence on volatile imported fossil fuels. Addressing distributional concerns and ensuring social fairness through targeted use of ETS revenues and the effective roll-out of the *Social Climate Fund* will be essential.

Ensuring a level playing field internationally is critical to protecting EU competitiveness. The ***Carbon Border Adjustment Mechanism*** **(CBAM)** reinforces the EU's climate ambition and strengthens the EU's ability to address carbon leakage, while its implementation should ensure continued competitiveness for exporters and downstream industries. Growing global **green subsidy programmes** highlight the need to strengthen Europe's attractiveness for clean investments.

Revenues from the ETS and CBAM, together with EU funding instruments and carbon-credit mechanisms, should be strategically deployed to accelerate industrial decarbonisation, scale clean technologies, and protect vulnerable groups**.** Their coordinated use can bridge investment gaps, strengthen competitiveness, and ensure that the transition delivers sustainable and inclusive growth across sectors and regions.

The **private sector** faces challenges in aligning with GHG emission reduction goals, including limited access to affordable finance for clean-technology deployment and energy-efficiency investments, uncertainty around carbon pricing and regulatory timelines, and high compliance and transition costs.

Dependence on **critical raw materials**, fragmented reporting standards, and uneven accountability frameworks further constrain progress, particularly in energy-intensive and hard-to-abate sectors where decarbonisation technologies remain costly or commercially immature.

Decarbonising the food and agriculture system is advancing but remains complex and politically sensitive. The **food and land sectors** remain constrained by limited abatement options in agriculture and declining land-based carbon sinks. Expanding climate-smart and regenerative agricultural practices, carbon-farming schemes, and sustainable forestry, supported by targeted incentives and robust monitoring, is essential to restore and enhance natural carbon sequestration.

GHG emission reductions can deliver major **socioeconomic and health co-benefits**, including cleaner air, lower energy bills, and improved living environments. Integrated policy design that captures these synergies, in particular in domains like energy efficiency, mobility and buildings, can enhance well-being while maximising the cost-effectiveness of climate policy.

2.1 Climate action

2.1.1 Reducing Greenhouse Gas emissions

The GHG emissions reduction target of at least 55% by 2030 (EU27 domestic plus international aviation emissions) is one of the key objectives of EGD climate policies, through the Fit for 55 package, and is central to the second pillar of the *Competitiveness Compass* for the EU [4]. By 2023, EU net emissions were 37 % below 1990 levels (or 39 % excluding international aviation), while the economy grew by 71 %, confirming continued decoupling of growth from emissions [41]. The reduction has been largely driven by the power sector, where emissions fell by over 8 % in 2024 thanks to record renewable energy generation and stable nuclear power, though transport emissions continued to rise and land-use removals go down. The latest projections show the EU is broadly on track to meet the 2030 target, provided current and planned policies are fully implemented [41].
The Council of the European Union has also agreed its position to amend the *European Climate Law* to establish a binding GHG emissions reduction target of 90 % by 2040 with some adjustments to incorporate greater flexibility for safeguarding competitiveness and accounting for national differences.
This section highlights the most critical challenges and enablers to achieve the climate targets. The selection of these factors is based on three main criteria: the impact of a specific target on GHG emissions, the gap between current progress and the target, and the presence of opportunities to accelerate progress towards the target.

The Emissions Trading System (EU ETS and ETS 2) remains central to driving emissions down

The EU ETS has enabled a stable and well-functioning carbon market, driving sustained emission reductions in the power and industrial sectors. Following the historic 16.5% reduction in ETS emissions in 2023 [42], the EU carbon market continued to deliver strong progress. By the end of 2024, emissions from electricity, heat generation and manufacturing were 50 % below 2005 levels, with a further 10.7 % decline in the power sector and 0.8 % in the industry compared to 2023 [41]. ETS allowance auctions generated around €39 billion in 2024, bringing cumulative revenues since inception to over €245 billion, which are channelled to Member States for climate and energy investments [41].
The anticipated tightening of the emissions cap in the EU ETS led to significant increases of the carbon price [43] up to the current level hovering around €80/tCO_2 in late 2025 according to market data. Carbon-pricing instruments continue to underpin Europe's decarbonisation trajectory, but they must be embedded within a broader mix of sectoral policies and complementary measures to ensure consistency with the climate targets [44].

While agriculture and land use are not subject to carbon pricing [45], the 2024 ***Carbon Removals and Carbon Farming Regulation*** introduces certification and incentive mechanisms to scale high-quality removals and sustainable land practices [46]. Meanwhile, the ETS2, covering buildings, road transport and small industry, entered its preparatory phase in 2025; its full entry into force was delayed from 2027 to 2028 under political pressure from member states concerned about inflation and energy affordability [41], [47].
The EU ETS was reformed with the introduction of the Fit-for-55 package. In particular, the cap trajectory was adjusted to reach the 55% emission reduction target in 2030 and free allowance allocations for industry are being progressively reduced to reinforce the price signal. The current ETS legislation provides a trajectory to phase out allowances in the EU ETS by 2039. This trajectory will be assessed in the context of the ETS review in 2026.

A challenge in the implementation of the Fit-for-55 package is its potential economic impact, especially that **of the ETS2 on household budgets and on small industry** [48]. Low-income households spend a higher share of their income on energy [49], [50].
To mitigate possible distributional impacts, of carbon pricing for road transport and buildings, auction revenues from the ETS2, together with 50 million EUR allowances transferred from ETS1, will partly be used to finance the *Social Climate Fund*, which is expected to mobilise at least 86.7 billion EUR over 2026-2032 [51], including a 25% "top-up" from Member States. The remaining ETS2 revenues can be used by Member States under the channels established in the EU ETS legislation.
Moving from the domestic to the international market, while the EU raises its own climate ambition, less stringent climate policies might prevail in many non-EU countries. To maintain competitiveness, prevent carbon leakage, and encourage cleaner production in non-EU countries, the EU introduced the

Carbon Border Adjustment Mechanism[1] (CBAM). However, there are still important aspects that are being discussed to further strengthen CBAM, concerning mainly **EU exports to third countries**. JRC calculations for the CBAM impact assessment show [52] that the phasing out of free ETS allowances **weakens the position of EU exporters on global markets**. The same may hold true for producers of products that use a high content of inputs from sectors covered by CBAM ("downstream sectors"). As part of the *Clean Industrial Deal*, the Commission proposed measures to further strengthen the CBAM, e.g. by extending it to downstream products and providing a temporary decarbonisation fund. The extension to downstream products could have drawbacks too as these products are more heterogeneous and complex, making it more difficult to assess the carbon emissions associated with their production.

1 CBAM is a tool to put a fair price on the carbon emitted during the production of certain carbon intensive goods that are entering the EU, and to encourage cleaner industrial production in non-EU countries. The CBAM will initially apply to imports of goods and selected precursors whose production is carbon intensive and at most significant risk of carbon leakage: cement, iron and steel, aluminium, fertilisers, electricity and hydrogen.

Therefore, to complement the existing CBAM, measures to **mitigate carbon leakage risk for EU exporters** are being considered.
An international level playing field can also be put at risk by the different policy approaches that are applied by the EU's main trading partners. The USA and China, for example, rely more heavily on subsidies to promote green technologies while the EU uses a more balanced approach with a mix of regulations, such as standards, carbon pricing and subsidies. This **difference in approaches can affect energy costs and basic material prices** across the continents. This will, consequently, also affect downstream industries that use energy or energy-intensive products as inputs.

Despite small emission reductions of 1.2% achieved in 2024, the EU agriculture sector represents around 11% of the total EU greenhouse gas emission [41]. A key barrier to climate change mitigation in this sector relates to the **complexity of the Polluter-Pays Principle.** Implementing the polluter-pays principle within agriculture is challenging, as the sector is inextricably linked to nature and ecosystems, notably the carbon, nitrogen and water cycles, with

Potential enablers

Reforming the ETS is expected to generate more revenues for Member States, which could increase funding to assist the clean transition of industries, e.g. through the *Innovation Fund* (which has already funded projects with a significant amount of ETS revenues), or be used to reduce taxes (e.g. labour taxes to foster employment creation).

The scope extension of the ETS to additional sectors and fuels used by households is supported by the introduction of a *Social Climate Fund* to shield the most vulnerable and to support the transition in these sectors. ETS revenues are used for this purpose. Member States lay out how exactly they will use their allocation of the *Social Climate Fund* in their *Social Climate Plans* (SCPs).

Given the need for significant EU-level investments in green technologies to promote the transition while creating synergies among Member States, the Commission has proposed to direct 30% of ETS revenues to the EU budget as a new own resource, together with revenues from the introduction of the CBAM.

The ETS carbon price could also incentivise emission removals to offset those which are difficult or costly to avoid; this would however require adjustments to the ETS – first steps in this direction are being made in the frame of the *EU Industrial Carbon Management Strategy* [53].

potential side effects on food price, and has a variety of GHG sources (e.g. enteric fermentation, manure management, nitrogen-based fertilisers and energy use [54], [55]).

While subsidies do not inherently prevent GHG emission reductions, they shape the economic context in which farmers operate. Shifting this responsibility to farmers could face resistance and economic hurdles, particularly for smaller or less profitable farms that may lack resources for mitigation measures. Moreover, the scope of technical measures in the food production sector is limited, so further emission reductions may affect productivity or farm viability and ultimately food price. As with fossil fuels for heating and transport, poor households typically spend a higher share of their budget on food products, which will have to be considered. [56], [57].

Addressing these challenges calls for greater alignment between climate policies in the food sector and the broader *Vision* for a sustainable EU food system - one that is fair, healthy and environmentally friendly, supports farmers in the transition, safeguards food security and leaves no one behind. This is particularly relevant given the distinct treatment of the agricultural sector compared to others, and the significant public investment through the *Common Agricultural Policy*. Recognising and addressing this systemic difference with transparency is essential to building trust and long-term legitimacy for the clean transition in agriculture.

Supporting the private sector to align with the GHG emission reduction goal

Increased demand for clean tech equipment (e.g. wind turbines and electric vehicles) driven by EU decarbonisation policies can facilitate decarbonisation in both EU and non-EU countries[2] through the effects of cost reductions and increased manufacturing capacity. In addition, expertise gained in deploying low-emission equipment in the EU can benefit non-EU countries through the expansion of EU-based companies and workers into non-EU markets.

An important challenge is related to the **accessibility of critical raw materials**, and to the geopolitical challenges thereof, as imports are currently sourced from a limited number of countries.

2 The argument is that the more a technology is manufactured the lower is its cost, making it more accessible. The EU is a net importer, in particular of clean technology and CRM.

Potential enablers

Food systems' emissions

The *Vision for Agriculture and Food*: this policy framework supports the transition towards more sustainable and climate-resilient agricultural systems by promoting innovation, knowledge exchange, and capacity building across Member States, thereby enabling the uptake of low-emission farming practices and more effective climate mitigation actions in the agricultural sector. It outlines both technical and financial support measures for Member States, including assistance to improve national carbon datasets and emissions inventories, especially for agriculture. It also promotes advisory services and knowledge-sharing platforms to strengthen data quality, reduce monitoring burdens on under-resourced Member States, and enable better-informed decisions on emission-reduction strategies.

Horizon Europe "Lighthouses" initiative: As part of the Mission "Restore our Ocean and Waters," these regional demonstration sites support innovative farming and aquaculture practices tailored to local conditions [58]. The initiative acts as a testbed for sustainable solutions, fostering peer learning, uptake of best practices, and systemic change across the food value chain.

Support mechanisms for low-carbon practices: Beyond high-level strategies, direct incentive schemes such as payments for ecosystem services, targeted agri-environmental measures under the CAP, or support for digitalisation in farming can accelerate the adoption of mitigation practices (e.g. precision agriculture, agroforestry, optimised fertiliser use) by reducing up-front costs and addressing risk aversion.

Dependency on only a few suppliers can, in some cases, challenge the operationalisation of specific targets or the uptake of specific technologies (Chapter 4.1 on **Critical Raw Materials**). Moreover, compensatory mechanisms can improve the penetration of clean technology in the private sector and at the same time address energy poverty (Chapter 7.1.1 on *Energy poverty*). Another challenge has been the absence of consistent, comparable GHG emissions data across the real economy. While large listed companies were already subject to disclosure requirements under the *Non-Financial Reporting Directive* (NFRD), the framework's flexibility on reporting standards and limited scope 3 requirements left gaps, particularly for large non-listed companies which fell outside the scope of the NFDR.

GHG emissions reductions can go hand in hand with socioeconomic and health benefits

Decarbonisation is expected to lead to significant **health benefits**, mostly through improved air quality, with related **economic benefits** that balance the direct costs of decarbonisation mentioned above [63]. These benefits are particularly important in the context of the EU's ageing population, as improving public health can help mitigate the projected rise in healthcare costs over time and support longer, healthier lives.

In particular, renewables and energy saving can lead to the same pollution reductions as installing expensive equipment (such as air filters). However, if renewable energy means wood-burning, for example, that tends to worsen air pollution [64].

Private sector

Potential enablers

A number of dedicated funds are already in place or have been recently launched, including the *Just Transition Fund, Social Climate Fund, Modernisation Fund, Innovation Fund*, and *Cohesion Fund*[3] [60]. These mechanisms help address societal resistance and counter the perception that the clean transition primarily burdens lower-income groups, by reducing costs for vulnerable households and communities. The "Green Deal Industrial Plan for the Net-Zero Age" [61] supports the scaling of "net-zero industry" in Europe by providing targeted fundings, streamlining regulation and ensuring open trade for resilient supply chains.

The Corporate Sustainability Reporting Directive (CSRD), which entered into force in January 2023, addresses data availability and comparability shortcomings. By mandating double materiality reporting under the European Sustainability Reporting Standards (ESRS), including scope 1,2 and 3 emissions and extending disclosure requirements to large non-listed companies for the first time, it enhances the granularity and comparability of transition relevant data for policy makers and investors. For complementary information on CSRD, please refer to Chapter 6 *Financing the Clean Transition*.

3 The *Just Transition Fund* supports the territories expected to be the most negatively impacted by the transition towards climate-neutrality, through economic diversification during the 2021-2027 period. The *Social Climate Fund* will alleviate the social and economic impacts arising from the ETS2. To achieve this, it will provide EU Member States with dedicated funding to directly support the most affected vulnerable groups, notably households in energy or transport poverty during the 2021-2027 period. The *Modernisation Fund* supports the modernisation of energy systems and the improvement of energy efficiency in 13 lower-income EU Member States during the 2021-2030 period. The *Innovation Fund* is financed by revenues from auctioning allowances from the EU ETS and with an estimated revenue of approximately EUR €40 billion between 2020 and 2030, and it helps businesses to invest in clean energy and bring technologies to market that can decarbonise European industry, while fostering its competitiveness. Finally, the *Cohesion Fund* supports environmental investments for EU Member States with a gross national income per capita below 90% (EU-27 average) to strengthen the economic, social and territorial cohesion of the EU.

Citizens' behaviours can directly impact GHG emissions reduction in the mobility, building, energy, sectors. Studies highlight direct governmental expenditures (such as investment in infrastructure, such as smart meters; subsidies) as behavioural leverages to boost climate mitigation in households [65], [66].

In addition to financial incentives, it is advisable to implement information dissemination and environmental awareness-raising policies, providing more understanding about renewable energy technologies and the benefits of energy renovations of multi-flat buildings and to ensure middle actor [67] activities in the market by increased assignment of energy efficiency renovation specialists. Examples of middle actors are, 1) in the energy sector: Municipalities, local energy companies, and local car dealers can influence the adoption of electric vehicles, and 2) in the building industry: Building professionals, including tradespeople, engineers, and designers, are key actors in delivering zero-carbon buildings.

Well-shaped social and behavioural policies, implemented in the framework of the *Farm to Fork strategy* (and now in the framework of the *Vision for Agriculture and Food*) [68], can contribute to raise consumers' awareness, empowering households to make good decisions, and creating initiatives at local level to improve the quality of homes, to save energy and, in turn, to reduce their energy poverty. There are two main approaches developed by behavioural economics insights: boosting and nudging. Both can address important behavioural barriers of climate change mitigation [67]. The IPCC has estimated that demand-side measures and new kinds of end-use service provision can reduce global GHG emissions in end-use sectors (in particular buildings, land transport, and food) by 40-70% (worldwide) by 2050 compared to baseline scenarios, while some regions and socioeconomic groups require additional energy and resources [65].

2.1.2 Leveraging the carbon sink of the LULUCF and agriculture sectors

According to the EGD, land should provide a carbon sink of at least -310 Mt CO_2eq/y by 2030. However, **the capacity of EU land as a carbon sink has gradually decreased since 2013** from -348 to -231 Mt CO_2eq in 2024 [69], [70].
In the EU the totality of the carbon sink is capture by forests and wood products. This declining sink is due to a combination of factors, including an increased in harvest rates, demand, age structure of the forests, increased of natural disturbances such as insect infestations droughts and wildfires, reduced growth owing to climate change, and increased frequency of droughts and heatwaves. In addition, reduced afforestation and forest expansion, and in some areas and fore some forest types, forest ageing and other climate-related impacts [69], [71]. While there is no specific target for agriculture to be achieved in 2030, current Member States notifications in combination with ongoing efforts (including CAP Strategic Plans) are estimated to ensure that agriculture will contribute its fair share to the Fit for 55 EU Climate Targets for 2030. At the same time, further acceleration of GHG emission reductions in the agricultural sector will be needed to reach carbon neutrality by 2050.
Forests act as a carbon sink if the biomass in the forests increases. Harvested wood products could also contribute to the land use, land use change and forestry (LULUCF) carbon sink, if more wood products are produced than wood that decays or is combusted. In addition, forest biomass can be used for bioenergy

[69], [72]. Emissions from wood-based bioenergy are considered part of the LULUCF sector estimates, and they are therefore zero-rated in the energy sector reporting of greenhouse gas inventories. This situation creates a **trade-off** between the *Renewable Energy Directive* that promotes renewable energy source uses, including bioenergy, and the *LULUCF Regulation*.
The LULUCF sector is inherently dependent on the natural ecological conditions in the EU Member States, and therefore forest management practices that try to optimise sinks are highly context-dependent, but preferable practices might differ across EU Member States [73].

It is important to find more ways to promote synergies between climate change mitigation, adaptation, biodiversity conservation and restoration, and the social value of forests. Forests are the only currently available option for large-scale carbon capture and the cheapest way to achieve carbon sequestration. Direct air capture is only at the experimental stage, and its cost is estimated to be between 25 and 60 times higher [74]. However, managed forests promoted for enhanced carbon uptake may be more susceptible to climate extremes, leading to higher tree mortality rates, making it harder to reach the theoretical capacity envisaged by the mitigation targets [75].

In many cases, this would mean limiting the harvest levels by, for example, lengthening rotation times where applicable (at the moment they are decreasing), making sure that thinning is done in time to promote growth, and making sure that new forest is regenerated as soon as possible after harvesting. Fulfilling the climate goals set for the EU would not mean abandoning forest management but rather ensuring that it is carried out in a climate-smart manner – in effect, the GHG emissions targets for the EU-wide LULUCF sector are less than the reported capacity of the sink before 2016.

Forest monitoring tools need better coordination between different institutions and teams and institutional/capacity barriers, smart forest management, carbon and nature credits and carbon farming. Some of the main drivers of the decreasing LULUCF sinks are related increased harvest rates and increasing natural disturbances. Incentives to lengthening rotation times, avoiding clear-cutting practices, and enhancing resilience through tree species diversity, more structurally diverse forests, and paying attention to forest and soil health are key.

The agriculture sector is generally seen as a 'difficult' and expensive area in which to achieve reductions. The sector is steered by the CAP policies, which have had limited success with emissions reductions in the past decade (Chapter 2.6, *Preserving and protecting biodiversity*). EU greenhouse gas emissions from agriculture have fallen by more than 20% since 1990, but the decrease has stagnated since 2010 [76]. Essentially, there are two main emission sources, the largest being livestock farming (65%), mostly methane emissions from enteric fermentation and manure management, followed by nitrous oxide emissions from soil management (31%) [77].

Moreover, large sink capacity of degraded ecosystems can be channelled by developing **biome or site-specific best management practices (BMPs),** the main objectives of which are to achieve integrated nutrient management, a year-round soil cover, enhanced soil structure, and rhizospheric enrichment (rhizosphere processes are biogeochemical processes occurring at the plant root-soil interface).

Potential enablers

The achievement of the carbon sink goal is proven to be effective through a series of practices supported under the strategic plans, the *Carbon Removals and Carbon Farming Regulation* (CRCF), the proposed revision of the legislation related to forest reproductive material, the *EU Bioeconomy Strategy*, the *Soil Monitoring* and *Resilience Law*, the *Nature Restoration Regulation* and the *EU Deforestation Regulation* (EUDR). There are synergies between improving the land carbon capture and the biodiversity conservation targets. In order to leverage these synergies, good practices include:
- Developing and implementing more effective reforestation strategies that take into account biodiversity and habitat safeguards [71].
- Promoting the use of sustainable forest management practices, including the use of native tree species and uneven-aged forests, natural regeneration, and the strict protection of primary and old-growth forests [78].
- Supporting reforestation and afforestation efforts.
- Developing and implementing effective conservation strategies at local and landscape level for biodiversity conservation and restoration.
- Increase the forest rotation length, increase stand age diversity [71].
- Improve deadwood management to enhance soil biodiversity and soil carbon [71].
- Improve the carbon storage in harvested wood products [71].

It is important to consider the immediate economic motivations and deeper societal, cultural, and policy-related factors influencing land use change decisions and the interplay between them [79], [80]. Examples are: recognising the varied motivations of landowners (including investments, conservation, cultural factors, and recreational uses) and leveraging these for sustainable land management [80].

Support for Carbon Farming: The EU's promotion of carbon farming, along with schemes for monitoring, reporting, and verification, incentivises farmers to adopt practices that capture carbon [81]. These practices can include regenerative agriculture, agroforestry, and improved soil management, which not only reduce emissions but can also enhance soil health and productivity.

There are (relatively expensive) strategies to reduce methane emission from livestock, such as breeding and feeding techniques including diet formulation and the use of feed additives [82]. Full adoption of the most effective strategies to mitigate methane emissions by ruminants can help to meet the 1.5 °C target by 2030 but not enough to reach net zero by 2050 [82]. Such strategies have passed laboratory and field trials, but large-scale implementation has not yet been demonstrated. Technology-driven solutions (e.g. enhanced-efficiency fertilisers) and optimisation of fertiliser rate may have a considerable mitigation potential. Agroecological mitigation practices (e.g. organic fertiliser and reduced tillage), while potentially contributing to soil quality and carbon storage, may enhance N_2O emissions [83]. All the strategies on soil management are largely affected by pedoclimatic and farming conditions.

Close the research-gap by [71]:
- Providing high-spatial-and-temporal-resolution mapping of forest characteristics.
- Modelling the present of future forest carbon sink.
- Quantifying the importance of long-lasting and controllable drivers of the forest sink decline.
- Understanding the potential trade-offs of nature-based climate solutions.

CLIMATE ACTION Navigator

This infographic helps **navigate the complexity** of the transition for achieving **climate action targets** while delivering on the **EU Competitiveness ambitions**. It presents a non-exhaustive overview of **challenges and enablers**, which are explored in full in the report.

Legend

- Financial / economic challenges
- Political / institutional challenges
- Technological / infrastructural challenges
- Socio-cultural / behavioural challenges
- Potential intervention areas
- Start — Transition paths
- Final milestones

If we go like this, we will achieve major clean transition policies!

*A cost-effective decarbonisation of the EU's economy requires an integrated mix of measures, including 1 **carbon pricing**, accelerated deployment of 2 **clean technologies**, 3 **social safeguards** to ensure fairness, and strengthened 4 **natural carbon sinks** under a solid 5 process orchestration mechanism.*

Start

CARBON PRICING

for predictable, fair and competitiveness - enhancing decarbonisation

Implementation ambitions

- Expansion of carbon pricing while remaining **fair**, particularly for **households** and **small industries**
- Carbon pricing as **predictable investment signal** to accelerate industrial decarbonisation
- Minimise **carbon leakage** risks as the EU raises climate ambition
- Extension to **agriculture** and **land use**, enhancing removals also for **hard-to-abate** emissions

Enablers' mix

- ETS/CBAM revenues — Strategic use to mobilise investments, reduce transition costs and accelerate industrial decarbonisation
- Existing Funds — Coordinated use of dedicated EU funds and industrial policy instruments to support industrial decarbonisation, competitiveness and social cohesion
- Scheme extension — Development of carbon removals, credits and carbon farming schemes to extend decarbonisation pathways to hard-to-abate sectors

CLEAN TECH

scale-up as industrial core of the transition

Implementation ambitions

- Scale up **clean technologies** across energy, industry and infrastructure
- Mobilise affordable investments to **de-risk the clean transition**
- Ensure secure, resilient and sustainable **access to critical raw materials**

What could we do?

Enablers' mix

- CRM Act implementation
- Coordinated use of EU funds — (e.g., Innovation Fund, Modernisation Fund, Social Climate Fund) to reduce risks and bridge the investment gap
- ETS/CBAM revenues — Strategic use to support large-scale deployment of clean technologies

See **Chapter 4.1** to explore **enablers** for Critical Raw Materials Act implementation

SOCIAL SAFEGUARDS

for a fair and just transition

Implementation ambitions

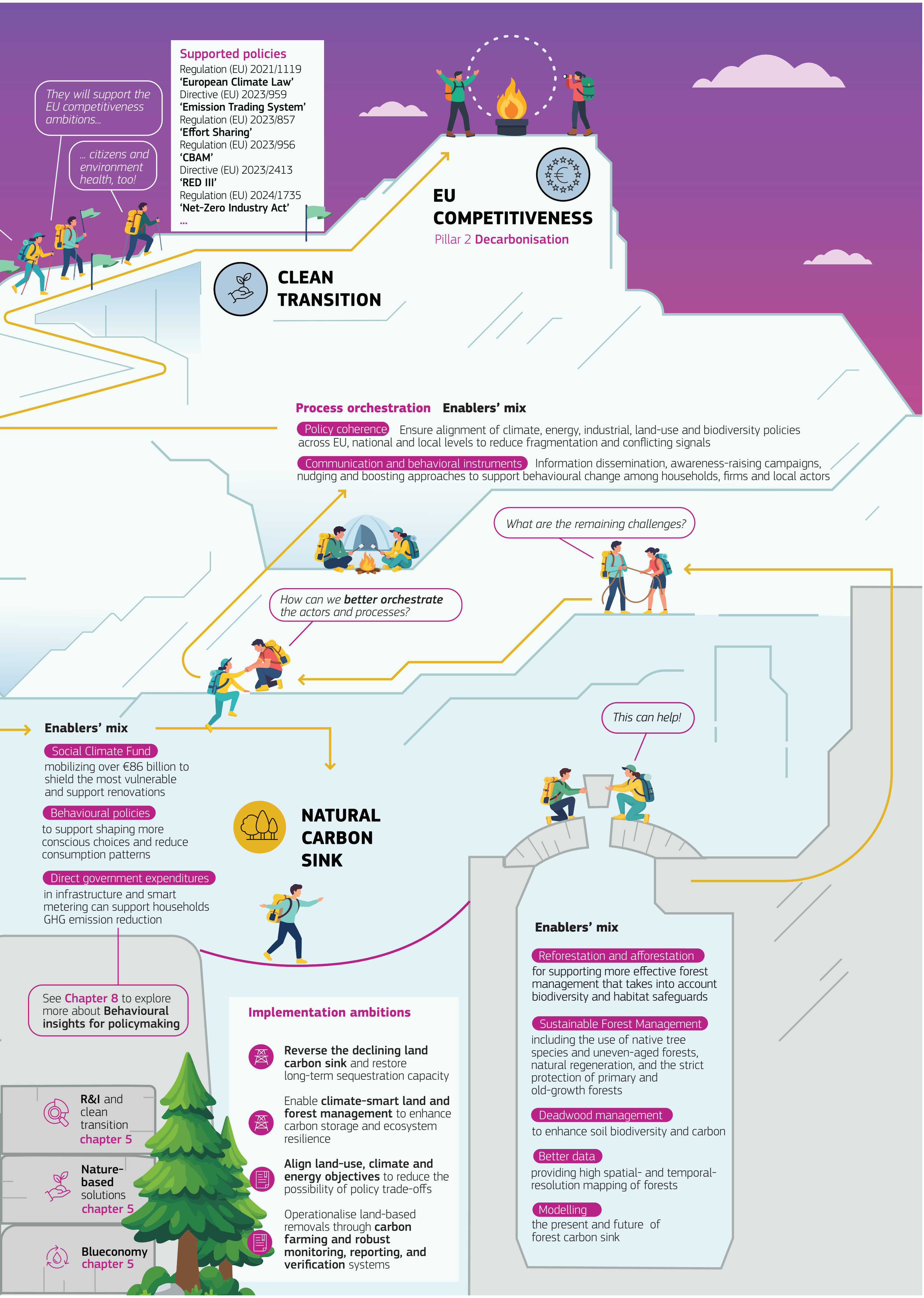
- Prevent **energy, mobility and transition-related poverty**, maximizing Socio-Economic and Health Co-benefits
- Strengthen societal acceptance and **behavioural uptake of the green transition**
- Achieve more sustainable **consumption patterns**
- Labour **market upskilling**, workforce resilience

Let's pay attention!

*These **cross-cutting enablers** will help us go faster...*

CROSS-CUTTING ENABLERS

- **Circular bioeconomy** — chapter 4
- **Financing** the clean transition — chapter 6


They will support the EU competitiveness ambitions...
... citizens and environment health, too!
Supported policies
Regulation (EU) 2021/1119
'European Climate Law'
Directive (EU) 2023/959
'Emission Trading System'
Regulation (EU) 2023/857
'Effort Sharing'
Regulation (EU) 2023/956
'CBAM'
Directive (EU) 2023/2413
'RED III'
Regulation (EU) 2024/1735
'Net-Zero Industry Act'
...
EU COMPETITIVENESS
Pillar 2 Decarbonisation
CLEAN TRANSITION
Process orchestration
Enablers' mix
Policy coherence
Ensure alignment of climate, energy, industrial, land-use and biodiversity policies across EU, national and local levels to reduce fragmentation and conflicting signals
Communication and behavioral instruments
Information dissemination, awareness-raising campaigns, nudging and boosting approaches to support behavioural change among households, firms and local actors
What are the remaining challenges?
How can we better orchestrate the actors and processes?
This can help!
Enablers' mix
Social Climate Fund
mobilizing over €86 billion to shield the most vulnerable and support renovations
Behavioural policies
to support shaping more conscious choices and reduce consumption patterns
Direct government expenditures
in infrastructure and smart metering can support households GHG emission reduction
NATURAL CARBON SINK
See Chapter 8 to explore more about Behavioural insights for policymaking
R&I and clean transition chapter 5
Nature-based solutions chapter 5
Blueconomy chapter 5
Implementation ambitions
Reverse the declining land carbon sink and restore long-term sequestration capacity
Enable climate-smart land and forest management to enhance carbon storage and ecosystem resilience
Align land-use, climate and energy objectives to reduce the possibility of policy trade-offs
Operationalise land-based removals through carbon farming and robust monitoring, reporting, and verification systems
Enablers' mix
Reforestation and afforestation
for supporting more effective forest management that takes into account biodiversity and habitat safeguards
Sustainable Forest Management
including the use of native tree species and uneven-aged forests, natural regeneration, and the strict protection of primary and old-growth forests
Deadwood management
to enhance soil biodiversity and carbon
Better data
providing high spatial- and temporal-resolution mapping of forests
Modelling
the present and future of forest carbon sink

Key messages (Clean, affordable, and secure energy)

Achieving the EU's clean-energy goals requires a rapid and coordinated scaling of renewables, electrification, system flexibility and modern grid infrastructure. Although deployment of these technologies has accelerated, progress remains constrained by slow permitting processes, high investment needs, and fragmented approaches across Member States. Predictable regulation, adequate financing and integrated system planning are essential to keep the EU on track for its 2030 and 2040 targets.

Solar PV is central to the transition and is expected to triple its installed capacity by 2030, yet deployment remains uneven. Fragmented markets, administrative bottlenecks and shortages of skilled workers slow installation rates. Addressing workforce gaps and improving policy coordination are key to accelerating deployment and strengthening the competitiveness and resilience of the EU's solar value chain.

Wind deployment must accelerate to meet 2030 objectives but faces persistent barriers. Slow and complex permitting, supply-chain risks and grid-integration challenges increase costs, delay project development and connection timelines. Competitive generation costs and a strong industrial base are important enablers, complemented by faster grid expansion and streamlined project approval procedures.

Renewable and low-carbon hydrogen will support the decarbonisation of energy-intensive industries and specific transport segments, but scaling remains limited by high production costs, uncertain demand and supply-chain constraints. Recent EU regulatory frameworks and investment efforts aim to improve technology readiness, provide market clarity and support early deployment.

System flexibility remains essential for integrating higher shares of renewables, but storage technologies, advanced batteries and sustainable bioenergy are developing unevenly. High investment needs, sustainability constraints for biomass and limited integration of storage into energy-system planning slow deployment. Expanding storage capacity, strengthening battery value chains and ensuring sustainable bioenergy supply can reinforce system reliability and support a secure renewable-based energy mix.

Decarbonising buildings remains a major challenge due to an ageing building stock, high renovation costs, limited skilled labour and health risks such as asbestos. Progress will require tailored financial support, wider deployment of clean-heating technologies, strengthened skills programmes and targeted attention to social-equity concerns to ensure fair access to renovation benefits.

Small Modular Reactors (SMRs) could complement the EU's low-carbon energy mix in the longer term but face hurdles in regulatory approval, supply-chain maturity and economic competitiveness. Standardisation, modularisation and coordinated policy efforts combined with investments in skills will be crucial for their future deployment.

Cross-cutting constraints such as skills shortages, supply-chain vulnerabilities and uneven affordability **shape the pace and fairness of the clean-energy transition**. Addressing workforce needs in solar and renovations, strengthening supply chains for wind and hydrogen, and ensuring that low-income households and regions can access the benefits of clean energy are essential to deliver a socially equitable and resilient transition.

2.2 Clean, affordable, and secure energy

The revised *Renewable Energy Directive* (RED III) took effect in 2023, setting a **binding target** for the EU's renewable energy share to at least 42.5% of final energy consumption by 2030, with an ambition to reach 45% [95]. Progress is already underway: in 2024, renewables represented 25.2% of the EU's gross final energy consumption, up from 23% in 2022, reflecting the continued expansion of renewable energy deployment across Member States. At the same time, the scale of the transition ahead remains significant, as **reducing external energy dependence** has become increasingly important for both energy security and strategic autonomy in the EU. In 2024, the EU produced 43% of its own energy needs, while imports accounted for the remaining 57%. Although renewables represented 20% of the overall energy mix, they already constituted the largest source of domestic energy production, accounting for 48% of total EU energy production [96]. This highlights the growing role of renewable energy not only in achieving climate objectives, but also in strengthening the EU's **energy resilience** and reducing reliance on imported fossil fuels.

Progress is particularly advanced in the electricity sector, where renewable energy accounted for 48% of EU electricity production in 2024, making it the leading source of electricity generation. As electricity currently represents 23% of total final energy consumption in the EU, **accelerating electrification** across transport, buildings, and industry, alongside continued renewable deployment, will be essential to reducing fossil fuel dependency across the wider energy system.
This section provides an overview of the main challenges and enabling factors shaping the development of renewable energy sources in the EU, including solar, wind, ocean energy, and bioenergy, as well as renewable hydrogen, energy storage, energy efficiency, building renovation and small modular reactors.

2.2.1 Solar energy

Solar energy, particularly photovoltaic (PV), will play a central role in the EU and global energy transitions. Solar thermal energy also has significant potential, particularly in heating, cooling, and industrial processes. However, to achieve this massive expansion of solar energy, the EU needs to address several challenges.

Deployment
By 2030, the EU aims to **triple** its installed solar capacity in line with the *REPowerEU* policy. This growth is expected to continue as electrification expands to meet new energy demands in transport, buildings, and industrial sectors. However, uncertainties around climate policies and regulations may hinder PV industry growth. For instance, inconsistent national policies create a fragmented market, and delays in transposing EU directives into national law can slow down progress. Fragmentation in national policies and markets is also identified as a pivotal issue in the *Competitiveness Compass* [4]. Photovoltaic electricity is now the cheapest source of power in most regions, yet streamlined planning and permitting processes are critical to facilitating expansion. Simplified procedures are necessary, from local to regional levels, along with the identification of priority areas. For example, the European Solar Rooftops Initiative promotes rapid PV deployment by requiring Member States to ensure that buildings are "solar ready." **Innovative deployment models**, such as agrivoltaics, floating solar installations, PV-integrated motorway sound barriers, and solar-enabled car parks, can reduce land-use competition [97]. Another challenge is the shortage of skilled workers in the PV industry. The EU is addressing this through the large-scale skills partnership under the *Pact for Skills*, which focuses on workforce development in the solar sector.

System Integration
Solar PV alone cannot meet energy needs – it depends on a robust, integrated energy system that balances supply, demand, and storage. Distribution networks must be adapted to accommodate **decentralised solar installations**. The EU is improving electricity networks and market rules to make the energy system more flexible and efficient. This addresses problems like extremely low electricity prices during high supply periods and reduced profits for renewable energy producers. Innovative PV deployment methods, such as East-West-facing vertical panels in agrivoltaics and motorway barriers, can help balance uneven production patterns. Strengthening the transmission system is also vital, ensuring rapid-response backup capacity as a substitute for traditional spinning reserves.

PV Manufacturing, R&D, and Strategic Autonomy

The EU currently depends heavily on imports from China, which dominates the global PV market with 87% of cell production and 82% of module production. In contrast, the EU manufacturing capacity accounts for just 0.3% of global cell production and 0.9% of module production. New policies like the *Net-Zero Industry Act* (NZIA) [98] aim to encourage investment in manufacturing capacities, reducing dependence on imports and increasing competitiveness. Initiatives such as Ecodesign for photovoltaic modules will help promote European production by enforcing carbon footprint limitations on products sold in the EU. Expanding domestic manufacturing comes with material supply risks – such as silica, silver, and PV glass shortages – but measures under the *Critical Raw Materials Act* (CRMA) [99] will play a key role in addressing these issues. The European Solar PV Industry Alliance supports these efforts, fostering collaboration and investment. Scaling innovation and reducing costs requires sustained R&D investment and deeper industry-research collaboration, as reflected in initiatives such as the proposed PV Research and Innovation (R&I) Partnership. Currently, private R&D investment in the EU lags behind that of China and other countries, underscoring the need for enhanced efforts.

Solar Thermal Energy

Solar thermal energy currently plays a niche role in electricity production and heating and cooling. Growth is also low, except for solar water heaters in Mediterranean regions and as a supply for district heating systems. The EU has strengthened support for greater deployment in recent policies and continues to fund a broad range of research and innovation projects. Realising the full potential of solar energy in the EU will require action across deployment, manufacturing, system integration, and skills.

Solar energy

Potential enablers

Expanding innovative deployment models (such as agrivoltaics, floating solar, and building-integrated PV) to reduce land-use competition and unlock new installation opportunities.

Scaling up workforce development through initiatives such as the Pact for Skills large-scale partnership, to address the shortage of skilled workers in the PV industry.

Strengthening distribution and transmission networks to accommodate decentralised solar installations and improve system flexibility, including rapid-response backup capacity.

Increasing domestic PV manufacturing capacity through instruments such as the Net-Zero Industry Act, reducing dependence on imports and strengthening the EU's strategic autonomy.

Addressing material supply risks through the Critical Raw Materials Act and related measures.

Boosting R&D investment and fostering industry-research partnerships, such as the proposed PV.

Research and Innovation Partnership, to drive innovation and reduce costs.

Expanding support for solar thermal energy deployment, particularly for district heating systems and industrial processes, building on existing EU funding and policy frameworks.

2.2.2 Wind and ocean energy

In 2024, the EU installed 13 GW of new wind capacity – 11.5 GW onshore and 1.5 GW offshore – bringing the total capacity to 241.7 GW (221 GW onshore and 20.7 GW offshore). While these achievements are encouraging, they remain below the trajectory required to meet the EU's ambitious 2030 targets [100].
This overview highlights key challenges facing the wind energy sector and enablers that can facilitate its growth and align with the 2030 objectives.

The wind energy sector faces several significant challenges that hinder its growth and development. One major obstacle is administrative challenges, particularly the **slow permitting** process for new installations. This bottleneck often results in delayed project timelines and increased costs.
Additionally, the sector faces supply chain risks due to the European Union's reliance on a single non-EU country for critical raw materials, such as the rare earth elements present in wind turbines with permanent magnet generators, which can disrupt supply chains. Another important challenge lies in grid integration and infrastructure, as incorporating wind energy into existing grids demands substantial investment in transmission and distribution networks to maintain grid stability and effectively balance supply and demand.
Public acceptance is also a concern, as wind energy projects often encounter resistance from local communities or organised opposition groups, citing issues like noise, visual impact, and wildlife protection. Finally, achieving **scalability** and meeting ambitious 2030 targets will require a significantly increase in annual deployment rates, which poses challenges in manufacturing, logistics, and workforce development.

Despite these challenges, there are several enablers driving the growth of the wind energy sector. Competitive costs are a key advantage, with the cost of onshore wind dropping significantly to a global weighted average Levelised Cost of Energy (LCoE) of EUR 32 per MWh [101], making it **highly competitive** with fossil fuels [102]. The EU is leading in the domestic wind market, with European companies dominating both onshore and offshore wind installation. Furthermore, the EU is a leader in public research and development (R&D) investment in wind energy, with Member States contributing 31% of the global public investment in the sector from 2014 to 2023 [100], [102].

New deployment opportunities are emerging through innovations such as **floating offshore** wind technology, particularly in countries with deep waters or steep shorelines. Lastly, implementing recycling and circularity practices can not only promote innovation but also alleviate supply chain pressures and enhance public acceptance of wind technology.

Ocean energy

Ocean energy technologies - particularly tidal stream and wave energy - represent a promising yet still **emerging pillar** of the EU's clean energy transition. Despite the EU's ambitious targets of 1 GW by 2030 and 40 GW by 2050 [103] global deployment remains limited. In 2024, just 1.8 MW of new capacity was installed worldwide, including 0.5 MW in the EU [100]. The EU remains a global leader in ocean energy R&D, accounting for 58% of worldwide public investment over the past decade [100], and supporting innovation through programmes such as Horizon 2020 and Horizon Europe. However, the sector still faces persistent challenges: high costs, limited private investment, complex permitting procedures, and uncertainties around long-term performance. Achieving scale and cost competitiveness will require coordinated support, continued R&I leadership, and accelerated deployment to meet strategic targets.

A Path Forward

While the EU wind energy sector faces notable challenges – including administrative barriers, supply chain risks, and infrastructure limitations – several key enablers offer a pathway forward. Addressing these will require coordinated action across permitting, infrastructure, supply chains, manufacturing, and emerging technologies.

Streamlining permitting and administrative procedures for wind energy projects, including the designation of renewable acceleration areas under the ***Renewable Energy Directive***, to reduce delays and lower project costs. Strengthening transmission and distribution grid infrastructure to accommodate increasing wind energy capacity and maintain grid stability.

Diversifying supply chains for critical raw materials, including rare earth elements, through the Critical Raw Materials Act and international partnerships, to reduce dependence on single non-EU suppliers.

Supporting workforce development and scaling up manufacturing capacity to meet the significantly higher annual deployment rates required to achieve 2030 targets.
Promoting community engagement and participation in wind energy projects to improve public acceptance and address concerns around noise, visual impact, and wildlife protection.

Advancing recycling and circularity practices for wind turbine components to alleviate supply chain pressures and support sustainable deployment.

Accelerating the development and commercialisation of floating offshore wind technology, particularly for Member States with deep waters or steep shorelines, opening new deployment opportunities beyond traditional fixed-bottom installations.

Scaling up public and private investment in ocean energy R&D and demonstration projects, building on the EU's global leadership, to reduce costs and unlock the sector's long-term potential.

Potential enablers

2.2.3 Renewable energy

Global hydrogen production is still dominated by fossil-based pathways, leading to high greenhouse gas (GHG) intensities across the supply chain [104]. Oil-based routes also remain carbon-intensive, while water electrolysis powered by the global average electricity mix results in even higher emissions due to the carbon intensity of electricity generation. Although carbon capture utilisation and storage (CCUS) can reduce emissions by up to 90% in steam methane reforming, its deployment is still marginal. Overall, the supply chain remains heavily reliant on unabated fossil fuels. This highlights the urgent need to accelerate renewable electricity deployment, harmonise life cycle assessment methodologies, and scale up low-carbon production routes to align hydrogen supply chains with EU decarbonisation goals.
Renewable hydrogen has the potential to be a **key driver in decarbonising energy-intensive industries** and transport, playing a crucial role in achieving net-zero emissions by 2050. It is particularly suited for sectors where direct **electrification is challenging**. The deployment of renewable and low-carbon hydrogen is intrinsically tied to the availability of renewable electricity, inheriting the challenges associated with scaling renewable energy sources [105].

Hydrogen applications

Current uses for renewable hydrogen include replacing fossil-based hydrogen in oil refining, fertiliser and methanol production, electronics, glassmaking, and metal processing. Emerging applications include steelmaking via direct iron reduction, heavy-duty transportation, hydrogen-based fuel production (e.g. ammonia and synthetic hydrocarbons), biofuel upgrading, high-temperature industrial heating, and electricity storage and generation.

Although demand for low-carbon or renewable hydrogen grew by nearly 10% in 2023, it still accounts for less than 1% of global hydrogen demand [106]. Its higher cost compared to fossil-based hydrogen remains a significant barrier, necessitating policy intervention to close the cost gap and stimulate adoption in new and existing applications.

Policy frameworks. The EU has developed a comprehensive regulatory and policy framework to support hydrogen's role in the energy transition. The EU hydrogen and gas decarbonisation package introduces a regulatory framework for hydrogen infrastructure, enabling the repurposing of natural gas assets for hydrogen use and promoting the use of renewable and low-carbon gases. It also mandates the Commission to set up and operate a mechanism under the European Hydrogen Bank to support the market development of hydrogen. This Hydrogen Mechanism runs on the EU Energy and Raw Materials Platform, launched in July 2025. The Delegated Act [107] outlines the methodology for defining renewable fuels of non-biological origin and defines the eligibility criteria for renewable hydrogen.

Technological readiness. Key hydrogen technologies, such as water electrolysers and fuel cells, are commercially available and scaling rapidly. Initiatives like the Clean Hydrogen Joint Undertaking are improving the efficiency of these technologies, addressing supply chain issues, reducing reliance on critical raw materials and addressing issues related to sustainability and recycling. Large-scale projects, such as Yara's 24 MW electrolyser in Norway and BASF's 54 MW project in Germany [108], [109] showcase progress, though efforts to enhance recycling and reduce reliance on critical raw materials persist.

Policy and regulatory gaps. The European Court of Auditors [110] has criticised the EU's hydrogen strategy for setting overly ambitious targets without sufficient impact assessments. A lack of harmonisation across EU policies and ISO standards for assessing GHG emissions of hydrogen production could slow down the hydrogen economy. A unified framework is essential to prevent greenwashing and ensure investor confidence.

Demand uncertainty. Only 12% of hydrogen projects in the EU have identified off-takers, with few securing binding agreements [111]. This lack of demand certainty delays investment decisions and project development.

Harmonisation of LCA Methodologies for Hydrogen Policies. Life Cycle Assessment (LCA) plays a central role in regulating the sustainability of hydrogen technologies. However, current methodologies applied in EU legislation are not fully harmonised. Differences in scope, treatment of multifunctional processes (e.g. co-production, recycling, energy recovery), and allocation methods create significant inconsistencies. Such disparities can lead to market distortions – where hydrogen from the same pathway may be deemed sustainable under one approach but unsustainable under another – and may undermine environmental integrity by promoting pathways that do not deliver real emission reductions. As hydrogen markets expand, these inconsistencies risk creating inefficiencies, investor uncertainty, and confusion in cross-sectoral applications. To mitigate these risks, strict and harmonised EU guidelines for hydrogen-related LCAs are urgently needed, ensuring consistency across legislation and alignment with international frameworks to support future trade [112], [113].

Policymakers, the LCA community, and industry stakeholders should jointly define methodological approaches for each production pathway, balancing scientific robustness, market stability, and environmental objectives.

Hydrogen delivery. Importing renewable hydrogen from regions with cheaper energy can be more cost-effective than domestic production, but the environmental impacts of long-distance transport remain under-assessed.

A recent JRC study [114] shows that while all delivery options reduce global warming potential compared to fossil-based hydrogen, shipping liquid hydrogen and transporting compressed hydrogen by pipeline are the most environmentally favourable, whereas chemical carriers increase impacts due to high conversion and reconversion energy needs.

Importing renewable hydrogen may deliver climate benefits but could raise pressures on other resources, highlighting critical trade-offs across environmental categories. Infrastructure choices will strongly influence the sustainability of future hydrogen trade, and harmonised life cycle assessment methodologies are essential to provide clarity, avoid distortions, and guide investment.

Preliminary evidence suggests renewable hydrogen transport is environmentally advantageous, but robust primary data on technologies and supply chains is needed to reduce uncertainties. Policy frameworks should prioritise pathways that minimise overall environmental burdens while supporting EU decarbonisation goals.

Competitiveness and supply chain challenges

High costs: rising electricity prices across European economies increase the levelised cost of hydrogen, weakening the business case for electrolysis technologies. European electrolyser systems, including both stacks and balance-of-plant components, are 3-4 times more expensive than their Chinese counterparts [105].

Global competition: Europe leads in proton-exchange membrane (PEM) electrolyser technology, which is well-suited for renewable energy systems. However, Chinese companies are rapidly advancing in this area, offering significantly cheaper electrolysers and narrowing the quality gap. Non-European countries have already surpassed Europe in manufacturing capacity for PEM electrolysers, with Asian producers offering lead times of 6–7 months compared to an average of 22 months for European manufacturers [115].

Manufacturing gaps: Although Europe holds a strong position in component manufacturing, it accounts for only 12% of global fuel cell production, lagging behind other regions. In contrast, Europe is a leading producer of electrolyser stacks [115].

Supply chain challenges: The hydrogen industry depends on over 40 raw materials and 60 processed materials for electrolyser production, with the EU supplying only 1% of raw materials needed for PEM electrolysers and 5% for solid oxide electrolysers. For PEM technology, 43% of critical raw materials are sourced from China, rising to 63% for anion exchange electrolysers. Europe also lacks a robust recycling infrastructure for electrolysis stacks [115].

Global dependence: Key suppliers of raw materials include China, South Africa, and Australia, while processed materials are predominantly supplied by US, China, and India, with the EU supplying only a marginal share for both [115].

Renewable hydrogen

Potential enablers

Harmonising EU and international standards for hydrogen GHG assessments and life cycle assessment methodologies to ensure consistency across legislation, prevent greenwashing, and support investor confidence.

Scaling up investment in electrolyser manufacturing, recycling infrastructure, and innovative designs to reduce costs and improve competitiveness with non-European producers.

Diversifying supply chains for critical raw materials (including iridium, platinum, and other precious metals) through the Critical Raw Materials Act and international partnerships, while strengthening domestic recycling capabilities, to secure long-term resource availability.

Developing dedicated hydrogen transport, storage, and distribution infrastructure, including the repurposing of existing natural gas assets, to support widespread adoption.

Creating demand-side incentives and facilitating long-term offtake agreements to provide certainty for investors and accelerate project development, building on the European Hydrogen Bank mechanism.

Advancing R&D into catalyst loading reduction, recycling of electrolyser stacks, and standardised methods for assessing the impact of renewable energy intermittency on electrolyser performance and durability.

Addressing environmental risks associated with large-scale electrolyser deployment, including PFAS emissions, through comprehensive data collection and targeted regulatory frameworks.

Precious metal constraints: Catalysts like iridium and platinum, essential for PEM electrolysers and fuel cells, are primarily sourced from South Africa, Russia, and Zimbabwe. Iridium supply, in particular, is a bottleneck for large-scale deployment unless advancements in catalyst loading and recycling are achieved [115].
Infrastructure deficits: The EU lacks a mature hydrogen transport, storage, and distribution network to support widespread adoption.
Environmental concerns: Large-scale electrolyser deployment may result in environmental risks, such as the release of per- and polyfluoroalkyl substances (PFAS) in wastewater. This area requires comprehensive data and further research [116].
Electrolyser performance: The intermittent nature of renewable energy sources creates additional challenges for electrolyser efficiency and safety [117]. Developing standardised methods is crucial to understand how intermittency affects performance and durability.

2.2.4 Bioenergy

The EU is a global leader in bioenergy, essential for the low-carbon transition. Established technologies like anaerobic digestion and biomass combustion coexist with emerging ones such as pyrolysis and hydrothermal processing. Biogas and biomethane production are rapidly growing, while Bio-LNG capacity is set to expand significantly by 2025 [118]. **Economic viability** is improving due to reductions in capital and operating expenditures and higher process efficiency. Bioenergy contributes significantly to the EU economy, with solid biomass and biogas turnover reaching EUR 32 billion in 2023. The sector also provides employment, supporting approximately 304,000 full-time equivalent (FTE) jobs. However, the EU maintains a trade deficit in biomass feedstocks and bioenergy carriers, reaching EUR 1.2 billion in 2024. This growing import dependency underscores the need for sustainable and diversified feedstock strategies to meet 2030–2050 climate targets [119].

The sector faces several **challenges**. Competition from alternative uses of feedstocks, low energy density, and variable biomass characteristics, combined with dependence on affordable feedstock, limit economic viability. Small-scale combustion, particularly in residential areas, can negatively affect air quality, and intensive biomass management practices may threaten biodiversity. Import dependency and volatile funding create economic uncertainty, while policy instability and the electrification of heating could restrict market growth.
Bioenergy also presents significant **opportunities**. It can enhance energy diversification and security, integrate variable renewable sources, valorise diverse feedstocks, support rural development, generate co-products, and facilitate the remediation of degraded land. It reduces fire risks from residues and can be cost-competitive with fossil fuels. Expanding technologies, including biogas, biomethane, and Bio-LNG production, further strengthen the sector's growth potential.
Addressing these challenges through stable policies, innovative policy tools such as the mechanism for biomethane on the EU Energy and Raw Materials Platform, sustainable feedstock management, and continued technological development is critical to maximise bioenergy's contribution to a low-carbon, resilient energy system.

Bioenergy

Potential enablers

Expanding innovative policy tools such as the biomethane mechanism on the EU Energy and Raw Materials Platform to stimulate production, aggregate demand, and provide market certainty.

Promoting sustainable feedstock management practices to reduce import dependency, address biodiversity concerns, and ensure long-term resource availability for bioenergy production.

Supporting the scaling up of emerging technologies (including pyrolysis, hydrothermal processing, and Bio-LNG production) through targeted R&D funding and demonstration projects.

Integrating bioenergy into broader energy system planning, leveraging its flexibility to complement variable renewable sources and support grid stability.

Supporting workforce development and skills training in the bioenergy sector to sustain employment gains and accompany technological transitions.

2.2.5 **Energy storage system**

Energy Storage Systems (ESS) are a key component of the transition to a low-carbon energy system. By integrating storage solutions, grid operators can optimise resource utilisation, manage the intermittency of renewable energy sources, and enhance overall system reliability. Energy storage also offers economic benefits, enabling low-cost energy to be stored and dispatched during peak-demand periods, while reducing the need for grid extension [120]. As the world transitions towards a low-carbon economy, ESS are poised to play a vital role in the future energy system. By integrating storage solutions, utilities can optimize resource utilisation, **mitigate intermittency** challenges associated with renewable energy sources, and enhance overall system reliability. Furthermore, energy storage technologies offer cost savings by storing inexpensive energy for use during periods of higher costs, while also reducing overall grid extension costs [120].

Performance Characteristics and Suitability

The performance characteristics of energy storage technologies, including cycle longevity, efficiency, energy density, and storage duration, vary across different systems. It is essential to consider these characteristics when determining the suitability of each technology for specific applications. This will enable policymakers to make informed decisions about the deployment of energy storage systems and ensure that they are used effectively to support the transition to a low-carbon economy.

Data and Research Gaps

Estimating the installed capacity of novel energy storage at the global and European scale is complex due to limited data from existing research, individual systems, and assumptions to approximate the order of magnitude. This underscores the need for more comprehensive data and research in this area to inform policy decisions and support the development of energy storage technologies.

Market Trends and European Leadership

The global turnover for energy storage technologies such as thermal energy storage, compressed air, and supercapacitors has been stable or slightly growing, while technologies like gravity energy storage, superconducting magnetic energy storage, and flywheels have seen declining turnovers. Europe dominates the thermal energy storage market and holds a significant market share in other energy storage technologies, with key companies based in Germany, France, Italy, Spain, and Finland. EU companies, including start-ups and established energy-related firms, contribute to technology development and deployment across various energy storage systems.

Research and Implementation Efforts

Research and implementation efforts vary among EU countries, with Spain, France, Germany, Italy, Greece, Ireland, and Austria being key players. The EU leads in public investments in energy storage technologies, with Germany being the fourth country with the highest number of patents registered. This demonstrates the EU's commitment to supporting the development and deployment of energy storage technologies.

Supply Chain and Raw Materials

The supply chain of energy storage technologies varies depending on the specific system used. Notably, the novel energy storage systems considered here have very low reliance on critical raw materials, reducing the risks associated with supply chain disruptions and supporting the development of sustainable energy systems.

Challenges and Opportunities

While some energy storage technologies boast high power density and high efficiency – addressing intermittency challenges and providing continuous energy supply when needed – others face challenges such as low energy density and energy losses. The commercialisation level of some technologies remains low, making it challenging to bring them to market. However, novel energy storage technologies also present several opportunities, including supporting the electrification and decarbonisation of energy systems; improving flexibility and reducing costs for energy suppliers; and providing energy security in rural or isolated areas.

Energy Storage System

Potential enablers

Investing in research and development to improve the performance characteristics of energy storage systems and reduce costs.

Developing standardised methodologies for data collection on installed capacity and system performance, addressing current research and data gaps at both EU and global level.

Supporting skills development and workforce training to ensure the availability of qualified professionals for the installation, operation, and maintenance of energy storage systems.

Facilitating cross-border cooperation and integrated system planning to maximise the value of energy storage across interconnected European electricity markets.

Strengthening the EU's industrial base by supporting domestic manufacturing and supply chains for energy storage components.

2.2.6 Stationary Battery Energy Storage

To ensure a high level of penetration of renewable energy in the EU energy mix, the development and deployment of Stationary Battery Energy Storage systems (BESS) is crucial [121]. BESS plays a vital role in **shifting energy from peak generation hours to peak consumption hours**, while adding inertia to the grid and enabling efficient grid balancing, essential for cost-effective, safe, and stable grid operation.

BESS Technology and Market Trends

The BESS technology is well-suited to address intraday energy shifts, but it is not expected to play a significant role in seasonal energy storage in the next 5-10 years [121]. The deployment of BESS is growing in both grid-level and behind-the-meter segments, with the grid BESS market accounting for about 72% of the global BESS market in 2023 [121]. The battery sector has reached a maturity level where technologies are diverging into solutions designed and optimised for specific uses, such as electric vehicle (EV) batteries and BESS batteries.
BESS Batteries and Raw Materials BESS batteries are optimized with a focus on cost, durability, and safety, which is why lithium iron phosphate (LFP) chemistry has become the first choice for BESS applications, unlike in most EV applications where nickel manganese cobalt (NMC) chemistry dominates [121]. Sodium-ion (Na-ion) batteries may also become a viable option in the near future due to their lower cost and potentially superior durability and safety.

EU Energy Security and Independence

In light of the changed geopolitical situation, independence and security of supply must be taken into account. The deployment of EU-produced LFP batteries would contribute to increased independence, as LFP is a low-critical raw material intensive chemistry. Na-ion batteries, with a Prussian blue analogue (PBA) cathode, would allow for further dependency reduction by eliminating critical lithium, phosphates, and copper foil. Domestic production of BESS-compatible batteries would eliminate the EU's dependence on imports in this segment of battery technologies. However, while the EU has invested heavily in the development and production of high-energy density batteries for EVs, the production of BESS batteries has not been a focus area. Therefore, it is essential to prioritize the development and deployment of BESS systems, including the production of BESS-compatible batteries, to ensure a secure and independent energy supply in the EU.

2.2.7 **Building renovation and energy efficiency**

The European Union is making significant progress in enhancing energy efficiency but still faces challenges in meeting its ambitious 2030 energy efficiency targets. Supported by key legislative documents. Including the *Energy Performance of Buildings Directive* [122], *Energy Efficiency Directive* (RED) [123], [124], and the *Renovation Wave Strategy* [125], this overview highlights key obstacles and potential enablers in the building sector, particularly regarding heating and cooling.

Retrofitting challenges in existing buildings
Most buildings in the EU were constructed before modern energy efficiency standards were established, making retrofitting a substantial and resource-intensive endeavour. While energy-efficient technologies like heat pumps, geothermal systems, and district heating are available, they may not be universally applicable. **Heat pumps**, for instance, may require additional upgrades in poorly insulated buildings, increasing upfront costs and limiting accessibility for many households, despite their long-term operational savings. Moreover, a shortage of skilled professionals to install and maintain these systems presents a further barrier.

Health and safety risks in renovation projects
The *Renovation Wave* strategy aims to renovate 35 million buildings by 2030, reducing energy consumption, lowering greenhouse gas emissions, and creating green jobs in the construction sector. However, it also raises health concerns, particularly around asbestos exposure among construction workers and building occupants. Inadequate documentation on asbestos presence and removal across the EU exacerbates this issue [126], with few countries addressing it in their Long-Term Renovation Strategies. Unexpected **asbestos** discoveries can delay renovation projects and pose health risks. Regions with both high asbestos use and seismic activity require special attention, as earthquakes can release harmful fibres.

Social equity and vulnerable populations
Achieving energy efficiency while ensuring occupant wellbeing requires a **human-centric approach**, particularly given climate-change-driven risks like summer energy poverty, which disproportionately affects vulnerable populations. Efficient subsidy schemes are necessary to make energy-efficient investments more attractive to building owners. In rural areas, larger, less compact buildings present energy efficiency challenges, but higher rates of home ownership (around 78%) may facilitate renovations. At the same time, **rural households** may face higher levels of energy poverty, spending more on energy due to less efficient building stock and greater heating needs. Nevertheless, rural areas lead in energy efficiency improvements and are particularly well-suited for self-consumption renewable systems such as rooftop photovoltaics, presenting significant opportunities to address these vulnerabilities [127]. Conversely, **urban areas** benefit from more energy-efficient building typologies, though lower ownership rates and higher rental expenditures can increase vulnerability to energy poverty, particularly in summer months [128]. The broader socioeconomic dimensions of **energy poverty** are discussed in Chapter 7.1.

Technological and digitalisation gaps
Despite the availability of innovative technologies (including smart grids, demand-response systems, and AI-driven energy management tools) their deployment in the building sector remains uneven. Scaling up digitalisation is essential to optimise energy consumption, reduce peak demand, and support real-time monitoring across the building stock.

Policy and financial support
High upfront costs and **fragmented financing** remain key barriers to renovation at scale. Governments and regulatory bodies play a vital role in advancing energy efficiency through policies like building codes, tax incentives, and subsidies. Green financing mechanisms, including green bonds and energy performance contracts, provide building owners and managers with the resources needed for energy-efficient renovations. Additionally, private investments and diversified funding options serve as critical enablers. Significant funding has been allocated to these efforts, over EUR 80 billion from the *Recovery and Resilience Facility* and around EUR 17 billion from the *Cohesion Policy Funds* for the energy performance of buildings (2021-2027) [129].

Defining deep renovation
The absence of clear and consistent numerical benchmarks for deep renovation risks locking in suboptimal outcomes and undermining progress towards nearly zero-energy and zero-emission standards, as well as the EU's 2050 decarbonisation goals.

Whole life cycle impacts
The building sector's contribution to embodied carbon, resource consumption, and waste remains underaddressed. A life-cycle perspective is needed to drive the sector towards climate neutrality and integrate it into a circular economy.

Occupant engagement and behavioural barriers
Low awareness, limited digital literacy, and insufficient participation in renovation decisions reduce the effectiveness of energy efficiency measures. Diverse occupant needs and cultural practices are often not adequately reflected in renovation approaches. Combining advanced technologies, such as adaptive thermal controls, with traditional strategies like natural ventilation, ensures balanced energy efficiency and occupant comfort. Behavioural interventions, such as default energy-efficient temperature settings and digital literacy training, encourage sustainable energy use. Participatory design that accounts for diverse occupant needs and cultural practices further enhances wellbeing while reducing energy consumption. Providing educational resources, training programmes, and consultations empowers building owners and policymakers to make informed decisions about renovations and technologies.
Realising the EU's ambitions for building renovation and energy efficiency will require coordinated action across technology, financing, regulation, and occupant engagement.

Building renovation and energy efficiency

Potential enablers

Streamlining and scaling up retrofitting programmes for existing buildings, with targeted support for upfront costs to make energy-efficient technologies such as heat pumps, geothermal systems, and district heating accessible to all households.

Addressing the shortage of skilled professionals through retraining programmes - including for gas boiler installers transitioning to heat pump installation - building on existing EU skills partnerships and the *Renovation Wave* strategy.

Developing comprehensive asbestos documentation and removal protocols across EU Member States, integrating health and safety requirements into Long-Term Renovation Strategies to prevent project delays and protect construction workers and occupants.

Designing efficient and targeted subsidy schemes that make energy-efficient investments attractive to building owners, with particular attention to vulnerable populations at risk of energy poverty.

Supporting rural renovation through tailored financing mechanisms that leverage high homeownership rates, while promoting self-consumption renewable systems such as rooftop photovoltaics to address energy vulnerability.

Expanding smart grid and demand-response systems, and leveraging AI-driven digitalisation tools, to improve real-time energy monitoring, planning, and decision-making at building and district level.
Mobilising public and private financing through green bonds, energy performance contracts, and diversified funding options, building on existing EU financial instruments.

Establishing clear numerical benchmarks for deep renovation to ensure projects meet nearly zero-energy and zero-emission standards, avoiding carbon lock-ins and supporting 2050 decarbonisation goals.

Adopting a whole life cycle approach to building renovation, minimising embodied carbon and resource consumption, and integrating the building sector into a circular economy framework.

Promoting participatory and human-centric design approaches that account for diverse occupant needs, cultural practices, and behavioural factors, combining technological solutions with educational resources and training programmes.

2.2.8 **Small Modular Reactors and their role in the green transition**

Small modular reactors (SMRs) are characterised by their compact size and limited power output (typically 20-300 MWe, compared to 1000+ MWe of a large reactor). They offer advantages such as more distributed energy and heat production, relatively close to urban areas and industrial sites. They are made of complete modules manufactured in a factory and delivered and installed onsite. SMRs aim to prioritise affordability and adaptability to local energy demand profiles [130], [131], aligning with the EU's ambitious climate neutrality goals.

The Global Picture

The SMR booklet of the International Atomic Energy Agency (IAEA) lists 83 SMR concepts at different stages of technological development worldwide. Russia and China already have operational SMRs and a few other countries have licensed certain SMR designs and prepare for construction [132], [133], [134]. In the EU, **the first commercial SMRs are expected to be operational by the mid-2030s.** The Nuclear Energy Agency estimates that SMRs could account for 5-15% of new nuclear capacity additions by 2035, potentially reaching 21-54 GW worldwide [135]. The United States, China, and Russia are leading in SMR development, with several designs in advanced stages of licensing and some with licensing completed. However, widespread adoption faces challenges such as regulatory approval, supply chain development, workforce build-up and training and economic competitiveness. Overcoming these barriers requires coordinated efforts in policy support, standardisation, and international cooperation [132], [136]. To address these challenges, the European Commission launched the **European Industrial Alliance on SMRs in early 2024** – aimed at fostering collaboration between industry, research institutions, and policymakers. Additionally, **12 Member States mention SMRs in their National Energy and Climate Plans (NECPs)** [137], [138], [137], [139].

Focus on the EU Regulation in EU Member States

The large-scale deployment of SMRs in the EU requires the harmonisation of licensing and requirements across EU Member States [136]. Unlike large nuclear power plants (NPPs), which are licensed on a case-by-case basis, the SMRs' edge is the standardised designs and factory-based construction which requires a streamlined, uniform approach to licensing.

The nuclear regulators of EU Member States have diverging views about whether "EU-wide type approval" could become acceptable for nuclear reactors, particularly SMRs.
While nuclear stakeholders advocate for harmonised licensing processes to facilitate SMR deployment across EU Member States [136], nuclear regulators remain cautious due to differences in national nuclear legislation, varying technical requirements for safety demonstrations, and distinct national approaches to safety assessment [139].

Harmonisation is also important for enabling cross-border deployment and series production economic benefits [140] [136]. A key aspect of this regulatory harmonisation effort is collaboration with international bodies such as the International Atomic Energy Agency (IAEA) and the OECD Nuclear Energy Agency (NEA) as well as in the Generation IV International Forum (GIF), ETSON and ENSREG. In fact, while all countries with operating NPPs largely follow the same standards (e.g. IAEA safety guides), the differences in reactor licensing come from technical details. Aligning the practices to the details internationally is crucial for facilitating the **export** of EU-developed SMR technologies and ensuring that imported technologies meet the EU's safety standards [141].
Progress towards **harmonisation** has been made through initiatives like the **European Utility Requirements (EUR) for Light Water Reactors (LWRs)** and the European SMR Pre-Partnership, Work stream 2 "Licensing". Licensing is a challenge, but it is expected to be addressed in the European Industrial Alliance on SMRs and by ENSREG.

EU competitiveness

The Horizon 2020 programme allocated a budget of EUR 40 million for SMRs project, and the newer Horizon Europe has allocated a budget of EUR 1.981 billion for the years 2021-27 to the EURATOM research and training programme [142], [143].
The European Union has seen a significant increase in venture capital investments in SMRs in recent years, from negligible amounts before 2016 to several hundred million euros by 2022 [131], [137].
For comparison, in the United States, private investments in nuclear startups, including SMR developers, reached over **USD 4 billion cumulatively by 2022** [144]. While the EU is making progress in attracting private capital to SMR development, there remains a significant gap compared to some other major economies. The net EU funding contribution under Horizon 2020 totals EUR 31 million, with research organisations receiving 42% of the funding while private companies and

small and medium enterprises (SMEs) 49% of the funding [142].

Opportunities for the European Union

The **economic model** for SMRs differs from that of conventional large NPPs. While large NPPs rely on economies of scale through larger output, SMRs aim to achieve cost reductions through design simplification, shorter lead times and replication. This approach, already used in the shipbuilding and aircraft industries, involves standardised designs and factory-based assembly of components. By producing multiple largely identical units, manufacturers can reduce costs through learning effects and streamlined production processes and improve quality.
This **modular approach** reduces construction time and upfront costs while enabling incremental capacity additions, making SMRs more flexible and responsive to evolving market demands. While large NPPs have demonstrated successful construction and cost performance in countries with continuous building programmes, SMRs aim to achieve similar benefits through factory-based manufacturing and simplified designs [145].

The nuclear industry has historically relied on **governmental support**, primarily due to long development cycles, high upfront costs, and regulatory complexities. Notably, NPPs built between the 1970s and 1990s have already delivered returns on investment. The observed decrease in total nuclear energy production in the EU and other top producer countries over the past decade can be attributed to a combination of economic, regulatory, and social factors. Market demand for nuclear energy has likely been influenced by increased competition from cheap fossil fuels and renewable energy sources, which have become more viable and attractive due to technological advancements and political support [141].

While NPPs typically become highly profitable after their initial investments are paid off – thanks to low operational costs and high reliability – their profitability can be significantly impacted by external factors, particularly policy decisions that vary across countries [132]. In some EU Member States like Germany and Spain, political decision makers have imposed special levies or taxes on utilities or increased mandated contributions to decommissioning and waste management funds. The same countries have decided to phase out nuclear power and, in the case of Germany, have done so already. This reduces reliable income streams for utilities. Changes in nuclear regulation or decisions by the regulator (e.g. safety upgrades imposed after the Fukushima disaster) have and may result in premature plant closures here and there, but utilities can cope with these by modest increases in electricity prices. **Policy-driven factors**, rather than inherent operational costs, **are the primary challenge to the continued economically feasible operation of NPPs**.

Prior to 2020, investment trends reflected a shift towards renewable energy technologies as the EU navigated its energy transition. However, since the onset of Russia's war of aggression against Ukraine in 2022, there has been a significant reversal in attitudes towards nuclear energy. This shift has been characterised by growing political and industrial support for nuclear power, including renewed interest in existing plants and advanced technologies like SMRs. Recent developments are outlined below.

- Several Member States, including France, Finland, Poland, Czechia and the Netherlands, have announced plans, or are strongly considering building, new NPPs. Slovakia and Hungary are already building new NPPs [146], [147], [148].
- The long-term operation (LTO) of existing NPPs (i.e. extension of the lifetime of operating NPPs beyond their initial design life) is common practice in most EU member states using nuclear power. Instead of an LTO of 50 or 60 years, some countries are considering a lifetime extension to 80 years.
- The EU's inclusion of nuclear energy in its green taxonomy recognises its role in climate change mitigation [149].
- Funding has increased for nuclear research and development, particularly in SMR technologies.
- The are growing discussions about nuclear energy's role in ensuring energy security and reducing dependence on Russian fossil fuels.

Looking ahead, there are indications that the next European Commission mandate may bring a significant shift in attitude towards nuclear energy [150], [151], [152]. This could lead to more supportive policies and increased investment in nuclear technologies, including SMRs.
NPPs and SMRs, for technical and economic reasons, are best operated at full capacity, providing consistent **baseload power**. This characteristic contrasts with the variability of wind and solar power. SMRs offer some advantages compared to large NPPs: they can integrate more easily into **local networks** or provide **dispatchable heat and power for local industry**. However, for grid-wide stability, large NPPs operating at full capacity remain the more effective option. These applications are recognised by European initiatives such as the Nuclear Cogeneration Industrial

Initiative (NC2I) under the Sustainable Nuclear Energy Technology Platform (SNETP) and on a global scale [153]. Finally, SMRs have the potential to **utilise existing infrastructure** in some cases, which could facilitate the decarbonisation of the energy sector without requiring extensive new construction. They may use the existing grid connections and cooling water supply infrastructure of existing fossil fuel power plants. However, regulatory constraints and other factors (e.g. emergency planning zone requirements) may limit the use of such sites for nuclear installations, such as SMRs.

Challenges for the European Union

To realise the full potential of SMRs in the EU's energy transition, several significant **challenges** must be addressed [139], [154]. In addition to the regulatory challenges already addressed above, there are technological, economic, and political challenges, requiring a coordinated approach from industry and research institutions. The newly established European Small Modular Reactor Industrial Alliance supports this coordination [139]. Its goal is to speed up the development, demonstration, and deployment of first SMRs projects in the EU, including revitalising and enlarging the nuclear supply chain.
The deployment of SMRs and any NPP requires long-term political support and governmental commitment to provide certainty for investment and innovation [137].

SMR deployment requires a robust **supply chain** with capable and adequately accredited and certified suppliers and sufficient manufacturing capacity, both for reactor components and fuel cycle infrastructure. Recent initiatives such as the *Net-Zero Industry Act* (NZIA) aim to strengthen the EU's nuclear supply chain capabilities. However, having a robust supply chain is a challenge. Supplying the nuclear sector usually mandates suppliers to run a stringent nuclear Quality Assurance (QA) programme. Obtaining and maintaining the necessary accreditation and certification for these QA programmes is a costly process, which suppliers are likely to undertake only if they foresee substantial future business opportunities. This emphasises the need for clear, long-term commitments to nuclear energy and SMR development by political decision makers.
In terms of fuel cycle infrastructure, securing the supply of critical raw materials and developing new fuel types represents additional challenges [155]. One example is High-Assay Low-Enriched Uranium (HALEU), which allows for longer fuel cycles and higher burnup rates, potentially improving efficiency and reducing waste. However, its currently limited availability necessitates investment in fuel cycle infrastructure [156] [157].

While extensive **R&D** has been conducted over decades for water-cooled reactors and certain non-water-cooled reactors (Gen IV reactors), some targeted research remains important for optimising SMR technologies and ensuring their effective market deployment. The nuclear industry can leverage existing knowledge, codes, and tools to design SMRs, applying well-established principles of reactor physics and safety. Key areas for ongoing **research** include:

- Adapting existing **safety** analysis methods to demonstrate that SMRs can maintain their safety profile across various deployment scenarios.
- Optimising the **integration of SMRs with renewable energy** sources and industrial applications in diverse energy system configurations.
- Exploring and refining SMR **applications in non-electrical domains**, such as hydrogen production or industrial process heat provision.
- Addressing **SMR-specific challenges** in areas such as use and qualification of reactor materials, advanced manufacturing techniques, modular manufacturing and construction, safe module transportation, in-service inspection, maintenance and repair and site-specific adaptation of standardised designs.

The development of an SMR industry requires a **highly specialised workforce**. Expanding education, training, and industrial capabilities could strengthen the EU's technological autonomy and energy security. Realising the potential of small modular reactors in the EU's energy transition will require coordinated action across regulation, financing, supply chains, workforce development, and long-term political commitment.

Potential enablers

Harmonising licensing and regulatory requirements across EU Member States, building on initiatives such as the European Utility Requirements and the European SMR Pre-Partnership, to enable cross-border deployment and realise the economic benefits of series production.

Strengthening collaboration with international bodies (including the IAEA, OECD Nuclear Energy Agency, GIF, ETSON, and ENSREG) to align regulatory practices, facilitate exports of EU-developed SMR technologies, and ensure imported technologies meet EU safety standards.

Developing a clear EU industrial strategy for SMR deployment, including targets, timelines, and support mechanisms, to provide the long-term certainty needed to attract investment and drive innovation.

Scaling up public and private investment in SMR development, building on the European Industrial Alliance on SMRs and Horizon Europe's EURATOM programme, to close the gap with leading economies such as the United States and China.

Strengthening the nuclear supply chain by supporting suppliers in obtaining and maintaining nuclear Quality Assurance accreditation and certification, including through instruments such as the *Net-Zero Industry Act*.

Securing the supply of critical raw materials and investing in fuel cycle infrastructure, including High-Assay Low-Enriched Uranium (HALEU), to support longer fuel cycles and improved efficiency.

Continuing targeted R&D to optimise SMR safety analysis methods, system integration with renewable energy sources, and applications in non-electrical domains such as hydrogen production and industrial process heat.

Exploring the reuse of existing fossil fuel plant infrastructure (including grid connections and cooling water supply) to facilitate SMR deployment and reduce construction costs, while addressing relevant regulatory constraints.

Scaling up workforce development and skills training in the nuclear sector, leveraging the SMR industry as an opportunity to enhance the EU's high-tech capabilities and technological autonomy.

Maintaining and expanding long-term operation of existing nuclear power plants where appropriate, providing a stable baseload foundation while SMR technologies are developed and deployed.

Fostering public engagement and transparent communication on SMR safety, environmental performance, and economic benefits to build social acceptance and support for deployment.

CLEAN, AFFORDABLE AND SECURE ENERGY Navigator

This infographic helps **navigate the complexity** of the transition for achieving **clean, affordable and secure energy targets** while delivering on the **EU Competitiveness ambitions**. It presents a non-exhaustive overview of **challenges and enablers**, which are explored in full in the report.

Legend

- Financial / economic challenges
- Political / institutional challenges
- Technological / infrastructural challenges
- Socio-cultural / behavioural challenges
- Potential intervention areas
- Start — Thematic transition paths
- Final milestones

If we go like this, we will achieve major clean transition policies!

Let's achiev
transition, t

Start

SOLAR ENERGY
deployment, integration, and scale-up

Implementation ambitions

- Overcoming **fragmentation** of national frameworks, **permitting** complexity and shortages of **skilled workforce** slowing down deployment
- Adapting systems to accommodate decentralised solar installations and **balacing** supply, demand, storage
- Accelerating growth of **solar thermal** technologies

Enablers' mix

- **Workforce** Development and skills partnership under the Pact for Skills
- **Permitting processes** Streamlined planning and simplified administrative procedures
- **Grid integration and flexibility** Upgrading electricity networks and market rules, strengthening transmission systems, deploying innovative PV integration solutions, and enabling rapid-response backup capacity
- **Solar thermal** Targeted deployment support, strengthened research and innovation funding
- **Policy drivers** Pact for Skills, European Solar Rooftops Initiative, Net Zero Industry Act, Critical Raw Material Act, European Solar PV Industry Alliance

SOLAR ENERGY
PV manufacturing

Implementation ambitions

- Reduce **dependence** on imports, e.g. from China
- Minimise **material supply** vulnerabilities

Enablers' mix

- **Ecodesign for PV modules**
- **Investment** Encouraging investment in (domestic) manufacturing capacity
- **Policy drivers** Net Zero Industry Act, CRM Act, European Solar PV Industry Alliance

What could we do?

WIND, OCEAN, OFFSHORE

This way

Let's pay attention!

Implementation ambitions

- Overcoming **administrative** barriers and slow **permitting** processes
- Overcoming **supply chain** risks, limited **manufacturing** capacity, and **scalability** constraints
- Support grid **integration**
- Ensure public **acceptance**
- **Workforce** development

Enablers' mix

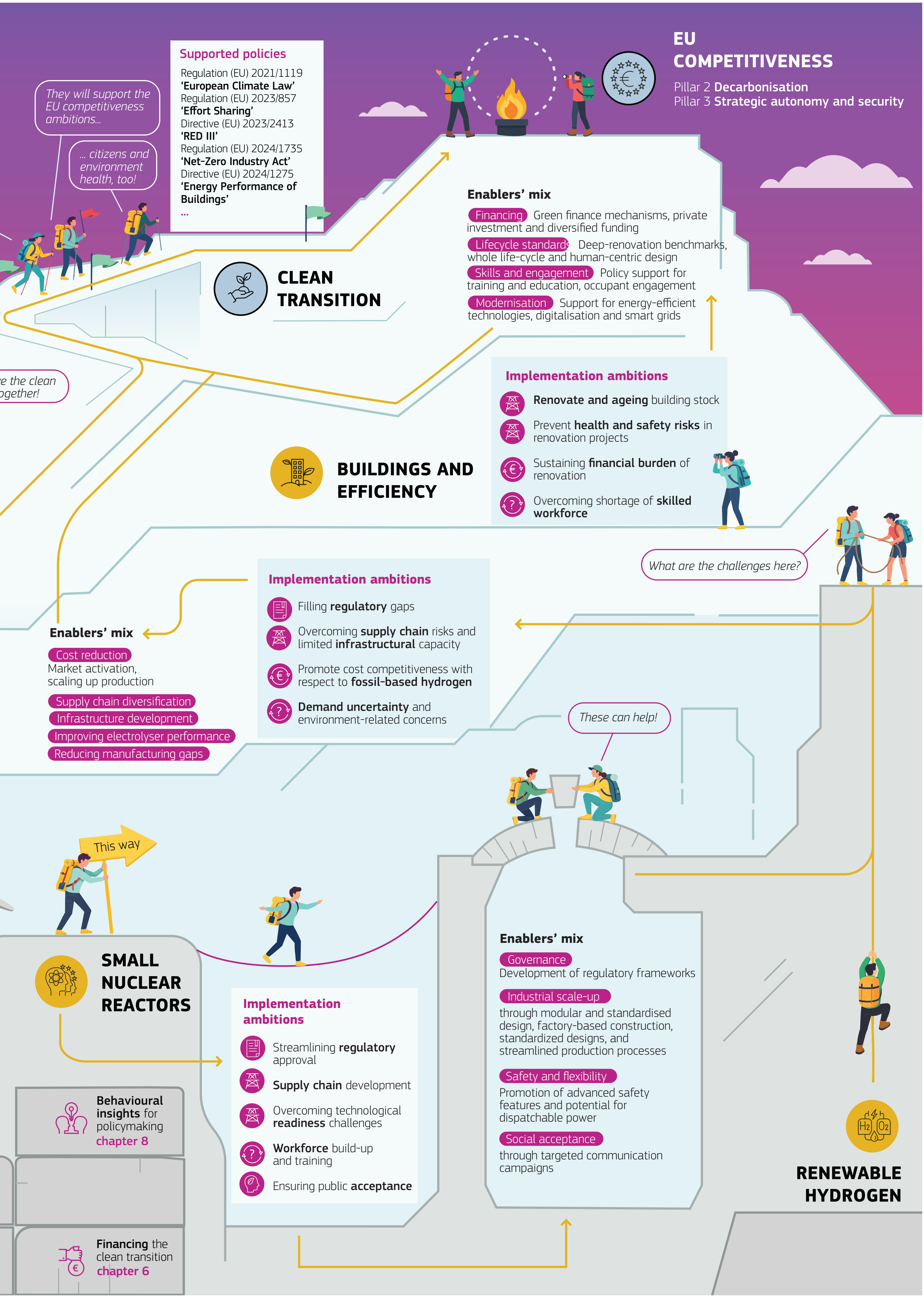
- **Simplification** Streamlining permitting processes
- **Infrastructure and supply chain** Diversifying supply chains, investing in grid infrastructure, increasing manufacturing capacity and logistics, public R&D and innovation investment (e.g. floating offshore wind technology)
- **Upskilling and behaviors** Support recycling and circularity practices, enhancing public acceptance, developing workforce and investing in upskilling programmes

See **Chapter 7** to explore more about a **Fair and Just Transition**

*These **cross-cutting enablers** will help us go faster...*

CROSS-CUTTING ENABLERS

R&I and clean transition **chapter 5**



EU COMPETITIVENESS
Pillar 2 Decarbonisation
Pillar 3 Strategic autonomy and security
They will support the EU competitiveness ambitions...
... citizens and environment health, too!
e the clean
ogether!
Supported policies
Regulation (EU) 2021/1119 'European Climate Law'
Regulation (EU) 2023/857 'Effort Sharing'
Directive (EU) 2023/2413 'RED III'
Regulation (EU) 2024/1735 'Net-Zero Industry Act'
Directive (EU) 2024/1275 'Energy Performance of Buildings'
...
CLEAN TRANSITION
Enablers' mix
Financing Green finance mechanisms, private investment and diversified funding
Lifecycle standards Deep-renovation benchmarks, whole life-cycle and human-centric design
Skills and engagement Policy support for training and education, occupant engagement
Modernisation Support for energy-efficient technologies, digitalisation and smart grids
Implementation ambitions
Renovate and ageing building stock
Prevent health and safety risks in renovation projects
Sustaining financial burden of renovation
Overcoming shortage of skilled workforce
BUILDINGS AND EFFICIENCY
What are the challenges here?
Implementation ambitions
Filling regulatory gaps
Overcoming supply chain risks and limited infrastructural capacity
Promote cost competitiveness with respect to fossil-based hydrogen
Demand uncertainty and environment-related concerns
Enablers' mix
Cost reduction
Market activation, scaling up production
Supply chain diversification
Infrastructure development
Improving electrolyser performance
Reducing manufacturing gaps
These can help!
This way
SMALL NUCLEAR REACTORS
Implementation ambitions
Streamlining regulatory approval
Supply chain development
Overcoming technological readiness challenges
Workforce build-up and training
Ensuring public acceptance
Enablers' mix
Governance
Development of regulatory frameworks
Industrial scale-up
through modular and standardised design, factory-based construction, standardized designs, and streamlined production processes
Safety and flexibility
Promotion of advanced safety features and potential for dispatchable power
Social acceptance
through targeted communication campaigns
RENEWABLE HYDROGEN
Behavioural insights for policymaking chapter 8
Financing the clean transition chapter 6

Key messages (Circular Economy)

Redirecting existing fiscal support for linear models towards secondary raw materials and circular business models, whilst ensuring that prices reflect the full social costs associated with environmental and security of supply externalities, could strengthen the competitiveness of circular practices.

Labour-intensive circular practices, such as repair and remanufacturing, still struggle to compete with large-scale linear production. Alongside stronger requirements under the *Ecodesign for Sustainable Products Regulation* (ESPR) for repair, preparation for re-use and remanufacture, **economic instruments** that facilitate the trade of these products, as well as reforms to the labour-oriented tax system, could improve the competitiveness of circular practices and business models.

Building well-functioning **secondary raw material markets** is pivotal to achieving a circular economy. Improving waste management infrastructure by **leveraging public-private initiatives** to stimulate investment in high quality sorting and recycling infrastructure and by **strengthening economic incentives** to deter landfilling is an essential step.

Ensuring a **steady and long-term demand** is essential to sustain well-functioning secondary raw material markets. There is now an opportunity to explore alternative policy instruments to recycled content requirements that could foster long-term demand with a lower administrative burden.

In light of current shifts in trade policy principles, there is a need to assess the **costs and benefits** of pursuing a ‘sourcing, recycling and using secondary raw materials in Europe’ or similar initiatives for secondary raw materials required by key and strategic EU industrial sectors.

2.3 Circular Economy

The **2020 *Circular Economy Action Plan*** (CEAP) has prompted a series of ambitious and innovative policies and legislation. Most policies on waste and circularity have succeeded in improving recycling and material recovery but have not had as much impact on upstream circular policy objectives (e.g. minimising waste through design) with greater environmental savings potentials [8], [158]. From a sectoral perspective, the European Commission has announced several product-specific circularity initiatives, such as the *Strategy for Sustainable and Circular Textiles* [159], the 2023 *Batteries Regulation* [160], the *Construction Products Regulation* [161] and the *Packaging and Packaging Waste Regulation* [162]. Circularity varies across resource groups, for instance metals show the highest circularity levels, thanks to well-established recycling systems and favourable economics. Nonetheless, metals still offer substantial scope for further circularity improvements, which could contribute to resource savings, decarbonisation, and reduced environmental impacts.

Some **circular economy** policies introduced in recent years can be characterised by a high degree of complexity (e.g. *Implementing Acts* defining technical rules), which can potentially lead to additional regulatory burden on EU businesses and Member State authorities. As the European Commission shifts focus to cultivating lead markets, including those for sustainable, circular, and low-carbon materials, any regulatory proposals that could increase unjustified administrative burden must be carefully considered. This analysis would ensure that any new proposals have a significant likelihood of achieving the intended outcomes without inadvertently distorting the market through potentially inaccurate predictions of technological and market evolutions.
The flagship report "*Delivering the EU Green Deal - Progress towards targets*" [8] showed that little or no progress had yet been achieved to meet the overarching ambitions of decoupling economic growth from resource use, reducing and keeping the EU's consumption footprint within planetary boundaries (Chapter 3, ***Environmental impact of future scenarios***), increasing circular material use rate or reducing waste generation. Such limited progress reflects the fact that this is a recent, highly complex, and broad-in-scope environmental policy work stream. Circular economy policies have largely been used as a means of reconciling economic growth with environmental protection, with a rather defensive approach.
However, an opportunity now exists to adopt a more proactive stance, leveraging circularity to enhance the competitiveness and resilience of the EU economy, as highlighted in the *Competitiveness Compass* (e.g. in the upcoming *Circular Economy Act*) [4] and the *Clean Industrial Deal* [163].

2.3.1 Moving to an economic and legal framework that supports circularity for competitiveness

Removing subsidies for linear models and internalising externalities in prices
Despite the growing political commitment of the EU to a Circular Economy, **high levels of fiscal support to linear business models still prevail**, to the detriment of the competitiveness of circular alternatives and their uptake [164]. Overall, resource extraction is still subsidised directly by government budgets and tax measures, and indirectly through economic instruments that distort price signals by not reflecting the full social costs associated with environmental externalities in material production and consumption [165].

This means that the prices of many primary raw materials remain low compared to those of secondary raw materials, thus affecting negatively the demand for recycled materials (which can only compete if their price is below that of primary raw materials and their quality is perceived as equivalent or at least sufficient) [165].
For example, the estimated average cost of producing recycled polyester from EU post-consumer textile is currently around EUR 2,480 per tonne compared to around EUR 950 per tonne for virgin polyester from Asia [166]. Similarly, the prices of recycled PET (through conventional mechanical recycling) remain higher than virgin PET [167].
Furthermore, this is particularly relevant for Critical Raw Materials (CRMs), whose market is largely dominated by primary raw materials, given that the recovery of CRMs in key waste streams is still immature, both in technical and economic terms [168] (Chapter 4 to discover more on ***Critical Raw Materials*** and supply chain dependencies).

As the EU continues to develop circular economy policies, there is now an opportunity to explore an alternative approach: **making recycled, sustainable, and decarbonised materials cheaper through economic incentives or through obligations for both** foreign and EU companies to finance the recycling or reprocessing of waste that stems from the products that they place on the EU market. By recalibrating economic incentives, it may be possible to strengthen the competitiveness of EU businesses, while pursuing more sustainable production and consumption systems and accelerating the transition to a climate-neutral economy.

Potential enablers

Subsidies

Shifting subsidies from primary to secondary raw materials, product reprocessing and dematerialisation.

Internalising still unaccounted environmental impact of mining and processing of primary raw materials through price mechanisms (e.g. levies or fees).

Moving towards 'servitisation' and increasing value chain vertical convergence

The linear economic model is largely based on cost reduction to offer attractively priced new products, resulting in a competitive relationship with suppliers. By contrast, **a circular business model encourages all actors in a supply chain to work together to preserve in the economy the value of products, materials and resources**. The circular economy also changes the hierarchy between products and services, with the latter embedding products use in transactions. This development known as 'servitisation' is based on the premise that by integrating services with products[4], companies can create bundles that are more valuable than products alone: people want light instead of light bulbs, cleaning services instead of vacuum cleaners, thermal comfort instead of heating or cooling systems. The *'Draghi report'* [5] has placed the **circular economy at the centre of EU competitiveness**, for example by advocating for vertical convergence in key value chains (e.g. batteries and vehicles), thus calling for full integration of circularity in value chains to improve competitiveness. While vertical convergence of waste management, recovery of secondary raw materials and the production of new materials (e.g. steel) may help harness the value of materials contained in waste, open questions remain on the alignment between individual corporate interests (particularly of multinational companies) and public interest in improving the competitiveness and resilience of the whole EU economy.

1 Orefice, M., Sakao, T., Mathieux, F. *Product-as-a-Service as an essential enabler for circular economy in the EU*, European Commission, Ispra, 2025, JRC143813.

Potential enablers

Servitisation and vertical convergence

Assessing the benefits and costs of developing legal and fiscal frameworks facilitating the switch from ownership to 'usership' models, whether through sharing or servitisation, such as changes in liability rules, facilitating vertical agreements for circularity or aligning patent legislation with the sharing and collaborative nature of circular practices.

Assessing the possibility of requiring large corporations to steadily increase the share of secondary materials compared to virgin materials and/or the share of remanufactured/reprocessed parts in their supplies.

Fostering demand for circular economy models and products

Circular Economy-related innovation has been confined to niche markets; as such, there are difficulties in scaling up and transitioning from R&D to large-scale production, which is considered a prerequisite for ensuring sufficient returns on investment [169]. Circular practices, such as repair and remanufacturing, struggle to financially compete with massive-scale linear production practices [164]. Whilst these practices could contribute to the creation of local skilled jobs, the increased labour component would also likely make several circular products (i.e. repaired or refurbished products) more costly than linear equivalents [169]. European consumers show little demand or willingness to pay for circular products and business models, due to higher prices and a lack of understanding of their benefits, including environmental ones. In this regard, the ***Ecodesign for Sustainable Products Regulation* (ESPR) will also enable mandatory Green Public Procurement (GPP) criteria**, which can further **incentivise the uptake of more sustainable products** and potentially stimulate **demand for circular products and secondary raw materials** [165]. Finally, the lack of economic incentives and the prevailing labour-oriented tax system can also negatively affect the competitiveness of circular business models [165].

Potential enablers

Demand for circular models and products

Increasing, through instruments such as ESPR, the obligation for enhancing repair, remanufacture, refurbishment and reuse of products and facilitate their trade through economic instruments.

Assessing benefits and costs of reducing labour tax for servitisation of access to circular or shared products.

Assessing the possibility of setting sectoral public procurement rules with regard to a minimum percentage share of circular products or secondary material use (i.e. buildings, infrastructure, transport, IT for refurbished products).

Fostering investments in recycling and better designed economic instruments for waste management

The **recovery of high-quality materials is essential to ensure circular flows across the economy**, as well as the displacement of primary raw materials and less reliance on resource extraction. Investing in high quality sorting and recycling operations requires high up-front investments. This is due to high transaction and search costs to predict the quality of input waste feedstock for recycling, their pre-treatment and to implement quality assurance systems to ensure recycled materials' quality [165]. This combined with volatile prices for virgin raw materials and the high risks and uncertainty of investing in new processes and technologies has led to a lack of investor trust in investing in CE-related activities [165].

Furthermore, a weak implementation of the polluter pays principle, notably through waste management financing system (e.g. EPR, PAYT, tax) and insufficient accounting of environmental externalities linked to some practices of waste management still make recycling an economically unattractive option (e.g. for concrete, insulation materials and bricks, and for CRMs). For instance, the European Environmental Agency (EEA) has estimated that the average EU-27 landfill tax on municipal waste is approximately EUR 38 per tonne, whilst for mineral waste JRC and EEA estimate approximately EUR 19 per tonne [170], [171]. Simply increasing landfill taxes does not appear to be the best solution. For example, a JRC project focusing on construction and demolition waste has noted that high landfill tax can in principle reduce landfilling, but parts of such waste might be deviated not towards the higher levels of the waste hierarchy (e.g. recycling), but to illegal dumping, aggravating potential existing enforcement issues [172]. Other policy measures, such as an advance fee paid at the moment of purchase (rather than at disposal) could be further analysed for different materials and products. In addition, the introduction of "pay-as-you-throw" waste collection systems (i.e. differentiated fees for sorted and unsorted waste) and the expansion of EPR schemes to waste streams, such as textiles, can contribute to increased collection and recycling rates [171].

Leveraging public-private initiatives to stimulate investments in recycling capacity and technologies (e.g. the planned initiative on Trans-Regional Circularity Hubs).

Assessing the benefits and costs of setting up a cap-and-trade system for residual waste at national level, with an annual predictable decreasing factor (considerations of such approach are currently made as part of the planned ***Circular Economy Act***; nonetheless, in addition to costs and benefits, the design and implementation specificities related to this policy instrument need to be further assessed).

Identifying and mapping missing regional capacity for the recycling and treatment of key materials and their use as secondary raw materials (e.g. aggregates from construction and demolition waste).

Developing a research agenda for affordable recycling technologies for high quality secondary raw materials.

Modernising waste management financing systems to support investments in high-quality recycling.

Introducing pay-as-you-throw (PAYT) waste collection systems for relevant waste streams.

2.3.2 Developing and improving the functioning of Secondary Raw Material markets

Secondary Raw Material markets enable the **circulation of high-quality recycled materials in the EU economy**, potentially substituting primary raw materials and decreasing the need to extract natural resources as a result [164]. Establishing a well-functioning EU secondary raw material market has been highlighted as a key component of the CEAP. However, the secondary raw material market for wood, plastics, bio-waste, aggregates from construction and demolition waste, and textiles have been found not to be functioning well, according to 2023 EEA study [165].

Supply: Improving circular product design and information

The **ESPR** [173] will contribute to overcoming several challenges related to product design and manufacturing, as it will enable the setting of 'Ecodesign requirements' for physical products [174], **facilitating products' disassembly, repair and recycling**.

Products' complexity and the *plethora* of additives and chemicals used in everyday consumer products make it difficult for recyclers to identify whether there are substances of concern in their products and ensure a constant quality output. The **digital product passport (DPP)** (implemented under the ESPR and other legislation, such as the *Batteries and Waste Batteries Regulation*) aims to **improve transparency by providing information about products' composition** and, where relevant dismantling information, which will not only contribute to improving recycling, but also to identifying and improving high-quality recycling, including of critical raw materials [175]. Increased knowledge on the presence of substances of concern in products covered under ESPR, made available via the DPP, should address the need to reduce those substances which have a negative effect on recycling and/or reuse.

Improving waste management

The new ***Waste Shipment Regulation*** [176] has **limited the export of waste to non-OECD countries**, thus aiming to **increase the availability of waste feedstocks for the EU's secondary**

Measures that foster design for recycling (through for example the ESPR), potentially including restrictions on substances and/or design characteristics hindering material recovery and recycling in all products containing certain quantities of valuable resources.

Assessing costs and benefits of promoting the use of harmonised of eco-modulated fees for Extended Producer Responsibility (EPR) schemes, this could create strong incentives to design products for increased repairability and recyclability, as producers would pay less to producer responsibility organisations if they were putting more repairable or recyclable products on the market.

Assessing benefits and costs of introducing a minimum circularity criterion as a market entrance condition for relevant material streams (e.g. electric and electronic equipment), for example following a similar approach to that used in the Packaging and Packaging Waste Regulation (i.e. recyclability performance grades).

Circular product design

raw material markets. However, ensuring supply of adequate waste feedstocks for maximum recycling continues to be a challenge. Furthermore, considering the current shifts affecting the principles on which trade policies have been based in recent decades, key questions arise. For instance, will it become possible and convenient to openly pursue an effective '**Recycle in Europe' strategy** or an initiative for secondary raw materials needed by the **energy-intensive, strategic or critical industries for competitiveness or resilience**, and for which materials and waste streams would this be beneficial.

The lack of separate collection obligations and/or Extended Producer Responsibility (EPR) schemes for some waste streams and the lack of harmonised collection systems continues to affect the functioning of the single market for waste and secondary raw materials [165]. For example, selective demolition of buildings is not currently 'mandatory'. In this regard, the JRC is currently working on a labelling system for packaging and waste containers that will enable consumers to better sort their waste and help produce higher quality secondary raw materials [177]. Under the proposed *Packaging and Packaging Waste Regulation* (PPWR) [178], uniform waste sorting labels will be mandatory. Harmonised waste sorting labels could be further expanded to tackle emerging challenges related to new materials (e.g. bioplastics) and risks associated with label proliferation and unreliability.

Significant losses exist at the collection, sorting and processing stages of recyclable materials. For example, sorting losses for plastic packaging are very high, particularly for polypropylene (PP) and polystyrene (PS) [179]. The lack of harmonised end-of-waste (EoW) criteria at EU level (defining when waste can be requalified as a product) impedes the development of a single market for secondary raw materials, hindering trade among Member States. This also creates administrative and economic burdens, especially for SMEs [165]. Harmonised EU-wide EoW criteria are in place for steel, aluminium, glass cullet and a series of waste-derived fertilisers. These were developed by the JRC, which has also published technical proposals with EoW criteria for paper [180] and plastics [181] and is working on harmonisation proposals for textiles, as well as construction and demolition waste [182]. This has been done in an overall policy context, in which the free trade of safe waste-derived materials was desirable. In an environment, where keeping waste-derived materials in the EU as an enabler for autonomy and resilience is a relevant factor, the approach to end-of-waste warrants reconsideration.

Insufficient waste sorting and recycling capacity can limit the expansion of EU secondary raw materials markets [183]. In addition, the lack of suitable recycling technologies at competitive costs can impact the price of secondary raw materials, making these less attractive for producers. Thus, there is a need to develop cheaper solutions to cope with specific features of each material stream. For example, the recovery and recycling of metals and other materials from batteries and waste electronic and electronic equipment (WEEE) might require different processes for each of the metals and materials [165].

Strengthening, harmonising, simplifying and possibly expanding EPR obligations to more products.

Improving and harmonising waste collection systems – developing harmonised waste sorting labels; using economic instruments to reduce the generation of unsorted waste (e.g. "pay-as-you-throw" schemes) and awareness-raising and information campaigns.

Developing a framework and criteria to categorise recycling quality and ensure high-quality recycling.

Assessing the costs and benefits of developing and possibly harmonising EoW criteria for more waste streams, while including safeguards to avoid by-passing of extra-EU waste export restrictions under the Waste Shipment Regulation that would facilitate leakage of those secondary raw materials.

Considering changing the approach to end-of-waste status, so that EoW status is only applied when a material has been fully recycled (e.g. into steel products).

Assessing the costs and benefits of pursing a 'sourcing, recycling and using SRM in Europe' or similar initiative and identifying the materials and waste streams that could benefit from such a policy measure.

Stimulate demand for high-quality of secondary raw materials

Ensuring a **steady and long-term demand for secondary raw materials** is essential to continuing the **development of secondary raw material markets**. Recycled content requirements (including minimum mandatory rates) is one of the policy options that can stimulate demand.

To set recycled content requirements, policymakers need to understand not only how recycling markets and technologies will develop over time, but also the specific nature of technological progress for the products in which recycled materials should be used. For instance, in the case of batteries, it is necessary to anticipate how changes to battery chemistries and progress in recycling technologies will affect the demand for specific metals, as well as the composition of waste batteries.

At the same time, implementation of such requirements imply the development of effective reporting and verification schemes involving all the relevant economic players along value chains (e.g. for non-EU secondary raw materials, challenges may be anticipated when verifying the origin of recycled materials). In the short-to-medium term, such systems could lead to additional administrative burden, especially when efficient digital systems are not yet operational.

As such, current work on recycled content targets (e.g. in packaging, batteries, and potentially soon in vehicles) will seek to develop fit-for-purpose technical guidance and assess the real costs and benefits of this policy option, depending on the materials and products in scope. EU competitiveness and open strategic autonomy (e.g. sharply rising prices for recycled materials affecting EU secondary raw materials versus non-EU secondary raw materials) will also be considered. Alternative or complementary policy instruments should also be explored to stimulate demand for secondary raw materials with a comparatively lower administrative burden than recycled content targets.

Demand for some secondary raw materials is still negatively influenced by quality issues and the risks

associated with recycled materials by manufacturers, brand owners and consumers [165].
In this sense, establishing standards for secondary raw materials could ensure the quality and technical performance of recycled outputs that also take into consideration the technical and economic feasibility of depolluting the relevant material flows. These actions should lead to increasing trust in the market and the potential of recycled materials to safely displace primary raw materials. For example, in the construction sector, metal, wooden and concrete structural elements are not covered by standards suitable for recyclates [165].

Furthermore, weak demand is not always the main problem affecting secondary raw material markets. In some cases, such as some types of scrap metal, it is expected that the decarbonisation of the energy intensive industries will naturally lead to a reinforced demand in the near-to-mid-term future. Therefore, it is necessary to assess, for specific types and quality grades of secondary raw materials, whether demand is indeed the weak link in the market, or whether additional supply support measures are warranted.

Secondary raw materials

Potential enablers

Further exploring and critically assessing the benefits and costs of recycled content targets for different types of materials contained in various products.

Assessing the possibility of requiring large corporations to source an increasing share of specific secondary materials in their supplies, while evaluating different sourcing scenarios (e.g. EU vs third countries).

Assessing costs and benefits of promoting the use of eco-modulated of EPR fees, based on recycled content declarations.

Measures to increase trust among industry and consumers, as well as to ensure the growth of safe and high-quality SRM markets in the EU (e.g. potentially through certification schemes for SRMs).

Further developing and possibly improving ‘Chain of Custody’ framework or similar initiatives that can support the traceability and verification of recycled materials throughout supply chains.

CIRCULAR ECONOMY Navigator

This infographic helps **navigate the complexity** of the transition for achieving **circular economy targets** while delivering on the **EU Competitiveness ambitions**. It presents a non-exhaustive overview of **challenges and enablers**, which are explored in full in the report.

Legend

- Financial / economic challenges
- Political / institutional challenges
- Technological / infrastructural challenges
- Potential intervention areas
- Start — Transition paths
- Final milestones

If we go like this, we will achieve major clean transition policies!

*Circular competitiveness in the EU depends, among others, on coordinated progress across two interconnected domains: 1 **enabling an economic and legal framework** — covering business models, demand incentives and recycling investments — and 2 **well-functioning secondary raw material markets**, underpinned by harmonised waste management practices and strategic sourcing pathways.*

Start

Moving to an economic and legal framework that

1 SUPPORTS CIRCULARITY FOR COMPETITIVENESS

Implementation ambitions

- Establishing a **'level playing field'** for **circular alternatives** by addressing high levels of fiscal support to linear business models
- Ensure that material prices reflect the **social costs** associated with **environmental externalities** in material production and consumption

Enablers' mix

- Subsidies: Shifting subsidies from primary to secondary raw materials, product reprocessing and dematerialisation
- Internalisation of impacts: Internalising unaccounted environmental impacts of extraction and processing of primary raw materials through price mechanisms (e.g. levies or fees)

1a CIRCULAR BUSINESS MODEL

and value-chain integration

Implementation ambitions

- Transitioning from ownership-based to **usership-** and **service-oriented** business models
- Strengthen **vertical convergence** across value chains to integrate waste management, secondary raw material recovery and manufacturing

Enablers' mix

- Usership: Assessing the benefits and costs of developing legal and fiscal frameworks to facilitate 'usership' models
- Secondary materials: Assessing the possibility of requiring large corporations to steadily increase the share of secondary materials compared to virgin materials and/or remanufactured/ reprocessed parts in their supply chains

1b FOSTERING DEMAND

for circular economy models and products

Implementation ambitions

- Support **circular practices (e.g. repair)** to **compete** with mass-scale linear production practices
- Incentivise **demand for circular business models**, products and secondary raw materials by leveraging existing instruments (e.g., ESPR) and by addressing the prevailing **labour-oriented tax system**

Enablers' mix

- ESPR: Increasing the obligations for repair, remanufacture, refurbishment and reuse of products, facilitating their trade
- Labour tax: Assessing the costs and benefi[ts of] reducing labour tax for servicification of access[…] circular or shared products
- Public procurement: Assessing the possibili[ty] of setting rules with minimum percentage sha[re] of circular products or secondary material use (e.g. buildings, infrastructure, transport)

Let's follow the path!

1c FOSTERING INVESTMENT

in recycling and better designed economic instruments for waste management

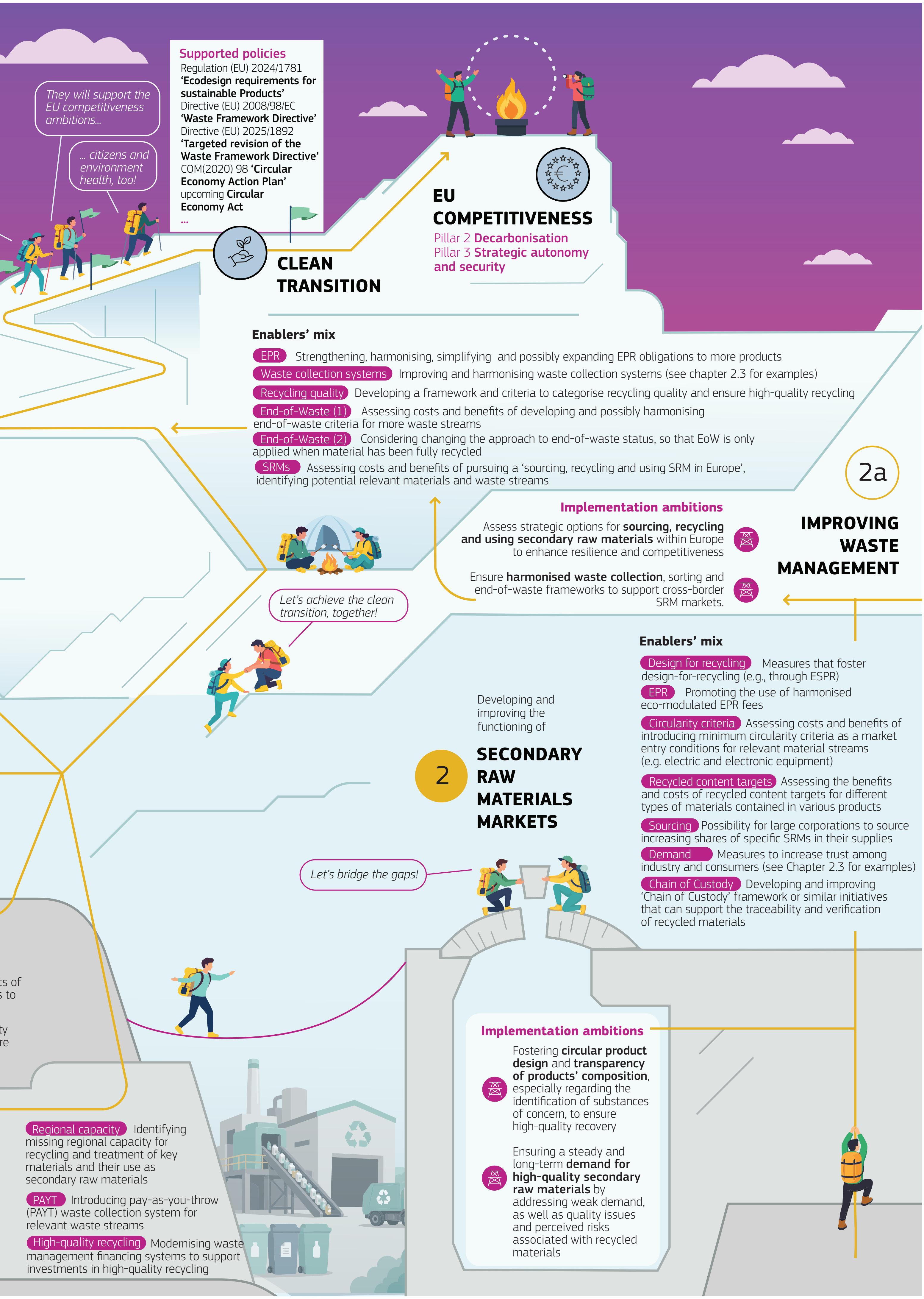
Implementation ambitions

- Reduce **investment risks** and **transaction costs** associated with high-quality sorting and recycling operations
- Strengthen economic instruments for waste management to **prioritise high-value recovery**

This way

Enablers' mix

- Public-private cooperation: Leveraging public-private initiatives to stimulate investments in recycling capacity and technologies (e.g., through trans-regional circularity hubs)
- Research agenda: Developing a research agenda for affordable recycling technologies for high-quality secondary raw materials
- Cap-and-trade system: Assessing cost and benefits of establishing cap-and-trade systems for residual waste at national level with annual predictable decreasing factor



They will support the EU competitiveness ambitions...
... citizens and environment health, too!
Supported policies
Regulation (EU) 2024/1781 'Ecodesign requirements for sustainable Products'
Directive (EU) 2008/98/EC 'Waste Framework Directive'
Directive (EU) 2025/1892 'Targeted revision of the Waste Framework Directive'
COM(2020) 98 'Circular Economy Action Plan'
upcoming Circular Economy Act
...
CLEAN TRANSITION
EU COMPETITIVENESS
Pillar 2 Decarbonisation
Pillar 3 Strategic autonomy and security
Enablers' mix
EPR Strengthening, harmonising, simplifying and possibly expanding EPR obligations to more products
Waste collection systems Improving and harmonising waste collection systems (see chapter 2.3 for examples)
Recycling quality Developing a framework and criteria to categorise recycling quality and ensure high-quality recycling
End-of-Waste (1) Assessing costs and benefits of developing and possibly harmonising end-of-waste criteria for more waste streams
End-of-Waste (2) Considering changing the approach to end-of-waste status, so that EoW is only applied when material has been fully recycled
SRMs Assessing costs and benefits of pursuing a 'sourcing, recycling and using SRM in Europe', identifying potential relevant materials and waste streams
2a
IMPROVING WASTE MANAGEMENT
Implementation ambitions
Assess strategic options for sourcing, recycling and using secondary raw materials within Europe to enhance resilience and competitiveness
Ensure harmonised waste collection, sorting and end-of-waste frameworks to support cross-border SRM markets.
Let's achieve the clean transition, together!
Enablers' mix
Design for recycling Measures that foster design-for-recycling (e.g., through ESPR)
EPR Promoting the use of harmonised eco-modulated EPR fees
Circularity criteria Assessing costs and benefits of introducing minimum circularity criteria as a market entry conditions for relevant material streams (e.g. electric and electronic equipment)
Recycled content targets Assessing the benefits and costs of recycled content targets for different types of materials contained in various products
Sourcing Possibility for large corporations to source increasing shares of specific SRMs in their supplies
Demand Measures to increase trust among industry and consumers (see Chapter 2.3 for examples)
Chain of Custody Developing and improving 'Chain of Custody' framework or similar initiatives that can support the traceability and verification of recycled materials
Developing and improving the functioning of
2
SECONDARY RAW MATERIALS MARKETS
Let's bridge the gaps!
ts of
s to
ty
re
Implementation ambitions
Fostering circular product design and transparency of products' composition, especially regarding the identification of substances of concern, to ensure high-quality recovery
Ensuring a steady and long-term demand for high-quality secondary raw materials by addressing weak demand, as well as quality issues and perceived risks associated with recycled materials
Regional capacity Identifying missing regional capacity for recycling and treatment of key materials and their use as secondary raw materials
PAYT Introducing pay-as-you-throw (PAYT) waste collection system for relevant waste streams
High-quality recycling Modernising waste management financing systems to support investments in high-quality recycling

Key messages (Sustainable and Smart Mobility)

Transport decarbonisation is urgent, with **road transport** as the main priority. Transport accounts for one quarter of EU GHG emissions and is the only sector where emissions show no consistent decline and are still substantially higher than in 1990; road transport represents over 75% of these emissions.

Electrification is the most effective and energy-efficient pathway for road transport, but progress must accelerate. Scaling up charging infrastructure, grid capacity, renewable electricity, targeted use of hydrogen, and critical materials supply chains is essential, alongside smart charging, interoperability and circularity.

Hydrogen-fuelled vehicles, such as fuel-cell electric vehicles, can support hard-to-electrify segments. These vehicles offer benefits for long-haul, heavy-duty and niche uses, but require affordable low-carbon hydrogen, more extensive refuelling infrastructure and further cost reductions and durability improvements.

Infrastructure and interoperability are major enablers. High-power and megawatt charging, depot charging, coordinated grid upgrades, and harmonised technical standards, including for data and cybersecurity, are indispensable for large-scale Zero-Emission Vehicle (ZEV) deployment.

Social acceptance and affordability will shape the transition. For the uptake of electric vehicles, behavioural barriers, range anxiety, uneven charging access, volatile prices, and high upfront costs risk slowing adoption. Inclusive policies are needed to avoid transport poverty and ensure fair access.

Automation and digitalisation offer opportunities if well governed. Integrated with shared mobility and public transport, automated mobility can improve efficiency and safety; without strong governance, it can increase travel demand, congestion, energy consumption and emissions.

Renewable and low-carbon fuels remain crucial for sectors that are hard to electrify. Advanced biofuels and RFNBOs (Renewable Fuels of Non-Biological Origin) are essential for aviation and maritime transport. They require stable long-term policies, sustainable feedstocks and significant investment.

Reducing transport demand and shifting to sustainable modes warrants greater attention. Active mobility, high-quality public transport, shared mobility and integrated urban planning can substantially reduce emissions while improving accessibility and wellbeing.

2.4 Sustainable and Smart Mobility

Transport and mobility are central to the clean transition, as they are major sources of greenhouse gas emissions and are also enablers of economic and social activity. Decarbonising the sector is therefore critical to achieving climate neutrality by 2050, but it is also one of the most complex transitions, given the scale of (a growing) demand, behavioural and socio-cultural issues, technological diversity and maturity, and strong dependence on fossil fuels in several hard-to-abate fields. Within transport, road vehicles are by far the largest emitter, exceeding aviation, shipping or rail combined. For this reason, this chapter focuses on road transport, addressing the dominant source of emissions and the area with the greatest potential impact on achieving climate-neutrality targets.

2.4.1 Reducing GHG Emissions in the transport sector

The transport sector is responsible for about a quarter of EU greenhouse gas emissions and is the only sector exhibiting substantial emissions increases since 1990. **Road transport accounts for 76% of these emissions**.
To achieve economy-wide carbon-neutrality in the EU by 2050 and 90% abatement of transport GHG emissions**,** it is necessary to act on several fronts, such as road vehicle stock, its efficiency and activity, new efficient technologies for the aviation and maritime sectors, transport demand management and transport infrastructure, and to promote low carbon-intensity solutions like rail, and the production of sustainable low carbon-intensity energy carriers (electricity, renewable fuels etc.), and improve alternative fuels infrastructure.

In line with the EGD objectives and the planned flagship actions of *Competitiveness Compass* [4], the EC launched in January 2025 a *Strategic Dialogue on the Future of the European Automotive Industry*, followed by the adoption of an *Industrial Action Plan* in March 2025 to support the transition to zero-emission mobility while strengthening industrial competitiveness and resilience. This is further reinforced by the broader *Automotive Package* of December 2025, which sets out key measures to accelerate zero-emission vehicle uptake, support battery value chains and critical raw materials resilience, and scale up charging infrastructure, thereby linking industrial, climate, and transport policy objectives in a coherent framework.

Together with emerging frameworks such as the *Sustainable Transport Investment Plan*, these initiatives underscore that achieving clean and competitive mobility requires addressing interconnected systemic, technological, and behavioural challenges, including infrastructure rollout, supply chain security, and consumers uptake [184].

Ambitious road transport electrification is essential for reaching climate neutrality in an energy efficient way

Electrification of fleets is the single most effective lever to reduce energy consumption and GHG emissions [185], especially for passenger vehicles, light commercial vehicles and urban/regional freights. Achieving its full potential requires a coherent "policy-mix": ambitious CO_2 standards, rapid infrastructure rollout, accelerated fleet renewal, availability of **low-carbon electricity** and on **system integration** across charging, grid operations and depot logistics.

The **electrification of road transport** and the deployment of electric vehicles (EV) or zero-emissions vehicles (ZEV) and charging infrastructure remain key priorities for the transition [8]. The EU CO_2 emission standards are delivering important results, but still emissions remain higher than the officially reported ones [186], [187]. Further, while passenger cars are electrifying more rapidly, for heavy-duty vehicles (truck and buses) combustion engines will be still notable in the 2050 vehicle stock according to JRC scenarios modelling [185]. Scaling-up heavy-duty ZEV deployment requires targeted approaches (e.g. battery-EV for short/regional haul, hydrogen and other options for long-haul) [188].

Electrification must also be complemented by continued efforts to **reduce energy consumption** through **vehicle efficiency, operational optimisation**, and **modal/logistics** improvements. These measures substantially reduce total energy demand and the scale of additional renewable generation needed [185], [189].
Critical material supply chains are an important bottleneck for a competitive and electrified automotive sector and therefore strengthening **circularity** across the vehicle life cycle - especially battery reuse and recycling - remains essential,

Potential enablers

Road Transport Electrification

Consistent investments are necessary to accelerate zero-emission vehicle uptake, driving innovation and strengthening industrial competitiveness.

A stable materials supply chain is needed, along with a high level of reuse, remanufacturing and recycling, in particular for batteries, magnets (for high-efficiency engines), electronics and sensors (for automation, connectivity, sharing) (Chapter 4.1, *Critical Raw Materials*): circularity can reduce the dependence on raw material imports and increase domestic employment.

Further increasing and incentivising the use of renewable energy, both in vehicle production and operation, helps to improve life cycle GHG emissions of EV, to secure real climate benefits.

Strengthening harmonised EU-wide vehicle and battery data systems and improving export monitoring would help unlock a more robust and accessible used-BEV market measure.

together with robust end-of-life solutions for batteries and fuel cells.
Another important element for the uptake of BEV is the availability of second-hand market, which is emerging but remains uneven across the EU, constrained by limited supply in many Member States, slow fleet renewal, high prices, and significant data gaps on battery condition and export flows that reduce transparency and buyer confidence [190]. This unevenness limits cross-country access to affordable BEVs and slows EU-wide fleet electrification.

The deployment of recharging and refuelling infrastructures needs to accelerate, and grid needs to be modernised

A major barrier to large-scale adoption of zero- and low-emissions road vehicles is the **availability**, **performance and interoperability of recharging and refuelling infrastructure**. Deployment in the EU needs to accelerate, many national plans for infrastructure build-up (NIRs) are also presently lagging behind the *Alternative Fuels Infrastructure Regulation* (AFIR) targets [8].
Scaling of infrastructure concerns in particular the need for high-power charging (including megawatt systems), depot charging and reliable public corridor coverage from trucks; Infrastructure rollout must go hand-in-hand with **grid integration**. Large-scale electrification will require substantial **reinforcement and modernisation of electricity networks**, including increased renewable generation, upgraded transmission and distribution capacity, and the deployment of smart-grid solutions to manage peak loads and support flexibility services. Bidirectional charging and advanced energy management systems can reduce system costs and improve consumer economics [185], [189].

Socio-cultural and behavioural barriers to ZEV adoption include "resistance to change" and "range anxiety"

"Resistance to change" is when **individuals prefer the status quo** having limited awareness of the benefits of EVs, and under cost-saving uncertainties demonstrate a preference for immediate gains [191], [192]. "Range anxiety" constitutes a behavioural barrier for the public. In this area, a potential enabler includes building-up appropriate infrastructure for recharging and refuelling in EU Member States, especially of fast chargers and on motorways (also addressed in Chapter 8.3, *Behavioral insights for policymaking*).

Potential enablers

Recharging and refuelling infrastructure

Implementation of common standards and interoperability: harmonising technical standards for charging infrastructure, data exchange, payment systems, cybersecurity, is essential to ensure a seamless user experience across borders and providers.

Advancing smart-grid technologies and demand-side management to avoid local overloads, improve the integrity and resilience of the electrical infrastructure, and in particular upgrade the grid system, enhancing its stability and capacity. Smart charging and energy management allow to align vehicle charging with periods of low electricity demand or high renewable supply; combining smart charging and local renewable integration can help to reduce system costs and grid stress in large-scale transport electrification, reduce emissions and strengthen the integration between transport electrification and the clean energy transition.

Accelerated deployment of Megawatt Charging Systems (MCS) for heavy-duty vehicles, including corridor networks and depot charging solutions, is necessary to enable long-distance travel and heavy-duty electrification.

Investing in bidirectional charging infrastructure and grid level optimisation could lower the charging costs for the consumer and provide additional flexibility to the energy system.

Enhance the development of high-power and fast charging infrastructure is essential for long-distance EV travel and also for heavy-duty and long-haul electrification.

Promoting urban planning strategies that integrate and prioritize EV infrastructure may ensure equitable access to charging in cities and peri-urban areas.

The Fuel Cell Electric Vehicle (FCEV) uptake is limited by technological and infrastructural gaps

Fuel cell electric vehicles (FCEVs) can complement battery-electric vehicles (BEVs) in the decarbonisation of road transport, especially for long-haul, heavy-duty, and niche applications where range and fast refuelling are essential. The use of hydrogen propulsion either through FCEVs or hydrogen-fuelled internal combustion engines is expected to grow in the European transport sector, particularly for **heavy road or non-road applications**, and is also expected to make its way into the railway sector, with the potential to replace diesel engine trains.

Further, FCEV technology can offer benefits for urban delivery applications and commercial fleet operators, where they can offer advantages such as higher flexibility in scheduling and increased loading capacity due to lower vehicle mass, and for **long ranges and high energy consumption** (e.g. large trucks). However, they still have a **very limited uptake** due to a series of challenges.

A first barrier lies in the **lack of refuelling infrastructure**. While electric vehicle charging networks are expanding rapidly, the number of hydrogen stations in Europe remains extremely limited [193].

Cost is another major hurdle. Both the production of hydrogen and the manufacturing of fuel cell vehicles remain significantly more expensive than battery-electric or conventional vehicles. The absence of large-scale production and economies of scale keeps prices high and undermines competitiveness. At the same time, the logistics of producing, transporting, and storing hydrogen - whether compressed or liquefied - add further costs and complexity [194].

Technological maturity also remains an issue. Fuel cell stacks still face challenges related to **durability** and **long-term performance**, with high replacement costs and unresolved questions about reliability in real-world conditions [195]. Moreover, while fuel cells allow fast refuelling and long ranges, their overall

energy efficiency is considerably lower than that of battery-electric vehicles. Well-to-wheel analyses show that producing and distributing hydrogen requires substantially more renewable electricity than directly charging batteries, raising concerns about system-level resource efficiency [185].

Finally, **consumer acceptance and market uptake** remain limited. The high costs of FCEV technology make it accessible only to high-income consumers or for specific niche applications and case-specific investment opportunities. Uncertainty about future resale values, and the scarcity of refuelling stations discourage private buyers. For fleet operators, the limited availability of models and unclear long-term cost competitiveness compared with battery-electric alternatives act as strong disincentives. Overall, economy of scale is very limited due to low market uptake and production volumes [194].

Fuel Cell Electric Vehicle

Potential enablers

Deployment of FCEVs can be fostered through the development of dedicated fuelling infrastructure, particularly in urban and regional areas; EU mandates for hydrogen infrastructure under the *Alternative Fuels Infrastructure Regulation* (AFIR) will be key to creating minimum refuelling coverage [194].

From a technological point of view, progress in stack design, hybridisation, and powertrain optimisation can improve efficiency by 5–15%, and further research into integration of fuel cells with hybrid battery systems enhances performance and flexibility [194].

Availability of low-carbon intensity hydrogen is crucial to fully exploit the benefits of FCEV technology, and large-scale hydrogen production from renewable electricity can lower costs through economies of scale.

Automation offers opportunities but requires strong governance

Automate and connected vehicles (AV) are key game-changers in the mobility and transport sector, but they have mixed potential, offering opportunities as well as risks: they can improve safety, accessibility and traffic flow, and - if integrated with shared services and policy measures - lower per-passenger energy use. But without targeted interventions they risk inducing extra travel, replacing active/public modes, and increasing energy consumption and emissions [196], [197].

The effects can be grouped into three main areas. First, automation introduces **additional energy demands** for sensors, onboard processing systems, and communication technologies. Second, it influences propulsion energy by **altering traffic dynamics** in both ways (e.g. smoother flows on highways can save energy; unstable mixed fleets can worsen it). Third, automation can **change travel behaviour** and modal preferences, often leading to increased trips and shifts away from active transport modes like walking and cycling (**behavioural rebound**). These behavioural shifts can produce up to 38-43% higher CO_2 emissions [197].

These factors create a complex energy profile requiring careful evaluation. While AVs may improve efficiency and safety, their energy impact is uncertain and could be significant as deployment moves from prototyping to adoption. This highlights the need to understand the relationship between automation development and energy use to ensure these technologies align with sustainability goals.

Overall, even though the shift towards road transport automation has started already, uncertainty remains about deployment timing, real-world driving models for high-level automation, offboard/cloud energy trends and user preferences, as well as on potential economic benefits [198]. The introduction of AVs faces multiple challenges, including technological

Potential enablers

Road Transport Electrification

Optimisation of on-board technologies is needed to reduce energy demand while maintaining safety standards. Supporting the relevant technological advancements (targeted hardware/software and improved electric/electronic architectures, among others) could reduce additional automation energy per km by more than 80% compared with today's prototypes, largely improving net benefits. This is key to addressing energy challenges and enabling cost effective, reliable AV adoption [196].

Automation has the potential to lower the energy intensity of urban transport up to 15% but achieving this requires carefully designed policies that promote shared mobility, encourage active travel, and manage private vehicle use. Shared automated shuttles, resembling public transport in their collective mobility design, can reduce energy demand by attracting former car users, provided supportive measures are in place [196].

Land-use and transport policy (reduced parking spaces, dedicated lanes for shared AVs, congestion pricing, fares/subsidies favouring pooled/shared services, active mobility investment) can prevent substitution away from walking/cycling and public transport. Integration of AVs into public transport networks (first/last mile shuttles) is a pragmatic path.

and non-technological aspects, such as regulatory frameworks, consumer behaviour, and public acceptance; monitoring of real-world impacts through staged pilots and EU-level regulatory harmonisation are essential

Gradually shifting vehicle certification, policy targets and consumers information towards real-world performance

Vehicle CO_2 emissions and energy consumption can be higher than reported under certification tests, due to a series of factors influencing in-use operation, user habits and the inherent variability of operating conditions. Therefore, to assess the effectiveness of transport policy measures to curbing greenhouse gas emissions, it is crucial to consider the emission and energy consumption reductions achieved in real-world vehicle operation [199], [200], and to monitor energy consumption in real driving conditions. A first step has already been made through the adoption of fuel consumption monitoring systems and the corresponding monitoring exercises of the European Commission. However presently **there is no link between the official certification-based monitoring and the in-use performance, and the respective information is not directly accessible to consumers when deciding on a vehicle purchase**.

Potential enablers

Real-wold performance monitoring

Future initiatives could strengthen the real-world monitoring of CO_2 emissions and energy consumption, and work on possible remediation initiatives in case significant divergences from the targets are observed.

Consumers should have access to information regarding the likely real-world performance of a vehicle prior to making a purchase decision.

Enhancing accessibility of zero emission vehicles
Zero and low emission vehicle (ZEV and ZLEV respectively) deployment is highly dependent on manufacturers' **pricing policy** and **production costs**. Upfront **technology costs** are usually higher than those of conventional vehicles but are expected to significantly decrease over the next years. The payback time also depends on the **electricity prices**. Other factors that affect the total cost of ownership of zero emission vehicles are national incentives, charging infrastructure cost, and taxation, especially for lower and medium income groups constituting the mass market segment.
Possible disruptions of the EU market by imported products that do not respect EU standards or fair-trade practices should also be further evaluated, and measures that protect the single market from dumping or unfair competition should be established. Ensuring a level playing field in the global market requires that EU's stringent production requirements also apply to imported goods. In the same sense, market entry and certification criteria could provide a more holistic overview of a product's identity, incorporating environmental impacts and possibly governance and social criteria throughout its value chain and lifetime.
It has been observed that original equipment manufacturers are promoting high-end high-profit vehicle configurations at lower sales numbers compared to more affordable high-volume sales. However, **entry level models**, and acceptable, predictable charging prices, are needed to establish a mass market for ZEVs. The situation is changing also thanks to the targets set by the CO_2 standards.

The transition to zero-emission vehicles needs to be managed inclusively, to ensure adequate, accessible and affordable transport avoiding transport poverty and social exclusion. Financial support and incentives need to be made available to low-income groups, and attention given to infrastructure and affordable alternatives (Chapter 7.1.2 on *Transport poverty*). In this context, the *Social Climate Fund* (SCF) can play a key role in reducing transport poverty by supporting vulnerable households' access to affordable, low-emission mobility options-through targeted income support and investments in public transport, shared mobility, and zero-emission vehicles
To assess the **economic feasibility of a mobility transition**, the JRC has carried out an analysis quantifying the total costs of ownership under different CO_2 standard scenarios. The analysis is based on 30 scenarios run with the JRC DIONE cost model to support the EC impact assessment for strengthened car and van CO_2 standards within the Fit-for 55 package. For Light Duty Vehicles (LDV), it was concluded that, over the use period, there are **net consumer benefits**, and that such **benefits increase with stricter emissions targets and over time**. Net savings are substantially higher for Heavy Duty Vehicles (HDV) than for LDV, due to their high annual and lifetime activity.

Accessibility of Zero-emission Vehicles

Potential enablers

Fostering domestic value-chains creation, to support EU competitiveness.

Expanding the second-hand market for zero-emission vehicles could also improve their accessibility and affordability, as lower purchase prices and a wider supply make them more attainable for lower- and middle-income households.

Benefits arise because savings in fuel/energy expenditure during vehicle use overcompensate the higher upfront capital costs of more efficient and zero- and low-emission vehicles. Prices for electric energy, particularly at public charging points, should be monitored and potentially contained, to allow total cost of ownership (TCO) savings for all ZEV user groups.

In addition to environmental criteria, social and governance aspects should also be part of a product's identity and passport for entry into the EU market.

Reversing the trend of increasing transport demand is an overlooked opportunity

The **rising demand for transportation**, particularly within rapidly growing and emission-intensive sectors like aviation, freight transport and private road transport, is an underexamined but significant component of EU efforts to reduce emissions, which could offset the positive effects of energy efficiency policy gains [189]. The European Scientific Advisory Board on Climate Change (2024) has pointed out that "the growth in **overall transport demand in the EU needs to slow down**" if the EU is to achieve the established GHG emission reduction objectives. At present, this necessary moderation is not adequately reflected in legislation, as it was not "considered as an option in the EU's Sustainable and Smart Mobility Strategy" ([201], p. 103).

A possible rebound can be linked to higher energy efficiency and higher comfort due to connected and automated vehicles). These improvements make the car, whether privately owned or consumed as a service, even more attractive in the mobility landscape [202]. However, so far, the potential effects have been assessed only marginally.

In general, the shift to more sustainable transport modes will be crucial to achieve substantial and continuous emission reductions in road transport [189].

There is a range of options to **change mobility patterns**, with a beneficial impact on total vehicle activity, energy consumption and emissions. **Behavioural changes** are required in order to change mobility patterns, supported by a new balance between trust in services, notably in terms of availability, safety, reliability and affordability, personal convenience and a collective ecological identity linked to the need to respect the planetary boundaries. In the medium-long term, additional enablers could be leveraged.

Potential enablers

Transport demand

Promoting active mobility including walking, cycling and micromobility enhancing the quality of public transport and shared/collective mobility services.

Re-orienting urban planning to encourage active forms of transportation that can contribute to health improvements

Fostering the development of Mobility-as-a-Service (MaaS) and of multimodality (MaaS describes the combination of various mobility services into a single digital platform, facing the difficulties to integrate data of diverse transport operators [203]).

Expanding Sustainable Urban Mobility Plans (SUMPs) to include connections with surrounding suburban and rural areas.

Properly designed measures to accelerate the turnover of the fleet, while avoiding counterproductive/unwanted incentives, at a point in time where zero carbon alternatives are available and economically viable.

Connected and automated vehicles to i) improve traffic efficiency and reduce the overall energy intensity of the transport sector, and ii) reshape the governance of the transport system in a way that optimises the energy required to satisfy citizens' mobility needs.

Supporting the shift of passenger and freight transport towards low-emission and energy efficient transport modes - known as modal shift.

Educational means (information campaigns promoting walking, cycling public transport, eco-driving, car-sharing and car-pooling.

2.4.2 Renewable Transport Fuels

Renewable fuels of biological origin (biofuels) and Non-Biological Origin (**RFNBOs**) offer a promising alternative particularly for the non-road sectors that are **hard to electrify**, such as aviation, maritime, non-road mobile machinery. They can function as drop-in fuels, requiring no technical modifications to existing engines, thereby reducing dependence on fossil fuel imports.
Their adoption enhances energy **security and diversification**. The RED III [95] includes in the definition of biofuels first-generation biodiesel and bioethanol (produced from food and feed crops) and second-generation or advanced biofuels, such as lignocellulosic ethanol and biogas. RFNBOs are synthetic drop-in fuels mostly derived from electricity. Production is still **limited** by upstream hydrogen supply and carbon capture solutions, but conversion technologies would be ready for market uptake.

Advanced biofuels

Advanced biofuels have **significant GHG reduction potential**, and contribute to energy supply diversification, enhance energy security, and reduce dependency on fossil fuel imports [204], [205]. Advanced biofuels are mainly derived from wastes and residues, and are therefore not in competition with food and are largely sustainable, though their production faces constraints, including feedstock availability, regional limitations, and competition from alternative uses [204]. Over the long term, feedstock availability and affordability may become challenging. These biofuels can **integrate** with existing fuel infrastructure, requiring minimal additional investment. They can be blended with fossil fuels or used as drop-in replacements without engine modifications. Biorefineries create synergies by combining traditional fuel and chemical production, maximising the use of existing infrastructure and logistics. However, several challenges hinder large-scale production [204]:
- **Industrial scale**: Large facilities are essential to achieve economies of scale.
- **Logistics**: The collection, transport, and storage of feedstock are complex due to their low energy density and variable characteristics.
- **Technologies**: Production relies on thermochemical and biological processes, which are at various stages of development.
- **Costs**: Although thermochemical and biological processes for advanced biofuels are technically mature, their high capital costs and scale-up challenges make production expensive compared to fossil fuels. Economic viability further depends on access to low-cost feedstock; the collection, transport, and preprocessing of residues and wastes add significant costs and variability.
- **Incentives**: A lack of robust policy incentives hampers large-scale deployment and the establishment of biomass supply chains.
- **Feedstock availability**: biomass used for biofuels production is a finite resource with competing uses (including food, feed, materials) that can constrain its availability for sustainable fuel production.

Overall, advanced biofuel production currently carries significant technological and economic risks.
The **sector is a significant economic contributor** in the EU, driving GDP growth and employment. Between 2015 and 2022, biofuel consumption in EU transport rose from 19 million litres to over 25 million litres, with biodiesel accounting for around 70% of the share [206]. Despite this growth, market uptake remains slow due to inadequate incentives, technological challenges, and the failure to achieve cost competitiveness through scaling.
In terms of research and innovation, several advanced biofuel technologies are nearing commercialisation [204]. However, others, like aquatic biomass conversion and dark/light fermentation to hydrogen, remain unproven in commercial settings [207]. Additionally, advancements in electric vehicle technologies for heavy-duty road transport electrification may limit the progress of biofuels in this sector.

Renewable Fuels of Non-Biological Origin (RFNBO)

Technological advancements have significantly **improved RFNBO production processes**, with Europe leading the way due to strong policy support and industrial capabilities. Production involves key technologies across the value chain, including hydrogen production, carbon capture (or nitrogen separation), and fuel synthesis. Despite progress, large-scale deployment remains limited due to high costs, high energy requirements, and the need for robust infrastructure [208]. Advancements in electrolysis and carbon capture, as well as the construction of new renewable energy generation facilities are critical to scaling RFNBO production. However, the upstream processes, particularly hydrogen production and carbon capture, need large-scale development to reduce costs. Currently, there is low availability of cost-effective hydrogen.
Key challenges to RFNBO adoption include achieving **cost competitiveness** with fossil fuels, addressing **technological and infrastructural barriers** both for RFNBO production and renewable energies. While existing fuel infrastructure can be utilized with minimal investment, constructing new facilities entails high upfront costs. Significant investment and innovation are required to scale the technology for widespread commercial use.

The biofuels industry has been an important source of employment within the EU, generating both direct and indirect jobs. In 2018, it supported 239,600 jobs, but this number declined to 149,700 by 2022 [208], [209]. Efforts are underway to transition skilled workers from fossil fuel industries to biofuels, preserving expertise while addressing workforce needs.

Biorefineries offer additional employment and business opportunities along the supply chain, particularly in rural areas, where advanced biofuels can drive agricultural, forestry, and industrial development. Attracting workers to these regions remains a challenge, but policies supporting rural biorefineries could enhance their appeal.

The lack of a stable, long-term policy framework remains a critical barrier to the development and deployment of advanced biofuels. Clear and consistent policy direction is essential to foster investment and innovation in the sector.

Potential enablers

RFNBO production depends heavily on the **availability and cost of surplus renewable electricity**.
One of the primary concerns for the production of RFNBOs and their widespread adoption is the dependence on (surplus) renewable electricity, which is often intermittent and requires energy storage and grid balancing solutions to ensure a stable supply. The use of solar and wind power to produce RFNBOs also competes with other uses, such as direct electrification of transportation and industry, Balancing these competing demands is essential.
The production process of RFNBOs is characterized by high energy **conversion losses**, resulting in costs that exceed those of fossil fuels. Furthermore, the current market uptake of RFNBOs would require higher incentives and strong policy support to drive investment and innovation in this sector.
Other challenges include the limited capacity of the electricity distribution grid to **integrate renewable generation**, slow progress in carbon capture solutions, and the phase-out of fossil-based CO_2 for industries[4] may lead to a shortage of available CO_2 feedstock, increasing costs and reducing the competitiveness of RFNBOs compared to fossil fuels [210]. The presence of competing markets, such as fertilizers, and the high GHG savings that must be achieved compared to fossil fuels (minimum GHG savings of 70% according to RED-III), also add complexity to the development of RFNBOs [208].
RFNBOs have substantial market potential, especially in sectors with limited alternatives, such as hard-to-abate transports and heavy industry.
Energy system models like the JRC's POTEnCIA and POLES [211], [212] project rapid growth in EU RFNBO production starting in 2025, positioning them as a key low-carbon fuel source for sectors like aviation and maritime by 2050.

4 The use of fossil-based CO_2 produced in some industrial processes (such as power plants, steel and cement industries…) as feedstock for RFNBOs production will be phased-out in 2035 for power companies and in 2041 for steel and cement companies. After that date, industries will need to find alternative sources of CO_2, such as direct air capture or biogenic CO_2, to produce RFNBOs.

Potential enablers

Opportunities lie in creating new value chains based on renewable hydrogen and carbon capture, leveraging existing fuel infrastructure, and integrating bio-based value chains for CO_2 recovery. Technologies such as Haber-Bosch and Fischer-Tropsch processes are already compatible with renewable hydrogen and can be retrofitted up to a certain level. However, all technologies could face limitations due to the unavailability of hydrogen or CO_2 supplies [210].

Overcoming cost and infrastructure barriers will be critical for RFNBOs to fulfil their potential. However, with continued technological advancements, policy support, and investment in new renewable energy facilities, RFNBOs are well-placed to play a role in Europe's decarbonisation strategy. Beyond decarbonisation, RFNBOs could support energy security, create new value chains, and generate job opportunities along the supply chain, including skilled labour.

SUSTAINABLE AND SMART MOBILITY Navigator

This infographic helps **navigate the complexity** of the transition for achieving **sustainable and smart mobility targets** while delivering on the **EU Competitiveness ambitions**. It presents a non-exhaustive overview of **challenges and enablers**, which are explored in full in the report.

Legend

- Financial / economic challenges
- Political / institutional challenges
- Technological / infrastructural challenges
- Socio-cultural / behavioural challenges
- Potential intervention areas
- Start — Transition paths
- Final milestones

If we go like this, we will achieve major clean transition policies!

*Advancing a competitive and climate-aligned mobility transition requires coordinated progress across different areas: 1 **electrification of road transport**, 2 **charging infrastructure**, 3 **inclusivity and desirability** of the transition, 4 deployment of **fuel-cell electric vehicles** (FCEVs) and 5 **renewable fuels** for hard-to-abate sectors.*

ELECTRIFICATION OF ROAD TRANSPORT

Start

across the vehicle life cycle

Implementation ambitions

- **Scaling zero-emission road transport** electrification while keeping total energy demand manageable
- Embedding **circularity across batteries** and critical components to secure strategic autonomy
- Promoting a **climate integrity approach**, avoiding burden-shifting across vehicle value chains and linking with **real-world emissions**
- Sustainable **upfront** (capital) costs and **operational** (electricity) costs and vehicle price stability

Enablers' mix

- Policy and investment mix — Coherent framework combining real-world CO_2 standards, infrastructure rollout, fleet renewal and renewable electricity deployment
- Industrial circularity — Resilient and circular battery and component value chains through reuse, remanufacturing, high-quality recycling and robust end-of-life systems
- Clean Energy — Uptake of renewable electricity for manufacturing processes and in-use operation
- Transparency — Functioning second-hand market by improving data availability on battery condition and export flows to increase buyer confidence

CHARGING INFRASTRUCTURE

to be grid-ready, interoperable, and scalable

Implementation ambitions

- Keeping **charging** and **refuelling** infrastructure at a pace **consistent with ZEV deployment** targets
- Ensuring **grid readiness** and **integration** to prevent congestion, inefficiencies and rising system costs
- Enabling **heavy-duty electrification** through high-power and megawatt charging solutions

Enablers' mix

- Standard harmonisation — EU-wide standards for charging hardware, data exchange, payment systems and cybersecurity
- High power systems — Deployment of high-power and megawatt charging systems, including corridor and depot solutions
- Grid integration — Smart-grid technologies and demand-side management to align charging with renewable supply and avoid local overloads
- System flexibility — Bidirectional charging infrastructure and grid-level optimisation to lower system and consumer costs
- Spatial planning — Urban and regional planning strategies prioritising equitable access to EV charging in cities and peri-urban areas
- National plans — Design coherent targets with AFIR for the infrastructure build-up

INCLUSIVITY AND DESIRABILITY

of the transition towards a zero-emission mobility

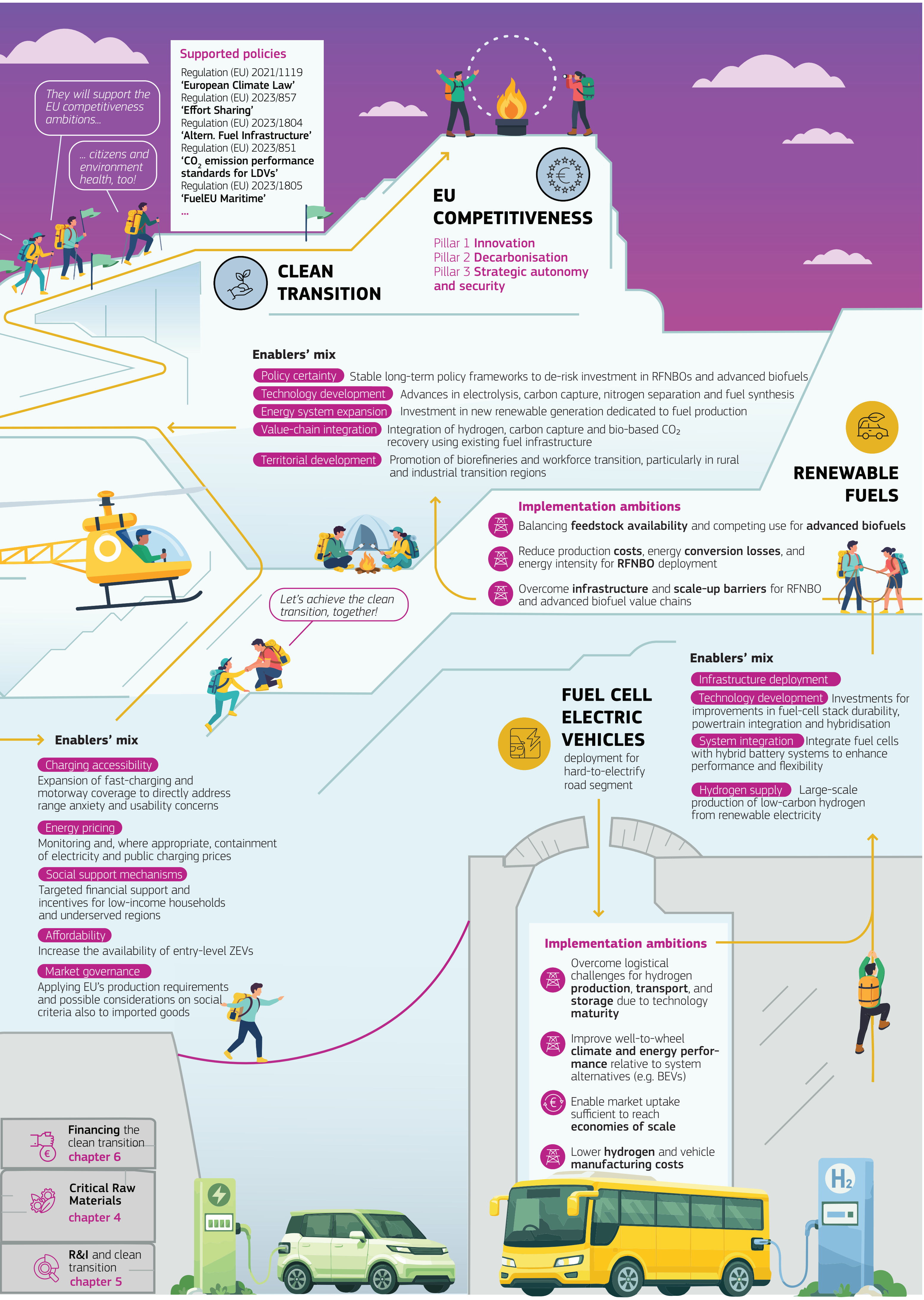
Implementation ambitions

- Removing **behavioural and cultural barriers** to ZEV uptake (e.g. range anxiety and acceptance)
- Prevent **transport poverty** and unequal access to ZEV and charging infrastructure
- **Stabilise cost** of ownership and **leverage benefits** for households and fleets despite price volatility and supply-chain risks

*These **cross-cutting enablers** will help us go faster...*

CROSS-CUTTING ENABLERS

- **'Active' mobility** and demand moderation
- **Behavioural insights** for policymaking **chapter 8**
- **Shared mobility** and **mobility-as-a-service**, expanding Sustainable Urban Mobility Plans



They will support the EU competitiveness ambitions...
... citizens and environment health, too!
Supported policies
Regulation (EU) 2021/1119
'European Climate Law'
Regulation (EU) 2023/857
'Effort Sharing'
Regulation (EU) 2023/1804
'Altern. Fuel Infrastructure'
Regulation (EU) 2023/851
'CO_2 emission performance standards for LDVs'
Regulation (EU) 2023/1805
'FuelEU Maritime'
...
EU COMPETITIVENESS
Pillar 1 Innovation
Pillar 2 Decarbonisation
Pillar 3 Strategic autonomy and security
CLEAN TRANSITION
Enablers' mix
Policy certainty Stable long-term policy frameworks to de-risk investment in RFNBOs and advanced biofuels
Technology development Advances in electrolysis, carbon capture, nitrogen separation and fuel synthesis
Energy system expansion Investment in new renewable generation dedicated to fuel production
Value-chain integration Integration of hydrogen, carbon capture and bio-based CO_2 recovery using existing fuel infrastructure
Territorial development Promotion of biorefineries and workforce transition, particularly in rural and industrial transition regions
RENEWABLE FUELS
Implementation ambitions
Balancing **feedstock availability** and competing use for **advanced biofuels**
Reduce production **costs**, energy **conversion losses**, and energy intensity for **RFNBO** deployment
Overcome **infrastructure** and **scale-up barriers** for RFNBO and advanced biofuel value chains
Let's achieve the clean transition, together!
Enablers' mix
Infrastructure deployment
Technology development Investments for improvements in fuel-cell stack durability, powertrain integration and hybridisation
System integration Integrate fuel cells with hybrid battery systems to enhance performance and flexibility
Hydrogen supply Large-scale production of low-carbon hydrogen from renewable electricity
FUEL CELL ELECTRIC VEHICLES
deployment for hard-to-electrify road segment
Enablers' mix
Charging accessibility
Expansion of fast-charging and motorway coverage to directly address range anxiety and usability concerns
Energy pricing
Monitoring and, where appropriate, containment of electricity and public charging prices
Social support mechanisms
Targeted financial support and incentives for low-income households and underserved regions
Affordability
Increase the availability of entry-level ZEVs
Market governance
Applying EU's production requirements and possible considerations on social criteria also to imported goods
Implementation ambitions
Overcome logistical challenges for hydrogen **production**, **transport**, and **storage** due to technology **maturity**
Improve well-to-wheel **climate and energy performance** relative to system alternatives (e.g. BEVs)
Enable market uptake sufficient to reach **economies of scale**
Lower **hydrogen** and vehicle **manufacturing costs**
Financing the clean transition
chapter 6
Critical Raw Materials
chapter 4
R&I and clean transition
chapter 5
H2

Key messages (Sustainable and Resilient Food Systems)

The transition towards sustainable and resilient food systems, as outlined in the *Vision for Agriculture and Food*, is framed within the broader objective of ensuring economic viability, competitiveness, and resilience of the agri-food sector. Key enabling conditions include stronger stakeholder engagement, improved policy coherence and implementation capacity, enhanced data and monitoring systems, and the promotion of innovation and digitalisation.
Ensuring fair income for farmers, strengthening their position in the value chain, and addressing food security challenges remain central to this transition. The **EU One Health** approach complements this vision by fostering sustainable, resilient food systems that safeguard health across people, animals, and ecosystems.

More sustainable **production practices and consumption patterns** need to be adopted across the entire food value chain, taking into account local specificities. Progress can be enabled through dietary shifts towards plant-based foods, the further adoption of sustainable farming practices, targeted policy interventions such as sustainable public procurement, innovation across value chains, and the further promotion of biodiversity in production systems.

Challenges such as inadequate consumer practices (e.g. regarding food purchases, storage, and meal planning), supply chain inefficiencies, and limited understanding of food safety standards (e.g. the difference between “use by” and “best before” dates) must be overcome to reduce **food waste**. These can be addressed by strengthening policies, fostering cross-sector partnerships, and promoting behavioral change among consumers.

Fair economic sustainability and viability are needed for all actors in the food supply chain while delivering affordable sustainable food. This means addressing market imbalances, supporting producer cooperatives, redirecting subsidies towards sustainable practices, and raising consumer awareness of the true costs of food production.

Supportive food environments can be created to promote **healthier and sustainable food choices**, which include making nutritious food more affordable, improving access and availability in public and retail spaces, regulating the marketing of unhealthy options, and increasing consumer awareness through education, labelling and community engagement.

Local authorities are often well placed to steer food systems approaches, to shape favourable food environments through **community-led initiatives** that foster dialogue on how to enhance the affordability and availability of healthy, high-quality food.

Strengthening the **resilience** of the EU **food system** requires integrated policies across all sustainability dimensions to address key challenges such as climate change, reliance on global markets, and social inequalities through support for sustainable farming, SMEs, innovation, inclusive food access, and cross-border cooperation.

2.5 Sustainable and resilient food systems

The EU food system provides food for over 450 million people in Europe, contributing significantly to economic development, employment and wellbeing. Achieving the EU's sustainability goals, including a 55% net reduction in GHG emissions by 2030, reducing hazardous pesticides and nutrient losses, expanding organic farming, minimising food waste, and improving energy efficiency, requires coordinated efforts [8].

EU policies such as the *Common Agricultural Policy* (CAP) and the *Common Fisheries Policy* (CFP) aim to foster sustainability, fairness, and resilience across the food system. The transition towards sustainable food systems is also linked to the EU One Health approach to protect the health of people, animals and ecosystems. The EC published the *Vision for Agriculture and Food* [213], building on the *Strategic Dialogue on the Future of EU Agriculture* [214] and aligning with the EC's *Competitiveness Compass* [4]. The Vision aims to secure the long-term competitiveness and sustainability of the EU's farming and food sector, emphasising technological advancements, decarbonisation, and economic growth, while ensuring agriculture and the food system contribute to the EU's broader economic and environmental objectives.

The R&I policy framework *Food 2030* has pioneered the systemic approach on food systems, which remains a valuable tool to address the above-mentioned challenges. The *Life Science strategy* has reinforced the message that Europe's excellence in health, biotechnology, agriculture, food and environmental sciences must be further supported by targeted investments and better coordination across sectors, regions, and scientific disciplines.

Current trends indicate that further efforts are required to advance the sustainability transition of the EU food system, including in relation to the climate neutrality objectives. Progress remains limited across several areas, notably nutrient management, pesticide risk reduction, and food waste prevention. However, the EU's climate and environmental objectives need to be pursued alongside the **economic viability**, **resilience**, and **competitiveness** of the agricultural sector. This implies a growing emphasis on improving resource and input efficiency, fostering innovation and digitalisation, and strengthening farmers' position in the value chain.

Unsustainable food consumption patterns and inefficient resource use continue to compromise progress towards climate and biodiversity goals [8]. At the same time, unhealthy diets remain key public health concern in the EU, being a main contributor to the social (health) and economic burden linked to overweight, obesity and non-communicable diseases.

This section examines challenges and enablers across the **environmental, economic and social dimensions** of sustainability. The environmental section focuses on cross-cutting issues, since the specific aspects related to climate change, pollution, biodiversity, resource use (land and soil, water, energy and aquatic living resources) are covered in the respective thematic sections of this report (Chapters 2.2 and 2.6). This also applies to elements related to a just and fair transition, and governance (here the focus is on a systemic view), which are addressed in Chapters 7 and 8.

2.5.1 Environmental impacts of the food value chain

Fostering the adoption of more sustainable production practices and consumption patterns across the whole food value chain

The consumption footprint of food shows an increasing trend (Chapter 3), primarily driven by animal-based products, despite recent decreasing trends of per-capita consumption of bovine and pig meat. Environmental impacts of the entire supply chain of food products (including beverages) consumed in the EU (i.e. from the extraction of raw materials to the end-of-life management, including trade) have increased around 20% since 2010.

The EU food system contributes to the transgression of planetary boundaries [218] due to barriers to transformative change as highlighted in the respective sections of this report on climate, pollution, biodiversity, and energy.

Environmental impacts

Potential enablers

Reduce the environmental footprint of EU food consumption through sustainability assessments covering production inputs, on-farm practices and the entire food value chain. Market projections show that improvement across environmental and climate impacts can be driven, among others, by the adoption of sustainable farming practices, e.g. the extensification of current livestock production systems, linking it more to grassland and pasture [219].

A shift towards diversified, healthier and more sustainable diets, e.g. by increasing the consumption of plant-based products, is key to reducing environmental impacts. Possible emerging trade-offs (e.g. for food waste, the use of mineral resources, land use and water use) could be tackled by specific actions [220].

The dietary shift can be driven by targeted policy intervention at relevant level (EU, National, local), such as the promotion of sustainable public procurement. This can act as leverage for the adoption of more sustainable production practices and consumption patterns, further promoting innovation and the wider availability of more sustainable products.

The development and introduction of innovative technologies and digital tools should be promoted throughout the value chains, such as investing in food innovation for advancing attractive alternative protein sources (e.g. advanced fermentation).

The biodiversity of production systems should be preserved and promoted – including through research.

2.5.2 Food waste reduction

Strengthening policies, fostering partnerships, and promoting behavioural change to reduce food waste

The importance of a systemic approach is highlighted by food loss and waste [221]. In the EU, over 59 million tonnes of food waste (132 kg/inhabitant) are generated annually [222]; more than half of the total food waste is generated by households [222]. All stages of the supply chain should be addressed, applying measures for direct reduction and developing circular methods for processing by-products is also key.

The reduction of food loss and waste is hindered by insufficient consumer food management leading to food waste generation at consumer level, inefficiencies and trade-offs in the food supply chain, and a lack of understanding and certainty regarding food safety standards (including possible misinterpretation of expiry date marking labels) [223].

2.5.3 Competitive and viable agri-food value chains

Ensuring fair economic sustainability and viability for all actors in the food supply chain while delivering affordable sustainable food

A fair profit distribution, from primary producers to processors, retailers and service providers lies at the heart of building a food system that is both economically robust and environmentally responsible. Such an approach is viable when the interests of various groups are balanced, and trade-offs are recognised. Achieving affordability of healthy and sustainable diets for consumers is equally important. There are multiple challenges to overcome in the path to fair economic viability [225]. Here the focus is on market and economic, structural and institutional factors (also check chapter 7.1.5 on *Fair, inclusive and ethical food system*, and 8.1.2 on *Learning for the clean transition*).

The challenges of economic sustainability are related to market dynamics and financial constraints. Specifically, these encompass ineffective incentives,

Food waste reduction

Establishing an enabling institutional, policy and regulatory framework. Facilitating the coordination of actors, enabling investments and incentivising the adoption of best practices in food waste reduction.

Supporting the implementation of the Directive (EU) 2025/1892 of the European Parliament and of the Council of 10 September 2025, setting legally binding food waste reduction targets, to ensure a sufficient and consistent response by all Member States to reduce food waste, in line with that of front-runners.

Developing national food waste prevention strategies, empowering national authorities in Member States to design tailored food waste prevention programmes that address relevant behavioural and market drivers, backed by solid evidence, following the indications of the food use and waste hierarchy as updated by the JRC [224].

Implementing the "Target-Measure-Act" approach: the evidence-based approach recommended by the United Nations Environment Programme (UNEP) [225], focusing on measurable targets, tracking progress and taking targeted actions for food waste prevention.

Promoting public-private partnerships, facilitating collaboration between government and supply chain actors to develop a common roadmap for food waste reduction at the national level.

Launching consumer behavioural changes campaigns to raise awareness and change consumer behaviour around food waste.

Strengthening research and innovation uptake, by supporting the deployment, scaling and interoperability of solutions developed under EU programmes (e.g. digital tools, behavioural interventions, logistics and retail solutions, and circular processing technologies), and facilitating their integration into real food systems operations across Member States.

imbalances of market power (including market concentration), sunk costs related to processing investments in R&D and advertising, and slow uptake of new technologies.

In addition, the trend towards an export-oriented model in certain sectors or commodities, as well as externalities that are not reflected in the food prices, can lead to market distortions [226], [227], [228], [229], [230].

Institutional challenges stem from the underlying structure of the food system, including policies, regulations, and power dynamics. Product imports can be cheaper than local production, or exports can result in higher profits. As a result, consumers may no longer be "connected" to the production resources and making informed choices becomes more difficult [231]. Also, in some cases, the political environment leans towards 'food sovereignty' or 'self-sufficiency' [232], [233], and trade can be viewed as a hindrance to achieving food security [234], though it may not necessarily be the most sustainable or fair option.

It should be noted that some of these challenges can fit into multiple categories, as they always interact with each other. These challenges are fully linked to natural resource limitations, environmental impacts, and climate change, such as pressure from land use competition, scarcity of natural resources (water or soil) and environmental externalities (Chapter 2.6, *Preserving and Protecting Biodiversity*, includes a **focus on soil**).

Competitiveness of the food system

Potential enablers

A multi-faceted approach is necessary, strengthening knowledge and public awareness of consumers on the economics of food systems, e.g. the impacts of sustainable production practices on food prices. At the same time, financial support and incentives can be provided for primary producers (farmers and fishers) transitioning to more sustainable practices to overcome barriers and adopt practices that contribute to both environmental sustainability and long-term profitability. Subsidies can be redirected towards sustainable practices, marking a fundamental shift away from those that do not support the intended policy objectives.

Local and sustainable food supply chains can be revitalised and strengthened to enhance food quality, reduce environmental impact, and improve rural-urban connections.

Technological advancements and improved management practices can be adopted that support agricultural productivity while mitigating climate change. Excessive market concentration should be prevented and sustainable domestic production secured to ensure a resilient food supply chain.

A robust trade strategy and Open Strategic Autonomy should prioritise sustainability and supply chain resilience, balancing competitiveness, sustainability and fairness to ensure a stable and equitable food supply.

Public and private investment is needed in green financing, alongside public and private participation to de-risk sustainable food production.

Primary producers' associations and cooperatives could help to increase bargaining power.

2.5.4 Sustainable and healthy diets

Creating supportive food environments to promote healthier and more sustainable food choices

Diets are central to shaping food systems, driving significant environmental and climate impacts by influencing food production activities, energy use and pressure on water, land and natural resources and biodiversity [235]. Creating food environments that make healthy and sustainable food choices easier is critical for supporting a dietary shift that is better aligned with nutrition, health and environmental goals.

Food environments can also empower consumers to make food choices that support the economic viability of an ethical and fair value chain. Key challenges that prevent consumers from making healthier and more sustainable food choices include [235], [236]:

- Limited **affordability** of and **access** to nutritious and sustainably produced foods, including emerging options such as alternative proteins, for which costs remain relatively high.
- Lack of **capacity and motivation** across food system actors to mobilise and transform food environments.
- Lack of adequate and understandable **information** to support consumers knowledge and awareness of the economic, environmental and social sustainability impacts of food choices.
- Exposure to the **marketing** and advertisement of unhealthy foods which may influence food preferences.
- Cultural **preferences**, habits and social norms, which often prevent consumers from making more sustainable and healthy food choices
- The limited **provision** of sustainable and nutritious foods in different physical contexts (e.g. schools, public institutions, retailers, restaurants).
- Limited availability of attractive, tasty and convenient sustainable food options.

At the same time, the quality of food environments is central to enabling all individuals to access healthy and nutritious diets and ensure food security. Food insecurity is also linked to geopolitical situations, socioeconomic vulnerabilities relating to poverty, employment, education and social protection. To support more sustainable food choices and achieve a more impactful outcome, a comprehensive approach that coherently addresses the complex dimensions of food environments is needed.

While no single solution exists to achieve sustainable diets, policymakers at EU and national level can implement a combination of integrated and aligned measures, as outlined below, to better support the transition towards affordable, healthier and more sustainable foods.

Potential enablers

Sustainable and healthy diets

Encouraging food systems governance at different territorial levels (EU, national, local), in support of healthier and more sustainable food environments.

Using fiscal measures to make sustainable and healthy food more affordable than the alternatives, addressing inequalities and reducing food insecurity and costs of certain food products.

Increasing knowledge and promoting awareness of how food choices affect health and sustainability by enhancing access to reliable information. Key actions include improving food labelling, advertising, promotion, and supporting local initiatives and educational campaigns on sustainable diets. Education, in particular of the young population, can boost food literacy, values, and social norms for sustainable eating. Updating national dietary guidelines to include sustainability goals can shape school education, inform consumers, and guide national food policies toward sustainable eating practices.

Improving communication on healthy dietary choices, particularly among children, including in relation to food advertising.

Engaging local communities, such as schools, public institutions and local farmers to create sustainable connections that strengthen awareness, motivation and values supportive of sustainable supply chains and food choices while promoting and building on existing models and best practices.

Increasing provision of sustainable food options, ensuring their availability in various food environments (e.g. restaurants, retailers, schools, public meals), and improving access to affordable, sustainable and healthy alternatives. Sustainable public procurement can influence food provision of public meals in line with sustainability goals.

Supporting food reformulation and innovation by providing incentives to align the quality of sustainable food products with consumers' preferences. This also includes promotion of industry actions through voluntary agreements and codes of conduct to deliver healthier, convenient and tasty options that increase demand for sustainable choices.

Investing in and fostering social innovation, which can boost transformative connections, offer new food systems design and shape food environments.

Digitalisation in support of information, traceability, knowledge and social innovation (e.g. digital tools for consumers to healthy diets choices and comparison of alternatives).

2.5.5 Food system resilience

Strengthening EU food system resilience through integrated policies across economic, environmental, and social sustainability dimensions

The **resilience** of the EU food system is essential for food security, economic stability, and environmental sustainability. Ensuring a resilient, food-secure future requires adaptive strategies, technological innovation, and policies that balance sustainability with economic viability [237].

One of the key challenges is **climate change**, with more frequent extreme weather events, which poses direct threats to agricultural productivity and ecosystem health [238]. At the same time, growing **geopolitical tensions** and the ongoing reconfiguration of trade and supply relations are emerging immediate risks for the resilience of the EU food system [239]. This is reflected in the EU's reliance on global markets for essential inputs like fertilisers and feed increases vulnerability to disruptions [240], as shown by the COVID-19 pandemic, Russia's war of aggression against Ukraine, and the recent tensions involving Iran, where high costs limited farmers' capacity to invest in adaptation measures [241]. Social inequities also weaken resilience, as access to affordable, nutritious food remains limited, especially for vulnerable populations [242].

To address these challenges, the EU requires cohesive policies with **better coordination** across EU member states and across economic, environmental, and social dimensions [243], [244].

Potential enablers

Food System Resilience

Revising domestic and foreign food trade policies to improve sustainability provisions across EU agri-food trade.

Increasing support for small and medium-sized enterprises to improve resilience and environmental outcomes over output.

Promoting sustainable farming practices like crop diversification, a shift to more resilient production systems, landscape elements, and agroecology, to address environmental degradation, restore soil health, and support a stable agricultural productivity growth over the long term.

Strengthening farmers' risk management through sustainable farming practices, innovation, advisory support, and appropriate financial tools.

Boosting investment in innovation, digitalisation, and data infrastructure to enhance risk management and resource efficiency.

Increasing the reach, accessibility, and quality of programmes to support farmers and rural communities in adopting sustainable practices.

Promoting inclusive food policies that prioritise diet diversification, health, nutrition, and affordability through public procurement, urban food strategies, and access for vulnerable groups (children and older population).

Enhancing cross-border research and innovation through EU programmes and open knowledge exchange.
Develop a strategic R&I agenda on food systems to foster development of competitive, sustainable and resilient food systems solutions, in complementarity with the strategic approach to R&I in agriculture, forestry and rural areas.

2.5.6 Food system governance

Adopt and encourage systemic approaches to support a transition towards sustainable and resilient food systems

To achieve sustainable and resilient food systems **systemic approaches** are required, due to the complexity and interconnectedness of activities and actors that are influenced by numerous social, economic, environmental, and policy drivers [215]. Such an approach is central to identifying coherent and adaptive solutions and engaging with all relevant actors to achieve transformative changes across all sustainability dimensions.

Along this line, since its launch in 2016, the Food 2030 R&I framework has encouraged the adoption of a systemic approach to connect, scale up, and boost EU R&I investments and impact with the support of Horizon 2020 and Horizon Europe framework programmes.

Identifying synergies and trade-offs is necessary to enhance resilience of the EU food system through the transition to sustainability and increase the cost effectiveness of measures. This in turn calls for **strengthening food systems governance** by underpinning policy coherence, coordination between the various sectors and actors, from local to global, as policy intervention should create long-lasting synergies for sustainable development [216].

Food system governance

Potential enablers

Promoting long-term sustainability of the food systems as a societal benefit in terms of food security and accessibility, as well as a key condition to preserve primary producers' capacity to produce food in the long run.

Acknowledging economic challenges linked to sustainable production and consumption of food and addressing them through strategic measures.

Supporting the development of inclusive and systemic strategies at both EU and national levels to transform food systems [217].

Fostering inclusive food systems governance at all levels (EU, national, local) by engaging all actors ensuring better coordination, accountability and alignment towards sustainability.

Aligning national food-based dietary guidelines with sustainability goals to better guide policies towards healthy diets which also include the sustainability of the food systems.

Promoting urban food policies that mainstream sustainability goals in the local context by engaging with consumers and actors in the public and private food service, retail, and direct distribution channels.

Strengthening research and innovation as a catalyst for transformation, for instance in making sustainable food options more attractive, affordable and available, developing more sustainable production technologies and consumption practices and re-designing food systems through policy and social innovation.

Improving knowledge, data and institutional capacity to support better decision-making and evidence-based policies.

Providing multi-stakeholder platforms for knowledge and information exchange and for cross-sectorial collaboration.

SUSTAINABLE AND RESILIENT FOOD SYSTEMS Navigato

This infographic helps **navigate the complexity** of the transition for achieving **sustainable and resilient food systems** while delivering on the **EU Competitiveness ambitions**. It presents a non-exhaustive overview of **challenges and enablers**, which are explored in full in the report.

Legend

- Financial / economic challenges
- Political / institutional challenges
- Technological / infrastructural challenges
- Socio-cultural / behavioural challenges
- Knowledge / operational challenges

Potential intervention areas

Transition path

n Final milestones

Multiple interconnected pathways reinforce each other and converge to enable a competitive and sustainable food system in the EU: 1 ***reducing environmental impacts***, 2 *strengthening* ***agri-food value chains***, 3 *enabling* ***healthy and sustainable diets***, 4 *enhancing* ***resilience*** *to shocks, and* 5 *ensuring* ***coherent governance***.

If we go like this, we will achieve major clean transition policies!

Start

ENVIRONMENTAL IMPACT REDUCTION

Implementation ambitions

- Reduce the **environmental footprint** of EU food consumption from production inputs to on farm sustainability assessments, and across the whole **value chain**
- Reduce **livestock-driven pressure** on land use while managing potential emerging **trade-offs**
- Scale sustainable **farming, fishing, and aquaculture** that deliver measurable environmental gains, including biodiversity in production systems
- Reduce **food loss and waste** across all stages (from agriculture to households) by tackling causes such as **supply chain inefficiencies** and ambiguous expiry data labelling

Enablers' mix

- Value-chain perspective: Integrate whole-value-chain and life-cycle perspectives in food system policies and decision-making
- Production practices: Reduce livestock pressure and land use where environmentally beneficial, including by scaling up sustainable farming, fishing and aquaculture practices
- Sustainable Public Procurement: Use sustainable public procurement to drive demand for lower-impact food products and catalyse innovation across value chains
- Consumption and diets: Promote sustainable diets, including increased uptake of plant-based options
- Food waste prevention: Enabling regulatory and institutional frameworks for food waste reduction, implementing national food waste prevention strategies using the Target-Measure-Act approach

COMPETITIVE AND VIABLE AGRI-FOOD VALUE CHAIN

Implementation ambitions

- Ensure **economic viability across agri-food value chains**, preserving affordability of sustainable and healthy food for consumers
- Address **market power imbalances** and structural distortions
- **Reconnect** consumers with **food production** systems to promote informed choices
- **Balance competitiveness**, **sustainability**, and **fairness** under increasing exposure to global market dynamics

Enablers' mix

- Financial incentives: Targeted financial support towards sustainable production, phasing out ineffective incentives
- Producers' positions: Support primary producers' associations to increase bargaining power and improve income stability
- Local supply chains: Strenghten local and regional food supply chains to enhance sustainable practices and reinforce urban-rural linkages
- Innovation and productivity uptake: Promote uptake of clean technologies that enhance productivity while mitigating climate and environmental impacts
- Public-private partnership: Public-private investment and risk sharing are key to scaling sustainable food production
- Strategic Autonomy: Align trade strategies with Open Strategic Autonomy to balance competitiveness, sustainability, and fairness across agri-food markets

SUSTAINABLE AND HEALTHY DIETS

Implementation ambitions

- Improve **affordability** of and **access** to healthy and **sustainable diets** for all
- Increase availability of appealing sustainable food options and access to **realiable information** on health, social, and environmental impacts of food choice
- Shift consumer awareness towards **healthier and more sustainable food choices**, removing barriers that constrain healthy and sustainable choices in everyday settings

These ***cross-cutting enablers*** *will help us go faster...*

CROSS-CUTTING ENABLERS

- **Innovative technologies** through the value chain
- **Behavioural insights** for policymaking chapter 8
- **Innovative and better use of data sources** (e.g. market intelligence, research data, Earth observation, administrative data)

or

They will support the EU competitiveness ambitions…

… citizens and environment health, too!

Supported policies

Communication(2025) 75
A Vision for Agriculture & Food
Regulation (EU) 2021/2115
'Common Agricultural Policy'
Regulation (EU) 2021/1119
'European Climate Law'
Regulation (EU) 2013/1380
'Common Fisheries Policy'
Communication(2021) 141
'Organic Action Plan'
Communication(2021) 699
'EU Soil Strategy'
Communication(2020) 380
'EU Biodiversity Strategy'
…

EU COMPETITIVENESS

Pillar 1 **Innovation**
Pillar 2 **Decarbonisation**
Pillar 3 **Strategic autonomy and security**

CLEAN TRANSITION

Enablers' mix

Governance framework — Strengthen coherent and inclusive EU and national food system strategies that integrate sustainability, competitiveness and resilience objectives across policy domains

Better coordination — Foster inclusive, multi-actor and multi-level governance mechanisms to improve coordination, accountability, and alignment across food system actors

Decision-support system — Enhance data sharing, monitoring systems, and analytical capacity (e.g., also through dedicated platforms for knowledge exchange) to support evidence-based, long-term policymaking

FOOD SYSTEM GOVERNANCE

Implementation ambitions

- Strengthen **systemic policy coherence** across food, agriculture, health, trade, and environmental objectives
- Improve **coordination across governance levels** and actors
- Enhance **monitoring**, **data availability**, and **evidence use** to support adaptive and long-term food system governance

Let's achieve the clean transition, together!

Let's bridge the gaps!

Enablers' mix

Sustainable farming — Enhance sustainable farming practices to buffer climate shocks and restore ecosystem health

Risk Management — Invest in innovation, digitalisation and data infrastructure to improve risk anticipation and crisis responses

Market stability — Revise trade policies affecting agri-food to improve sustainability provisions, reduce exposure to external shocks and strengthen supply-chain continuity

R&I — Innovation, training, knowledge sharing

Enablers' mix

Food availability
Increase the provision and visibility of healthy and sustainable food options across retail, catering, schools and public settings

Sustainable Public Procurement
Ensure access to healthy and sustainable meals and stimulate supply-side adaptation

Financial measures
Support making healthy and sustainable food more affordable than alternatives

Information symmetry
Improve food labelling and education, reducing exposure to marketing of unhealthy foods, especially for children

Social innovation
Foster community-based innovation linking schools, public institutions, local producers and citizens

Implementation ambitions

- Increased EU food system capacity to **face and adapt to climate-related shocks**
- Reduce vulnerabilities arising from **dependence on global markets** for critical inputs and agri-food commodities
- Improve **preparedness** in **response to supply-chain disruptions** affecting food availability and affordability
- Reduce inequalities that undermine resilience and fair **access to nutritious food**

Financing the clean transition **chapter 6**

Genetic biodiversity of the value prod. system

R&I and clean transition **chapter 5**

Key messages (Preserving and protecting biodiversity)

Embracing nature **protection and restoration** is both a requirement and an enabler for a thriving society. The persistence of nature loss and degradation poses substantial challenges to societal competitiveness, adaptability and resilience.

Effective biodiversity protection is constrained by persistent gaps in **monitoring**, indicators and data availability. The absence of harmonised biodiversity indicators, inadequate monitoring tools and technical challenges in capturing ecological change at relevant spatial and temporal scales hinder assessment and policy implementation.

Companies struggle to measure and integrate biodiversity impacts and dependencies due to **methodological complexity**, limited **data** and **behavioural** barriers. Improving measurement approaches and strengthening disclosure practices would support more systematic consideration of biodiversity in corporate decision-making.

Public and private **financial flows** remain insufficient to meet biodiversity conservation and restoration needs. Low levels of private investment, in particular, restrict the scaling of restoration efforts across ecosystems and slow progress toward long-term nature objectives.

Agricultural intensification remains a major driver of biodiversity loss, placing pressure on farmland and soil ecosystems. Addressing management and accounting gaps and supporting innovative policy designs can improve conservation outcomes in agricultural landscapes.

Restoring farmland and soil ecosystems requires **coordinated approaches** that link conservation measures with sustainable farming practices and climate objectives. Actions include agri-environmental schemes, organic farming, biological pest control and dedicated funding for nature restoration beyond the *Common Agricultural Policy*.

Marine ecosystems face persistent pressures from overfishing, eutrophication and invasive alien species. Strengthening monitoring and assessment systems under the *Water Framework Directive* and improving their integration with other sectoral policies can support more effective restoration and long-term marine preservation.

Cross-cutting challenges in monitoring, data systems and policy coordination continue to limit progress across terrestrial, freshwater and marine ecosystems. Enhancing coherence between monitoring frameworks and aligning biodiversity objectives with agriculture, fisheries and land-use policies are essential to achieving effective and lasting restoration.

2.6 Preserving and protecting biodiversity

Preserving, protecting and restoring nature is **both a requirement and an enabler for a resilient and thriving society**, given the foundational role that nature plays in human and societal wellbeing and the interactions identified between biodiversity, food, health, water and climate change [245]. This requires a radical change of views, structures and practices in the **relationship that society has with nature** and its services [246]. A particular focus can be put on the relations between biodiversity, business and trade, since the latter two both depend on and affect the biodiversity, thus creating risks and opportunities [247]. Thus, adopting a **systemic paradigm shift** in governance and policy making that embraces nature protection and restoration would foster prosperity and competitiveness, while delaying action would be costly and expose to more frequent and severe crises [245]. International cooperation, multilateralism, equity and inclusivity are important facilitators toward such systemic change [245], [246], [248].

2.6.1 Challenges and data gaps in monitoring and tracking biodiversity

Preserving, protecting, and restoring biodiversity is a challenge that takes different shapes depending on the ecoregion considered and the local biogeographical factors. The *Nature Restoration Regulation* is the most comprehensive policy framework with legally binding targets to protect and restore biodiversity. With many of these targets already anticipated by the 2020 *EU Biodiversity Strategy* (and monitored by the EU Biodiversity Strategy Dashboard), the *Nature Restoration Regulation* (adopted in June 2024) has several indicators and monitoring tools yet to be put in place.

At the EU level, relevant **datasets and indicators** should be integrated and harmonised to ensure consistency, high resolution, and long-term continuity, with regular updates. This would support the establishment of a comprehensive mapping and monitoring system with appropriate spatial and temporal resolution, geographical coverage, and thematic granularity.
Monitoring the progress of the *EU Biodiversity Strategy* targets presents several challenges, from the lack of multi-temporal high-resolution maps to track changes, to the absence of suitable ground-based biodiversity data for training and validation [249], [250].
The difficulties in collecting local level and harmonised biodiversity data at pan-European level hampers the understanding of the condition of ecosystems and, therefore, the ability to create and implement effective conservation strategies (UNEP - UN Environment Programme) [251]. Current efforts to mitigate these data constraints are on-going but not yet operational [250].
The Evaluation of the EU Biodiversity Strategy to 2020 has identified two key lessons from the initiative itself. First, effective implementation requires **specific, measurable targets** with clear definitions, timelines and assigned responsibilities for implementation. Second, actions to halt and reverse biodiversity loss need to cover a wide range of pressures on all ecosystem types and, therefore, a **mix of policy instruments** is needed to deliver the biodiversity commitments.

The EU needs to monitor shifts in geographic ranges of species, multi-temporal and multi-tax assessments, and the distribution and conditions of species population and habitats as a function of changing climate. This is particularly challenging in certain ecosystems, such as freshwater and wetland habitats. In freshwater ecosystems, there are knowledge gaps in understanding freshwater ecosystems and uncertainty about the type and magnitude of stressors affecting EU rivers ecological status [252].

Moreover, the diversity and connectivity of freshwater ecosystems is not always properly mainstreamed into conservation policies and objectives [253]. Member States lack a common definition for wetlands, and their geographic coverage is low in quantity and quality [250].

Investing in better data collection and monitoring systems.

Improving ground observations for calibration and validation of remote sensing and modelling products.

Improving the accuracy of bioclimatic modelling and develop products ready for applications (under development by Copernicus Climate Change Service (C3S) [250].

Developing a comprehensive mapping and monitoring system for biodiversity, ecosystems condition, pressures, incorporating data at various spatial and temporal resolutions, geographical coverage, and thematic granularity.

Applying principles of adaptive standards, monitoring protocols and co-management practices including comprehensive site pre-restoration baseline measures and ongoing monitoring of ecological, social and economic effectiveness of actions (functional ecosystemic approach) [254], [255]. Such an approach will require conducting detailed ecological studies and monitoring can provide the necessary data to design effective corridors that support biodiversity [255]. Notably, the Natura 2000 network of protected areas is aimed at this objective and is having positive results.

Strengthening the ***Water Framework Directive*** in monitoring and assessment of freshwater ecosystems, including the development of indicators and metrics to track changes in ecological status.

Developing a common definition for wetlands and improving their geographic coverage in terms of quantity and quality.

Promoting the use of ground-validated remote sensing products and improving their multi-temporal comparability.

Monitoring and tracking

Potential enablers

2.6.2 Accounting for the impact of the private sector on biodiversity

Several challenges hinder companies from measuring and taking into account their impacts and dependencies on biodiversity. Some of the main barriers are the complexity of biodiversity, which cannot be captured by a single metric, the lack of good quality data, the lack of data for harmonised assessments, and the cost of accounting. Nature credits can play a key role, mirroring **carbon credits**; however, it is important to account for the limits of reforestation/afforestation efforts' outcomes, as they may not sufficiently deliver on carbon sequestration, biodiversity recovery, influence on climate and sustainable livelihoods [256], [257].
Moreover, Nature Credits and Carbon Credits would not always work in synergy, since carbon credits could be, in some instances, drivers of pressures on biodiversity.

The *Taxonomy regulation* defined the criteria for economic activities aligned with the clean transition targets, and the subsequent *Corporate Sustainability Reporting Directive* (CSRD) and *Corporate Sustainability Due Diligence Directive* (CSDDD) defined the reporting duties for companies. However, companies showed concern, fearing that compliance with the directives would be complicated and costly. The reporting obligations have been largely **relaxed** with the recent Omnibus package, freeing SMEs from any obligation.
Potential enablers would include the Roadmap towards Nature Credit published in July 2025 by the European Commission. The Nature Credits will channel private finance into biodiversity and ecosystem restoration, and climate objective, by rewarding those who contribute to ecosystem restoration and conservation (such as farmers, foresters, fishers, landowners, and local communities).

2.6.3 Policy and Financial Frameworks for Biodiversity Conservation and Restoration

The mobilisation of public and especially **private finance** for biodiversity remains low overall (particularly when compared to climate finance). The substantial **data gaps** and inconsistencies on biodiversity financing flows and their destinations hamper the assessment of their effects [258]. The lack of policy coherence and coordination across different levels of government and sectors is a major barrier to effective biodiversity conservation and restoration. Additionally, the lack of **financial incentives and economic benefits** for biodiversity conservation and restoration, together with the persistence of environmentally harmful subsidies and financial practices, hinders the implementation of effective conservation strategies [246], [259].

Potential enablers

Conservation and Restoration

A smooth implementation of the *Nature Restoration Regulation* and the development of financial frameworks for biodiversity conservation and restoration.

Promoting the use of sustainable finance policies and practices, including the integration of biodiversity risks and opportunities into financial decision-making.

Evaluating and acting upon the environmentally harmful subsidies to counterbalance their negative effects on a sustainability and circularity driven economy and finance [246].

Developing and implementing effective conservation strategies for biodiversity and ecosystems restoration.

Natural and restored floodplains which support multiple EU policy objectives. More specifically they provide flood protection, and other ecosystem services such as improved water quality, improved conditions for biodiversity conservation and improved recreational value [260].

An emergency recovery plan for freshwater biodiversity loss at EU level [261].

2.6.4 Land and Soil ecosystems

Agricultural intensification is one of the main drivers of biodiversity loss and ecosystem degradation in Europe

While **agricultural intensification** remains one of the main drivers of aboveground biodiversity loss [262] and ecosystem degradation in Europe (e.g. the use of **pesticides** is the main driver of the decline of pollinators, the excessive use of fertilisers is the main driver of coastal eutrophication, and both pesticides and fertilisers together with mono-cultures drive loss of key soil organism groups), **sustainable agricultural practices** are essential for the restoration of ecosystems. Moreover, the agricultural sector accounts for about 11% of the EU's domestic GHG emissions [201]. Several EGD targets related to food production, biodiversity protection, carbon sequestration, reduction of GHG emissions and pollution are interconnected between their respective thematic areas (1, 5, 6 and 7) and are addressed jointly in this section.

The CAP contribution has not halted the decline of biodiversity on farmland [263]. The key challenges in the formulation of the agriculture targets are:

- targets are **hard to monitor**;
- the coordination between EU policies and strategies is currently weak. Genetic diversity is only marginally addressed (e.g. the DNA metabarcoding of bacteria and fungi is an indicator listed in the *Soil Monitoring Directive*, but otherwise it is not accounted for);
- policies do not address declining genetic diversity;
- the tracking of CAP spending for biodiversity needs improvement in transparency. Moreover, both the Commission and the Member States have favoured low-impact options, e.g. including nitrogen-fixing crops instead of greening. Given the synergies between the protection and restoration of the forest ecosystem with the carbon removal from the **LULUCF sector**, challenges and enablers are tackled together in chapter 2.1.2.

The key aims of enablers should be: 1) improving the coordination and design of the post-2020 *EU Biodiversity Strategy* (including better tracking expenditure); 2) enhancing the contribution of direct payments to farmland biodiversity; 3) increasing the contribution of rural development to farmland biodiversity; and 4) developing reliable indicators to assess the impact of the CAP on farmland biodiversity.

Models indicate that conserving at least 20% semi-natural habitat within farmed landscapes could primarily be achieved by spatially relocating cropland outside conservation priority areas, without additional carbon losses from land-use change, primary land conversion or reductions in agricultural productivity [264].

Member States call an EU-wide benchmarking system in agriculture and food systems to harmonise methodologies of on-farm sustainability assessments, including monitoring and verification tools with common metrics and indicators. This would be financed by a *Just Transition Fund* established outside the CAP [265]. Some data collection is ongoing, (see the LUCAS, EMBAL, INSIGNIA projects), and a future step is to link it to actual farming practices.

Well-designed measures for biodiversity protection, restoration and sustainable use can bridge wider environmental and socioeconomic benefits. This includes tackling the conflict between soil conservation and the implementation of REPowerEU-related initiatives and trade-offs between nature conservation and restoration and bio-economy objectives and their associated socioeconomic dynamics, which might lead to land use intensification.

Potential enablers

Ecosystem accounting in farmlands

In farmland, ecosystems accounting and management gaps could be met by innovative policy designs

The EU needs to improve the **monitoring and understanding of insects' decline**. There is a limited understanding of the effects of environmental changes on insect communities. Enhance understanding of insects decline and their role in ecosystem services requires research and data collection, developing effective conservation strategies and mainstreaming the information to the stakeholders [266].

Regarding chemical pressures, single, **substance-specific assessments** limit ecosystem-wide risk evaluations, **and do not account for cumulative impacts** under changing climate and ecological pressures [267], [268].

Resistance management also becomes challenging when availability limits the rotation of pesticides, leading to increased resistance risks [269]. Although low-risk pesticides and biopesticides offer promising alternatives, the lengthy development and approval processes hinder their timely availability, often forcing farmers to rely on conventional chemicals [270].

Potential enablers

Using an integrated approach helps prevent "pollution swapping". Moving beyond farmer-centric policies to include other agri-food stakeholders, such as manufacturers and wastewater treatment companies, could strengthen overall policy impact [271].

Shifting regulatory focus to product and design standards for fertiliser manufacturers, similar to fuel efficiency standards in the automotive industry, could drive innovation and encourage enhanced efficiency fertilisers, reducing nitrogen runoff at the source [271].

Strengthening pesticide risk indicators is critical for assessing and managing pesticide impacts effectively. Tools like the Pesticide Load Indicator [272], the soil risk indicators under development [273], or the Aggregated Total Applied metric [274] align with global initiatives, fostering data-driven decision-making and regulatory alignment across countries [269], [275].

Boosting actions to ensure soil ecosystem protection

The EU Soil Degradation Dashboard shows that 62% of EU soils are not in healthy condition [273]. The lack of understanding of soil biodiversity, with only 10% of species identified, is major knowledge gap, which combined with the complexity of soil ecosystems, makes it difficult to develop effective conservation strategies [276]. Furthermore, there are many unknowns about **the biodiversity losses and tipping points for soil**. Unlike for physical and chemical soil properties such as texture [277], pH, and NPK [278], **high-resolution and molecular tools needed to investigate soil biodiversity** have been applied only recently at EU-level and harmonised datasets are just starting to emerge (i.e. LUCAS Soil Biodiversity module - [279]).

Soil degradation (in particular when combined with global warming) not only harms soil-related ecosystem services but also depletes the **soil organic carbon (SOC) stock** [280]. Recarbonising soil by creating a positive soil carbon budget (wherein carbon input exceeds carbon loss) can alleviate these effects [281]. However, two key aspects need to be considered regarding soil recarbonisation. The first is that with increasing soil carbon input, a new equilibrium state will eventually be achieved, leading to carbon gain attenuating after a few decades [282], [283]. Secondly, the carbon gains achieved through changes in management practices are reversible, i.e. much or all of the carbon gained can be lost if management practices are not maintained in the long term [284].

So far, the adoption of **carbon farming and soil actions** has been limited, despite the potential for emissions reductions and carbon sequestration at farm level. The EU has recently passed the *Carbon Removals and Carbon Farming* (CRCF) and the *Soil Monitoring Law*. There are also non-legally binding instruments, such as strategies and plans (e.g. *Soil Strategy* for 2030). Policymakers and other stakeholders revealed that the main barriers to the adoption of carbon farming policies are **concerns over carbon leakage** (EU Member States, might compensate for the loss of food production by increasing food imports from third countries) and competitive advantage in the absence of multilateral action, the **need for a just transition**[6] **and structural issues in the food value chain**. Despite being regarded by researchers as a main barrier to carbon farming, the **agricultural lobby** is not perceived as a barrier by policymakers [93].

6 This point is linked to the importance of agriculture to rural economies. For example, the farmers' dependence on CAP subsidies is a challenge for policymakers in the event of any reform to the CAP. This is also an argument for a food system transformation to increase farmers' resilience and the sustainability of their business.

The ultimate aim of introducing soil carbon management practices (SCMP) is to increase the amount of organic carbon in the soil of agricultural areas to ensure the soil's long-term productivity and resilience. This requires a combination of regulatory framework as well as informative/engagement actions, to encourage sustained behavioural change on the ground. Ultimately, farmers need to understand the long-term benefits of SCMP and be encouraged and empowered to find long-term solutions. Given the **dual benefits of increased soil carbon** in restoring soil health and combatting climate change this might be a worthwhile investment for policymakers [94].

The uptake of SCMP can be encouraged in three ways:

- The introduction of specific **economic incentives** to assist with, for example, the purchase or sharing of specialist machinery or to cover the transitional periods without benefits [94].
- Improvements in **farmers' technical skills**, particularly in relation to the more technically challenging practices, such as minimum tillage and cover crops (**conservation agriculture** [73], [285], [286]).
- The facilitation of **networks for farmer-to-farmer learning** opportunities to help farmers to identify and build their confidence in SCMPs that will work in their local area.

Farmland and soil ecosystems can be restored in synergy

At Member States level, better use of **integrated land use planning** enables the harmonisation of conservation goals with other land uses [255]. Moreover, successful management of multifunctional landscapes (including, for example, biodiversity corridors in farmland) requires the combination of context-specific land-sharing and land-sparing measures within spatially well-connected landscape mosaics, resulting in land-sharing/-sparing connectivity landscapes [292].

Stakeholder engagement is essential to addressing all the above challenges: inadequate involvement of local communities in conservation efforts may reduce the effectiveness of initiatives on soils and their biodiversity. The main barriers to easing the tension between food-production activities and biodiversity protection are **short-term economic pressures**: farmers and policymakers frequently prioritise immediate economic benefits over long-term soil health and biodiversity, often failing to account for potential consequences in the coastal marine environment and linked activities.

Any incentives to encourage the uptake of SCMP cannot be implemented at EU-wide level; regional policies, including subsidies and communicative interventions, need to be tailored to overcome specific local and regional agronomic, technical, social and cultural barriers [94]. Similar conclusions have been reached in relation to encouraging the uptake of agri-environmental and climate change practices in agriculture [94].

It is worth noting the potential of biochar (depending on specific conditions and source material for the biochar) in improving the long-term SOC balance [284].

Member States could boost the uptake of biological control of plant pests, and reduce the influence of agro-chemical companies, and promote agro-biodiversity, to reduce external inputs, improve nutrient management, advance in the decarbonisation of mineral fertilisers and develop and use biocontrol. Precision agriculture techniques that optimise fertiliser and pesticide applications on plants help reduce losses, minimising environmental impact [270], [287]).

Organic farming plays a key role in the transition to sustainable land management in the EU [265], [288]. Conversion to organic farming includes high transition costs, insufficient technical knowledge among farmers, lower yields, limited access to quality organic inputs, increased food price, financial risks and complex regulatory challenges related to organic certification. Conversely, there is growing consumer demand and enhanced market access for organic products, education and training programmes, and collaborative initiatives among farmers for resource sharing. Supportive EU policies, subsidies and financial incentives can promote organic farming and facilitate sustainable practices [265], [288], [289]. Changes in production practices would be more effective if combined with reduced consumption levels and changes in patterns of demand [290].

Rewarding and incentivising farmers will establish and continue providing ecosystem services, with environmental payments that “go beyond what is required by EU legislation and aim at the highest ambition in a system to be linked to quantifiable results using robust indicators”, also considering the land-sea continuum. To this end, the Strategic Dialogue on the Future of EU Agriculture recommends that a *Temporary Just Transition Fund* should be established outside the CAP [265].

To take into account the EU clean transition goals, according to the next CAP should focus on [265]: (1) providing socioeconomic support targeted to the farmers who need it most; (2) promoting positive environmental, social, and animal welfare outcomes for society; and (3) invigorating enabling conditions for rural areas. Implementing practice-based incentives (e.g. subsidising beneficial methods for soil biodiversity protection) to encourage farmers to adopt sustainable practices and coupling those with regulatory soil protection legislation with incentive-based instruments could help in making CAP more effective in promoting soil and its biodiversity conservation [276].

Further analysis is needed to better understand the effectiveness and scope of current EU food labelling legislation, particularly with regard to measures addressing marketing to children [265]. Moreover, fiscal tools should be provided in the form of tax reductions for consumers to foster coherent price signals and Member States should foresee measures to safeguard food affordability for lower income consumer segments through social and fiscal policies.

Diet changes, reduced post-harvest losses, and reduced food waste contributes to eradicating poverty and promoting well-being and sustainability.

Improved forest management, soil carbon sequestration, peatlands and coastal blue carbon management (as also addressed in Chapter 2.1, *Climate Action*) can enhance biodiversity and ecosystem functions and increase employment in those sectors [65].

Potential enablers

2.6.5 Water ecosystems

Overfishing, eutrophication and Invasive Alien Species are the main challenges in marine ecosystem restoration

Key remaining challenges in the marine water ecosystem include **overfishing** and **destructive fishing practices**, stagnant and poorly sustainable **aquaculture** [293], **pollution** from agricultural runoff, industrial activities, and wastewater [294], and inadequate **governance** and enforcement of environmental regulations, including for the EU aquaculture [295], [296].

Notably, eutrophication is exacerbated by climate change [295]. The trend and rate of alien species introductions are also increasing [297], [298]. Marine Invasive Alien Species (IAS) are primary drivers of biodiversity loss, through habitat modification, competition with native species, predation, disease agents or vectors [299]. Their diverse and widespread impacts means that they affect all marine conservation programmes including marine protected areas, habitat management (effects of fishing), and marine mammal conservation [300], [301], [302].

The Water Framework Directive (WFD) monitoring and assessment systems

Freshwater biodiversity is extraordinary **rich** despite it small area footprint, it includes one-third of all vertebrate species. Yet it is steeply declining, leading to the proposal of a global "Emergengy Recovery Plan" [240]. Monitoring cannot just be a case of identifying the cause of degradation (due to poor linkage between pressures and effects on the ecosystem).

Under the *Marine Strategy Framework Directive*, each Member State must prepare and implement a strategy for its marine waters, in cooperation with those sharing the same marine region or subregion, and the strategy must be reviewed and updated every 6 years [305]. Moreover, the *Ocean Pact* [306] (expected to be adopted in the Q42026) should include the adoption of a legal act (*Ocean Act*) which will provide support to the integration of the WFD with other sectors.

At **regional level**, managing species and ecosystem diversity at the landscape scale means identifying and preserving specific and very often marginal habitats within forests, such as water springs, watercourses, wetlands, peatlands, rocky sites and topographically extreme sites with lower tree density, which provide excellent opportunities to maintain and promote biodiversity [307].

Potential enablers

Blue Carbon Initiatives: Pilot programmes on blue carbon farming link the food system to aquatic and marine ecosystems, focusing on reducing emissions in fisheries and promoting sustainable aquaculture. This integration broadens the approach to climate change mitigation, including a lesser-known carbon sink.

Policy coherence is key. For marine ecosystems, it is necessary to review policies that present risk of supporting unsustainable fishery and eliminate support to such practices. Support should be conditional on vessels carrying their flag and being authorised to fish in their waters [303]. The land-sea continuum should also be systematically foreseen to avoid the creation of issues at sea originating from land and river management.

Develop and implement effective conservation strategies for freshwater and wetland ecosystems.

Suggestions to enhance the WFD Monitoring and assessment systems [304] include: 1) communicating progress toward good status more effectively; 2) incorporating innovation into monitoring and assessment, 3) improving diagnosis of cause of deterioration.

Moreover, WFD Policy needs integration with other sectors, especially agriculture [304]. Along the same lines, it is recommended to consider hydrological connectivity in freshwater conservation [253].

Marine ecosystem restoration

PRESERVING AND PROTECTING BIODIVERSITY Navigato

This infographic helps **navigate the complexity** of the transition for achieving **biodiversity targets** while delivering on the **EU Competitiveness ambitions**. It presents a non-exhaustive overview of **challenges and enablers**, which are explored in full in the report.

Legend

- Financial / economic challenges
- Political / institutional challenges
- Technological / infrastructural challenges
- Socio-cultural / behavioural challenges
- Knowledge / operational challenges

Potential intervention areas

Start — Transition paths

Final milestones

If we go like this, we will achieve major clean transition policies!

*Preserving, protecting, and restoring biodiversity in the EU builds upon cross-cutting pathways (1 **monitoring, data and indicators**, 2 **economic and financial levers**, 3 **policy coherence and capacity building**) as well as 4 **healthy land, soils**, and 5 **water** ecosystems.*

Start

MONITORING, DATA AND INDICATORS

for biodiversity monitoring, conservation, and restoration across ecosystems

Implementation ambition

Enable a harmonised, high-resolution and **policy-relevant EU biodiversity monitoring** and tracking backbone across ecosystems, overcoming **data and validation gaps** and lack of **standard protocols** across Member States

Enablers' mix

- Monitoring backbone — EU-wide, interoperable biodiversity monitoring and mapping system, combining remote sensing, in-situ data and modelling, with multi-temporal comparability
- Direct observation — Improved ground-based observations for calibration and validation of remote sensing and modelling products
- Modelling capacity — Improved bioclimatic modelling accuracy and application-ready products
- Standards — Establish adaptive monitoring standards and protocols, including robust site baselines pre-restoration and ongoing monitoring of ecological, social and economic effectiveness
- Wetlands — Establish a common definition for wetlands with improved geographic coverage/quality

Let's achi[…] transition

ECONOMIC AND FINANCIAL LEVERS

for biodiversity conservation and restoration across ecosystems

Implementation ambition

Align **public/private financial flows** and corporate practices to **integrate** biodiversity impacts into **economic decision-making**

Couple the opportunities for **simplification** (*Omnibus*) with the need for **reporting**

Enablers' mix

- Market instruments — Deployment of Nature Credits to channel private finance
- Corporate disclosure & assessment — Harmonised and robust biodiversity impact and dependency assessment frameworks for companies
- Sustainable finance integration — integration of biodiversity risks and opportunities into finance policies, investment decision-making and capital allocation
- Incentive structures — Biodiversity offset schemes, conservation funds and targeted incentives to improve the business case
- Policy framework — coherent financial and policy frameworks to support implementation of the Nature Restoration Regulation and large-scale restoration investment

POLICY COHERENCE AND CAPACITY BUILDING

for biodiversity monitoring, conservation and restoration across ecosystems

Implementation ambition

Ensure **coherent, coordinated** and implementable **biodiversity governance** across EU and national policies, aligning objectives, instruments and responsibilities to enable effective conservation and restoration

*These **cross-cutting enablers** will help us go faster...*

CROSS-CUTTING ENABLERS

- **Financing** the clean transition — chapter 6
- **Reforestation** to couple carbon capture and adaptation
- **Regenerative** practices in agriculture, forestry, aquaculture
- **Nature-based** solutions and **agro-ecosystems** — chapter 5
- **Circular bioeconomy** and sustainable use of biomass — chapter 4

They will support the EU competitiveness ambitions...

... citizens and environment health, too!

Supported policies

Regulation 2024/1991
'Nature Restoration'
COM(2020) 380
'EU Biodiversity Strategy'
COM(2021) 699
'EU Soil Strategy'
COM(2023) 103
'Fisheries and Oceans Pact'
...

EU COMPETITIVENESS

Pillar 2 **Decarbonisation**

CLEAN TRANSITION

Enablers' mix

- **Monitoring and assessment** Upgraded and integrated monitoring and assessment frameworks for freshwater and marine ecosystems
- **Policy enforcement** Coherent enforcement of fisheries, water and environmental policies across ecosystems, eliminating support to unsustainable practices
- **Pollution prevention** Source-oriented nutrient and pollutant control through integrated river basin and coastal management
- **Restoration** Design and implementation of targeted restoration strategies
- **NbS** Support for Nature-based Solutions linking climate mitigation and aquatic ecosystem restoration and Blue carbon initiatives

WATER

Implementation ambition

- Reduce **pressures** from **overfishing** and **unsustainable aquaculture** on marine ecosystems
- Reduce **nutrient**, **chemical** and **wastewater pollution** affecting freshwater and marine ecosystems
- Prevent and manage the **spread of invasive alien species** in aquatic ecosystems
- Strengthen **monitoring**, **assessment** and **diagnosis** of freshwater ecosystem degradation
- Integrate freshwater and marine protection through **coherent governance** across the **land–sea continuum**

...eve the clean ..., together!

This way

This way

Enablers' mix

- **National implementation** National implementation of Nature Restoration Regulation demanding clear targets, timelines, accountability, monitoring
- **Policy coherence** Alignment of biodiversity objectives with sectoral policies (agriculture, fisheries, land use, water)
- **Strategic planning** Development of coherent EU and national conservation and restoration strategies, including emergency recovery planning where biodiversity loss is critical
- **Multi-level governance** Strengthened coordination across EU, national and local levels, clarifying mandates and enforcement

LAND & SOIL

ecosystem restoration and sustainable management

Enablers' mix

- **CAP** Alignment with biodiversity, soil health, and long-term ecosystem outcomes
- **Ecosystem accounting** Accounting frameworks capturing cumulative pressures
- **Input and production design** Upstream regulation and innovation to reduce chemical pressures and external inputs
- **Soil carbon** Targeted support for soil carbon management and recarbonisation practices, biochar (where appropriate), and organic farming transition
- **Targeted Rewarding** Beyond compliance (e.g. to farmers for ecosystem services)
- **Connectivity** Landscape-level planning and incentives for multifunctional and connected agro-ecosystems

Implementation ambitions

- Reverse **biodiversity loss driven** by agricultural intensification while maintaining productive capacity
- Improve **monitoring and transparency** for better farmland biodiversity and CAP spending tracking
- Address **genetic, insect and below-ground biodiversity decline**
- Reduce cumulative ecosystem impacts from **agrochemicals and nutrient management**
- Restore **soil carbon stocks and soil functions** through long-term, enforceable soil management

Natural 'sanctuaries' for biodiversity restoration

Shift towards more **healthy and sustainable diets**

R&I and better data
chapter 5-8

Key messages (Zero-pollution ambition)

Achieving zero pollution requires more **integrated approaches** across air, water, soil and ecosystems. Pollution pressures remain significant and stem from multiple sources, while monitoring, enforcement and policy frameworks are often fragmented. Strengthening coherence across air, water, soil and chemical policies is essential to address cumulative impacts and protect ecosystems and human health.

Existing policies such as the *Water Framework Directive* and the *Nitrates Directive* provide an essential basis for reducing pollution, but **monitoring and assessment systems** remain fragmented and often focus on individual pollutants. This limits the ability to understand cumulative impacts and ecosystem-level interactions, underscoring the need for more integrated monitoring approaches.

Holistic approaches such as ecosystem-services assessments, **One Health** and **Safe and Sustainable by Design** can help align environmental, health and social objectives. Applying these frameworks more consistently would support more coherent policy design and better address the interconnected sources and impacts of pollution.

Agriculture remains a significant source of air, water and soil pollution through nitrogen losses, pesticides and emerging contaminants such as microplastics. Addressing these pressures requires action beyond the farm level, including upstream and downstream actors across the food chain. Enhanced-efficiency fertilizers and related **innovations** need stronger **investments into R&D**, as well as support for market entry and scaling, to effectively target **pollutant emissions at source**.

Citizen science and **participatory monitoring** can meaningfully complement traditional environmental data systems, but their contribution depends on institutional support, robust data-quality protocols and accessible platforms. Public initiatives already demonstrate value in tracking soil and water quality, and improving the visibility, standardisation and interoperability of citizen-generated data can strengthen their use in environmental assessment and decision-making.

2.7 Towards zero-pollution ambition

The Zero Pollution thematic area of the European Green Deal builds on pre-existing and well-established policies, like the *Water Framework Directive* [308], the *Nitrate Directive* [309], and the *Marine Strategy Framework Directive* [310] which have been implemented in recent decades. Some have recently been reviewed, like the *Ambient Air Quality Directive* [311]. A rich literature exists on the implementation of these policies, highlighting challenges and possible solutions for the achievement of the Zero Pollution objective. This section focuses on three potential levers for the implementation of these policies: 1) adopting holistic concepts and mitigation strategies; 2) addressing nutrient pollution in agriculture through an agri-food chain lens; 3) promoting participatory and bottom-up approaches in environmental monitoring.

2.7.1 Adopting holistic concepts and mitigation strategies

The WFD explicitly recognises the interconnected nature of water systems and the diverse societal, environmental, and economic factors influencing them. Monitoring strategies often focus on single drivers and fail to capture the **complex interactions between pressures**, leading to an incomplete understanding of ecosystem properties. In particular, many Member States have designed their monitoring programmes based on individual parameters rather than overall ecosystem health, leading to persistent issues with water quality and ecosystem management. This indicates a need for more **comprehensive monitoring and pressure-impact analysis** to ensure effective water management and compliance with WFD goals [312], [313].
In the field of **nitrogen pollution**, most policies generally have a siloed approach with policies specific to certain sinks: for instance, in the EU, NO_3 pollution is controlled under the *Nitrates Directive*, while ammonia (NH_3) and NO_x emissions are subject to the *EU National Emission Reduction Commitments (NEC) Directive*. This fragmentation has sometimes raised concerns about potential trade-offs or "pollution swapping," where measures to reduce one type of Nitrogen pollution may inadvertently increase another [271]. However, recent policy evaluations suggest that this risk can be mitigated through coordinated implementation. The evaluation of the *NEC Directive* (SWD(2025) 394 final) concludes that the *Nitrates Directive* and the *NEC Directive* are overall coherent and can generate synergies when implemented jointly at national level, particularly when combined with relevant provisions under the *Industrial Emissions Directive* for livestock production.

The development of more holistic, coherent mitigation approaches would help in cross-cutting fields such as nitrogen pollution and water management. Concepts developed in social-ecological science, e.g. the ecosystem services and "**One Health**" approach may help overcome fundamental obstacles in the implementation of environmental policies. They have the potential to integrate policies and administrative areas and to capture the **connections between environmental and socioeconomic systems**. Similarly, in the field of chemicals pollution the development of the **Safe and Sustainable by Design concept** and framework enables the integration of considerations related to human health risk assessment with the environmental and social sustainability assessment in the early stage of the innovation process. This allows the risk of burden shifting to be taken into account and prevents any unintended substitution with hazardous chemicals.

Holistic approaches

Potential enablers

The promotion of interdisciplinarity and integration into policy making, encouraging cross-pollination.

The establishment of multi-disciplinary research units or teams on environmental health topics in local health authorities, in order to enhance collaboration between medical staff and environmental agencies and integrate competences for mutual benefit.

2.7.2 Addressing nutrient pollution in agriculture through an agri-food chain lens

The **agricultural sector** is a substantial source of pollution of water bodies, air and soil. Fertilisers and pesticides are among the major polluting components of drinking water. Mulch films and sewage sludge are also sources of microplastics. The *Environmental Implementation Review* notes that limited progress has been made in the reduction of pollution of water bodies due to excessive fertilisation in the primary sector. In particular, many Member States have problems in relation to the implementation of the *Nitrates Directive* and should step up their efforts to further reduce nitrate pollution from agriculture in groundwater and eutrophication [314].

The current policies on nitrate pollution reduction focus on changing farmer behaviour, but policymakers might consider **targeting actors in the agri-food chain beyond the farm**. For instance, the fertiliser industry and wastewater treatment companies can influence farm-level nitrogen management. This approach would shift the regulatory burden away from farmers and transform a complex non-point-source problem into a series of more manageable point-source approaches [271].

Fostering research and innovation is a primary objective within the *Competitiveness Compass* [4]. This is particularly important for the development of **enhanced-efficiency fertilisers**, which can significantly reduce nitrogen pollution. Globally, the fertiliser industry has a limited number of R&D policies and insufficient budget devoted to nitrogen pollution compared, for example, to the pharmaceutical and seed industries [315].

The 'Knowledge for INMAP' project, developed by the JRC during the year 2021, aimed to gather scientific knowledge and data available in the EU to support the discussion and preparation of the *Integrated Nutrient Management Action Plan* (INMAP). The plan covers all sectors and environmental compartments involved in the nitrogen (N) and phosphorus (P) cycles. The JRC project included the description of the current flows of nitrogen and phosphorus in the EU, considering all sources and sectors involved (agriculture, industries, urban, energy and transport) and all environmental losses in air, water, and soils. It evaluated the distance to environmental targets and analysed the possible measures to reduce nutrient pollution at different intervention points in the nutrient cycle. The project concluded that **nitrogen pollution can be reduced** by leveraging several following enablers [316].

Potential enablers

Nutrients in agriculture

Optimising agricultural practices promoting balanced mineral fertilisation to adjust nitrogen application in areas with a surplus or deficit.

Adopting agroecological practices, including cover cropping, residue management, and agroforestry, to improve soil health and reduce nitrogen losses.

Developing and implementing novel techniques for nutrient recovery from organic waste (e.g. manure, sewage sludge, and bio-waste) and increasing recycling efforts to transform waste into nutrient-dense, safe fertilisers.

Upgrading domestic wastewater treatment to reduce nitrogen discharges into aquatic systems.

Encouraging shifts in dietary patterns to reduce reliance on animal protein, which would decrease nitrogen-intensive livestock production.

Utilising diverse modelling tools to assess impacts, adapt measures to specific regional contexts and integrate multiple measures (e.g. wastewater treatment, emission reduction, and agricultural improvements) to achieve significant reductions in nitrogen losses to air, soil, and water systems.

2.7.3 Participatory approaches and citizen-science initiatives

The assessment of **air quality-related targets** shows that improvements have been achieved, considering the decreasing trends in years of life lost per 100 000 inhabitants for PM2.5 [8]. At the same time, The Environmental Implementation Review [314] notes that in many Member States the limit values for these pollutants are persistently exceeded, leading to infringement proceedings for key pollutants, such as particulate matters and nitrogen dioxide.

In some of these cases, the **Court of Justice** of the EU has already handed down judgments. Infringement cases against two Member States focus on shortcomings in monitoring networks. **Flawed reporting** with incomplete and incorrect assessments of activities also affects water bodies, demonstrating a lack of precise information and knowledge as well as assessment and monitoring capacities in environmental management.

Air pollution and water quality monitoring can be improved by adopting **participatory and bottom-up approaches** and **involving citizens in the monitoring** [313], [313], [317], [318]. Civil society can play an active role in co-producing air quality information. Citizen science practices for measuring air pollution introduce a new dynamic by leveraging citizen-generated air quality data to address the air pollution problem and enhance monitoring efforts. This citizens' active participation can lead to greater **awareness and concern**, and therefore behavioural change and better compliance with air quality standards [314].

In recent years, numerous **cities** have initiated citizen science projects to monitor air pollution, actively involving residents in decision-making processes. For instance, in Gothenburg, locals construct sensors that provide real-time air quality data. Similarly, the 'Curieuzenair' project in Brussels distributed NO_2 tubes to measure air pollution in areas beyond standard measuring stations. These projects not only raise awareness about air pollution among citizens but also empower them to participate in data collection that informs decision-making. Furthermore, cities can enhance public awareness about clean air by highlighting the health benefits of improved air quality. For example, in Krakow, better air quality has been linked to a reduction in children's asthma cases [319].

In the case of water quality, participation in **environmental governance** (e.g. participatory river basin management planning) has improved the environmental outcome and the quality of the *Water Framework Directive* implementation. In particular, an increasing quality of outputs was observed in line with increasing intensity of local participation [320]. It was also demonstrated that citizens are central stakeholders in the development of the UN treaty on plastic pollution [321].
The JRC initiative Gems of Water is another example of citizen engagement for water quality monitoring. It connects local groups concerned with water quality issues around the world to scientists, who provide methodological, technical and analytical support to monitor pollution caused by organic contaminants.

Citizen science also has a clear role to play in monitoring soil health, e.g. in generating data on soil biodiversity, vegetation cover, soil organic carbon and nutrients. A Horizon Europe project called *Engaging citizens in soil science: the road to healthier soils* (ECHO, 2023–2027) has citizen science as its primary focus. The project aims to engage citizens by enhancing their knowledge and interest in soil health, motivating them to protect and restore soils [322].

A review of **citizen science tools** related to **soil** suggests that engagement of citizen can be facilitated through providing feedback protocols on their scientific contribution and assigning qualified mediators or activity leaders to support participants throughout the project [323]. Citizen science approaches have also been applied also in biodiversity-related projects, e.g. for reversing the decline of wild pollinating insects [324] and controlling the invasive species [325]. Despite the demonstrated potential, challenges remain in **legitimising** citizen-generated data as scientific evidence [318]. The most commonly reported barrier to the use of citizen science data and knowledge by academics, research organisations and decision-makers relates to their openness and perceived lack of quality. Measures to enhance the use and the quality of citizen science could include the following ones, as analysed in [326].

Potential enablers

Participatory approaches

Raising awareness of citizen science for environmental monitoring and promote it within public institutions.

Giving visibility and recognition to citizen science outcomes.

Supporting the creation, extension and/or upscaling of pan-European citizen science initiatives in priority areas under the EU green transition ambitions.

Supporting the establishment of open data portals and platforms where citizen science initiatives and public authorities can publish, preserve and curate monitoring data and information.

TOWARDS ZERO-POLLUTION AMBITION Navigator

This infographic helps **navigate the complexity** of the transition for achieving **zero-pollution targets** while delivering on the **EU Competitiveness ambitions**. It presents a non-exhaustive overview of **challenges and enablers**, which are explored in full in the report.

Legend

- Financial / economic challenges
- Political / institutional challenges
- Technological / infrastructural challenges
- Socio-cultural / behavioural challenges
- Potential intervention areas
- Start — Transition paths
- Final milestones

If we go like this, we will achieve major clean transition policies!

*Achieving the **clean environment** ambitions requires an integrated implementation mix, combining* 1 ***systemic pollution governance**, strengthened monitoring, compliance and* 2 ***administrative capacity**, accelerated* 3 ***nutrient and agri-food** chain transformation, and reinforced* 4 ***societal engagement***

Start

INTEGRATED POLLUTION GOVERNANCE

from siloed policy to ecosystem-level management

Implementation ambitions

- Moving from **single-parameter** compliance and **compartments** to ecosystem-based assessment
- Eliminating **policy silos**, achieving better coherence across pollution domain governance frameworks
- Prevent **cross-media burden** shifting in pollution mitigation

Enablers' mix

- Holistic approach — Shift from parameter-based compliance to ecosystem-oriented pressure–impact assessment across air, water and soil
- Nutrient cycle governance — Operationalise integrated nitrogen and phosphorus management across directives to prevent pollution swapping
- One-health — Mainstreaming integrated frameworks (e.g. One Health, Safe and Sustainable by Design) to better integrate environmental and socio-economic sustainability into policy design

MONITORING AND CAPACITY BUILDING

for compliance and overcoming delivery bottlenecks

Enablers' mix

- Monitoring redesign — Link improved and interoperable monitoring networks to corrective plans
- Inspection capacity — Strengthen inspection systems, modelling capacity and enforcement follow-up at national and regional level
- Administrative capacity building — Enhance technical skills in procurement, planning, environmental assessment and reporting across governance levels
- Compliance-driven investments — Target EU and national funds to wastewater systems, nutrient removal, monitoring infrastructure and remediation

Implementation ambitions

- Ensure **monitoring systems are representative**, robust and linked to corrective action
- Close persistent **compliance gaps** in air, water and soil legislation
- Strengthen administrative, technical and **enforcement capacity** across governance levels
- Close the **environmental investment gap** and align investment-infrastructure planning

NUTRIENT & AGRIFOOD CHAIN

Implementation ambitions

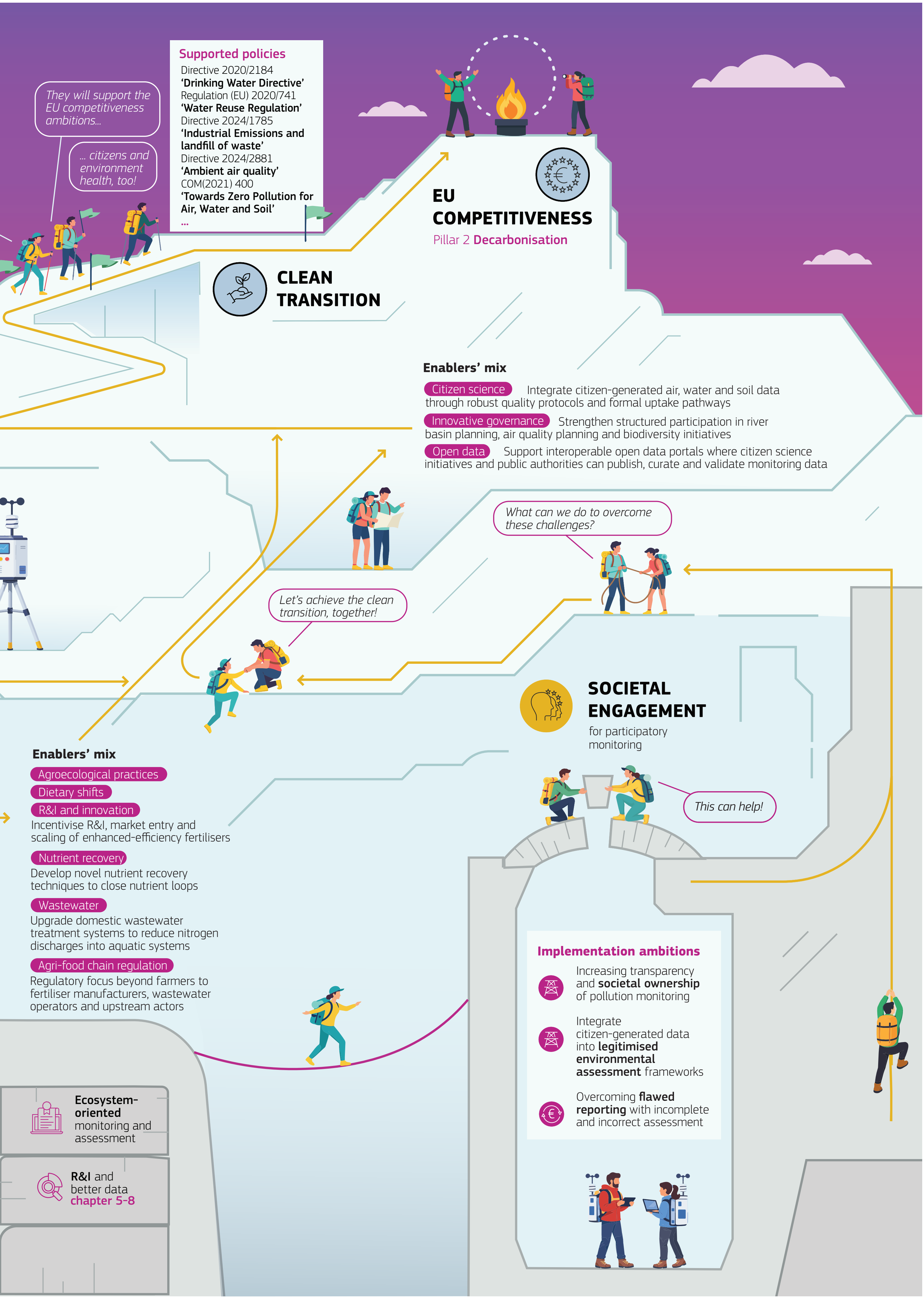
- Reduce diffuse nutrient pollution across the full **nitrogen** and **phosphorus cycles**
- Move beyond farm-level behavioural focus towards **agri-food chain responsibility**
- Ensure measurable implementation of the Nitrates Directive, properly design **vulnerable zones** and **action programs**
- Address agricultural emissions (especially armonia) contributing to **air and water pollution simultaneously**

This way

*These **cross-cutting enablers** will help us go faster...*

CROSS-CUTTING ENABLERS

- **Capacity building** for implementation
- **Financing** the clean transition chapter 6
- **Compliance-driven** investment programming


They will support the EU competitiveness ambitions...
... citizens and environment health, too!
Supported policies
Directive 2020/2184
'Drinking Water Directive'
Regulation (EU) 2020/741
'Water Reuse Regulation'
Directive 2024/1785
'Industrial Emissions and landfill of waste'
Directive 2024/2881
'Ambient air quality'
COM(2021) 400
'Towards Zero Pollution for Air, Water and Soil'
...
EU COMPETITIVENESS
Pillar 2 Decarbonisation
CLEAN TRANSITION
Enablers' mix
Citizen science Integrate citizen-generated air, water and soil data through robust quality protocols and formal uptake pathways
Innovative governance Strengthen structured participation in river basin planning, air quality planning and biodiversity initiatives
Open data Support interoperable open data portals where citizen science initiatives and public authorities can publish, curate and validate monitoring data
What can we do to overcome these challenges?
Let's achieve the clean transition, together!
SOCIETAL ENGAGEMENT
for participatory monitoring
This can help!
Enablers' mix
Agroecological practices
Dietary shifts
R&I and innovation
Incentivise R&I, market entry and scaling of enhanced-efficiency fertilisers
Nutrient recovery
Develop novel nutrient recovery techniques to close nutrient loops
Wastewater
Upgrade domestic wastewater treatment systems to reduce nitrogen discharges into aquatic systems
Agri-food chain regulation
Regulatory focus beyond farmers to fertiliser manufacturers, wastewater operators and upstream actors
Implementation ambitions
Increasing transparency and **societal ownership** of pollution monitoring
Integrate citizen-generated data into **legitimised environmental assessment** frameworks
Overcoming **flawed reporting** with incomplete and incorrect assessment
Ecosystem-oriented monitoring and assessment
R&I and better data
chapter 5-8

03

Environmental impacts of future scenarios

3.1 Integrated environmental assessment based on the Consumption Footprint
3.2 Synergies and trade-offs of environmental impacts across thematic areas: key examples

Key messages

While environmental impact is decreasing in EU territory, demonstrating a decoupling from consumption growth, the **Consumption Footprint**, accounting for international supply chain operating also beyond EU borders, remains far beyond **planetary boundaries**.

Reversing this trend is an unprecedented policy challenge. The greatest area of concern is **consumption**, in particular due to the shifting of environmental impacts beyond EU borders, due to imports.

This quantitative assessment highlights the **positive influence** of clean transition policies on environment, supporting the decoupling of **environmental impact** from consumption growth and keeping impacts at a similar level to that of 2022. These benefits would be largely attributable to the **food sector**, especially due to the implementation of measures to reduce pesticide use.

There are policy opportunities to reduce the impacts in the areas of **food** (sustainable, healthy diets) and **housing** (reduced energy demand via the *Renovation Wave* and related initiatives). However, even if all clean transition ambitions are reached, impacts will continue to rise in mobility, household goods and appliances due to **increasing consumption**.

Mineral and metals resource use remain critical, with similar impacts across all considered scenarios.

Progress on environmental impacts is positive overall but should be **accelerated** to achieve policy targets. The achievement of the European clean transition targets and ambitions considered in this chapter can facilitate EU competitiveness by reducing environmental externalities, resource dependencies and deterioration of available natural resources.

Reducing the environmental impacts of EU production and consumption would reduce the **environmental externalities**, for instance by lowering the costs of mitigating and adapting to extreme weather events linked to climate change, as well as **public health** costs associated with pollution-related diseases.

Improving the sustainability of EU production and consumption can also reduce dependencies on natural resources, thereby strengthening **security** and **strategic autonomy**. It can further ease pressure on available resources by reducing environmental burdens, including soil degradation, which can limit land availability and productivity.

An integrated approach is needed to assess the role of the clean transition in mitigating the environmental impacts of EU consumption and production patterns, accounting for multiple environmental impact categories and adopting a full supply chain perspective. To this end, an integrated environmental assessment based on the **Life Cycle Assessment (LCA) Consumption Footprint and Domestic Footprint** models, provides initial insights into the expected environmental impacts of possible clean transition scenarios by 2030.

The exercise considers selected EGD targets and ambitions, with a focus on physical environmental indicators (Chapter 3.1; Annex III for details). In this study, the clean transition was assessed against the *European Green Deal* targets and ambitions, as evaluated in [8]. These are referred to throughout as Green Transition Targets and Ambitions, following [327]). The analysis shows the importance of **considering synergies and trade-offs across areas** of consumption and environmental impacts. This exercise is complemented by zooming in on selected key examples concerning raw materials, land use and circular economy (Chapter 3.2).

3.1 Integrated environmental assessment based on the Consumption Footprint

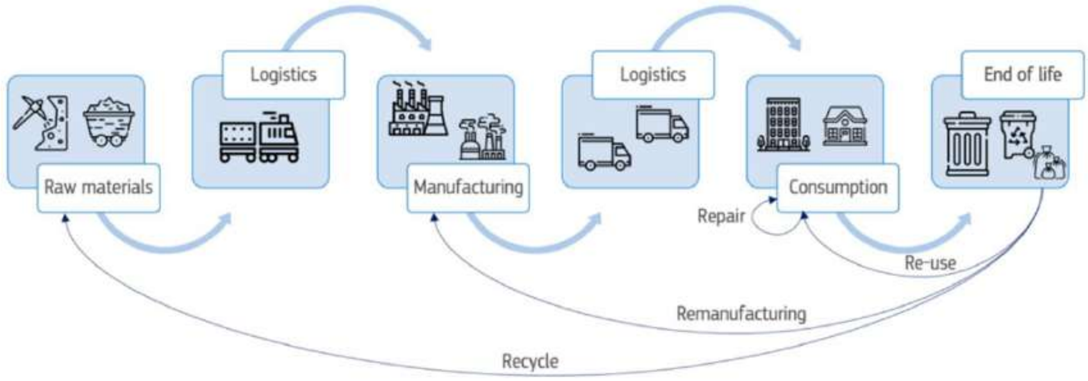
3.1.1 Consumption perspective and effects in global supply chains: the need for a holistic approach

Environmental impacts of products need to be evaluated in an integrated manner along their whole supply chains and including the **entire life cycles** of products, from resource extraction and manufacturing to use and waste generation (Figure 8). This can be done with quantitative systemic impact assessment methodologies such as **LCA** [328]. Through this approach, potential **trade-offs among environmental impacts, life cycle stages of products, economic sectors and geographical regions** can be identified, **thus enabling prevention strategies to avoid the burden shifting of impacts**. For instance, an improvement in energy efficiency in the use phase of a product may require the extraction of more raw materials elsewhere in the value chain [329].

To perform environmental integrated impact assessments, specific models can be designed to exploit the power of data at the EU level and provide sound evidence support to policy. The **Environmental Footprint (EF)** is the LCA method recommended by the European Commission [330]. It takes into account 16 environmental impact categories on air, water, land, resources and toxicity[1].

1 Climate change; Ozone depletion; Particulate matter; Ionising radiation; Photochemical ozone formation; Acidification; Eutrophication, terrestrial; Eutrophication, freshwater; Eutrophication, marine; Water use; Land use; Resource use, fossils; Resource use, minerals and metals; Human toxicity, cancer; Human toxicity, non-cancer; Ecotoxicity, freshwater.

Figure 8. Overview of life cycle stages from raw materials to end of life, including alternative end of life pathways according to Circular Economy strategies.



Source: [327].

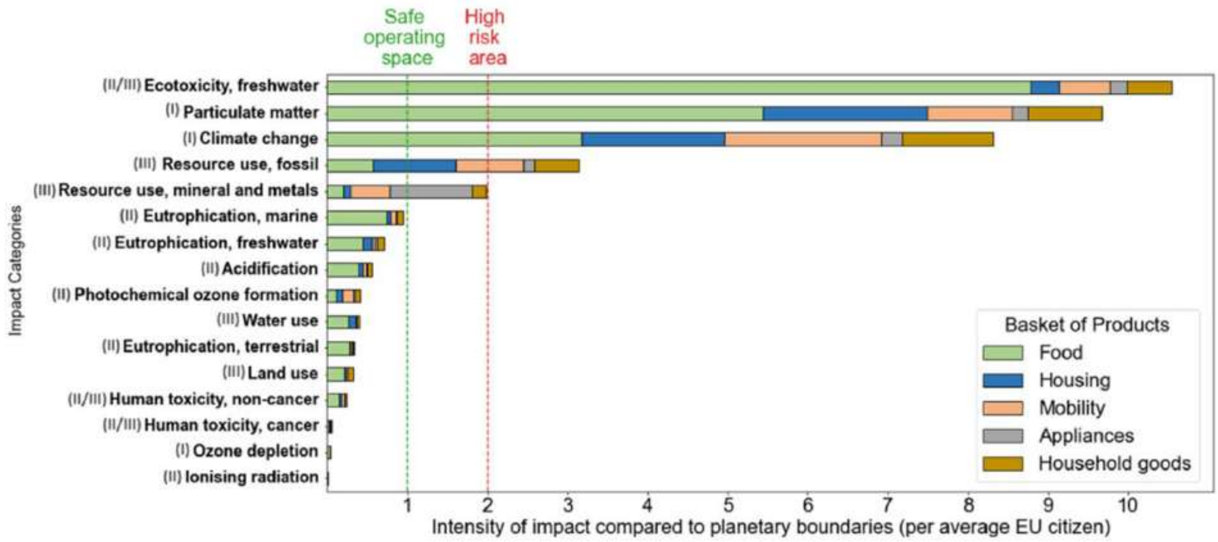
Using this method, the JRC has developed a modelling framework composed of two simulation models analysing EU environmental impacts by adopting complementary perspectives. The **EU Consumption Footprint (CF) model** considers 164 representative products across their **international supply chains** to calculate the environmental impacts associated with EU consumption for five main areas, namely food, mobility, housing, household goods and appliances. In addition, the **EU Domestic Footprint (DF) model** adopts a **production and territorial-based perspective** to assess the environmental impacts associated with emissions and resource extraction occurring within Member States' boundaries, and for the whole EU. For both models, the resulting environmental impacts are derived according to the 16 impact categories of the EF method. These can also be aggregated as a single weighted score indicator, which is currently used for monitoring in different EU policy frameworks. These include the *8th Environmental Action Programme* [331], the *Zero Pollution Action Plan* [332], the EU Sustainable Development Goals monitoring exercises [333], the EU Circular Economy monitoring framework [334], the Resilience Dashboard [335], and the EU Food System Monitoring Dashboard [336]. Data are available in the European Platform for Life Cycle Assessment (EPLCA) [218].

One important strength of the CF and DF indicators is that they can be compared with the nine planetary boundaries framework. **Planetary boundaries** are the safe self-regulating environmental limits for human pressures which together maintain a stable and resilient Earth. The EU's ***8th Environment Action Programme*** (8th EAP) calls for the EU to significantly reduce its consumption footprint by 2030, and to **bring it within planetary boundaries** as soon as possible. In the CF, the 16 EF impact categories have been mapped to the planetary boundaries. Currently, the EU consumption footprint crosses planetary boundaries for 5 out of 16 EF impact categories (Figure 9): ecotoxicity freshwater is exceeded by 10 times, particulate matter by 9 times, climate change by 8 times, resource use in fossil fuels by 3 times, and minerals and metals by 2 times.

Comparing the evolution of the consumption footprint and the domestic footprint in relation to the real gross domestic product (GDP) per capita of the EU-27 for the period between 2010 and 2022 highlights the increasing role of imports in determining the environmental impact of EU consumption (Figure 10, from [337]). While the domestic footprint shows a continuous decrease (-19%) between 2010 and 2022 across all impact categories, thus indicating an absolute decoupling from economic growth, the consumption footprint is increasing (+8%). This demonstrates only a relative decoupling of consumption impacts from growth, as the consumption footprint is growing more slowly than GDP per capita (+16% in 12 years) [338]. This comparison reveals the extent to which the **environmental impacts of EU consumption also occur in third countries**.

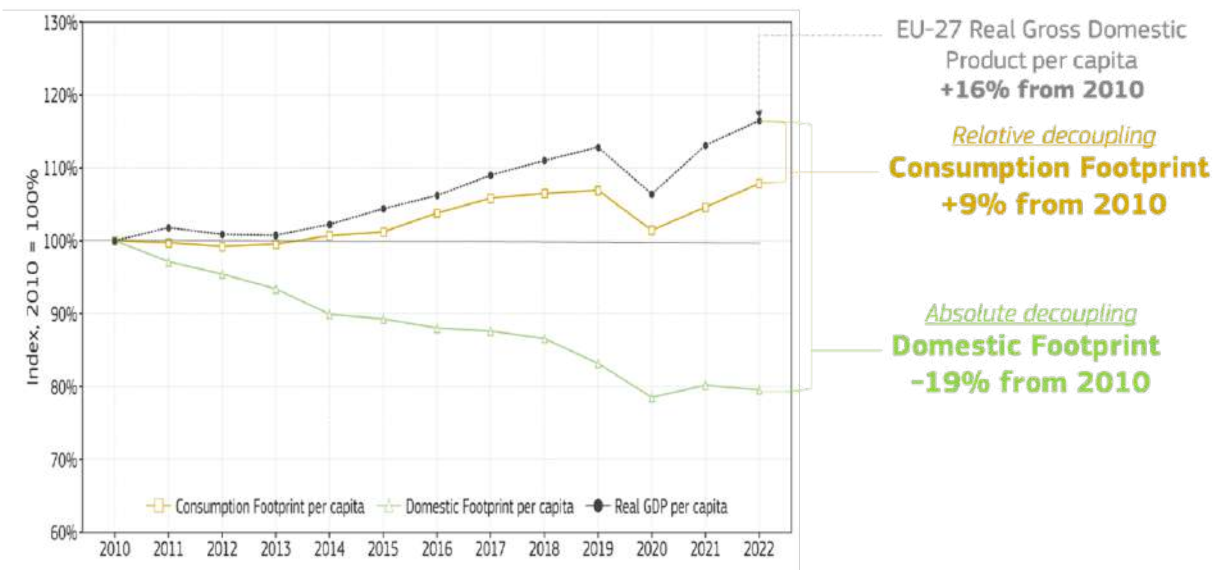
In other words, the **reduction of environmental impacts on EU territory is being offset by delocalised impacts in other world regions** through the supply chain of imported raw materials, intermediary and final products. In this respect, recent pieces of EU environmental legislation have shifted their focus to the EU market rather than to EU producers, switching from a territorial to a consumption approach, namely by setting product requirements to enter the EU market regardless of the origin of production such as the *Ecodesign for Sustainable Products Regulation* [173] and the *Regulation on Deforestation-free Products* [339]. When disaggregating the CF based on the different areas of consumption, it turns out that most of the environmental impacts of consumption are associated with **food** (Figure 11), which appears to represent 49% of the environmental burden in 2022, followed by housing (17%), mobility (16%), household goods (11%), and appliances (7%). The effects of the COVID-19 pandemic are visible between 2019 and 2020, mainly due to the lower use of transport, which has fully recovered by 2022 **with total environmental impacts surpassing pre-pandemic levels**.

Figure 9. Consumption Footprint impacts and the planetary boundaries.



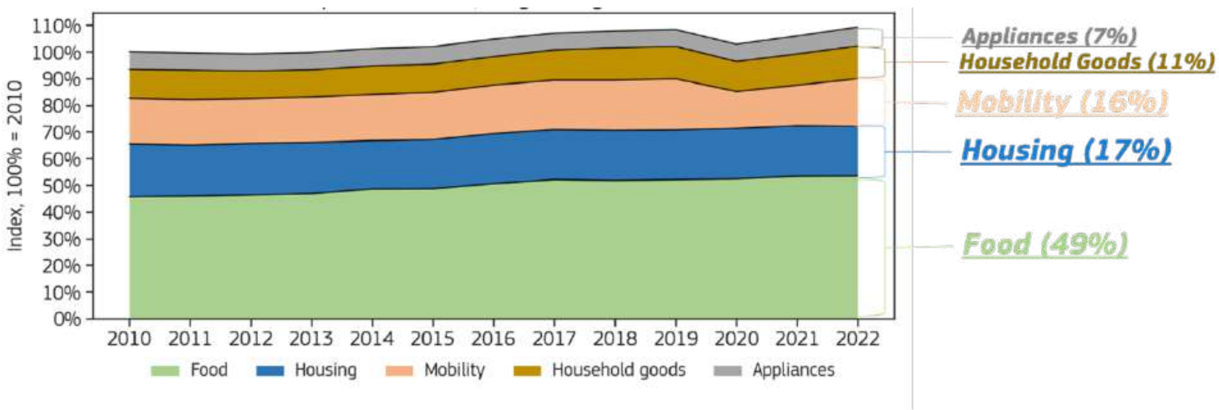
Source: EPLCA [218]. The, model robustness between 'I' (or high confidence) and 'III' (or low confidence) of the impact assessment model used to assess each indicator is available in [332]

Figure 10. Evolution of the EU Domestic Footprint and EU Consumption Footprint compared with Gross Domestic Product per capita index (2010=100%), for the period 2010-2022.



Source: [337]

Figure 11. Contribution of the areas of consumption to the EU Consumption Footprint from 2010 to 2022.



Source: [337].

3.1.2 Description of the future scenarios and key questions addressed in the integrated environmental assessment

Based on the JRC progress report on the EGD [8], targets considered here were progressively included in **three green transition target (GTT) scenarios** that describe increased ambitions in the achievement of clean transition objectives. The scenarios are modelled as follows (Annex III and [327] for full methodological details):

- **No GTT**: this scenario assumes the continuation of existing policy trends before the implementation of the EGD. This scenario provides a reference for the analysis, thus helping to measure the potential environmental benefits that can be achieved by clean transition policies.
- **GTT on Track**: this scenario is based on the production and consumption expected trends and considers all the targets assessed as **"on track to be achieved"** by 2030 in the assessment [8].
- **GTT ambitions**: this scenario expands the scope of the '**GTT on Track**' scenario by assuming the full achievement of **all clean transition targets**, encompassing legally and non-legally binding targets (i.e., binding targets from EU regulations and directives and non-legally binding targets from proposals and communications, such as the *Farm to Fork strategy*) as well as **further** identified **ambitions** (e.g. a change in food diet).

The comparison between scenarios addresses the questions below:
- *What is the expected evolution of the environmental impacts of EU consumption and production by 2030?*
- *How much will the Consumption Footprint change by 2030 if all clean transition targets and ambitions are achieved?*
- *Which are the most relevant trade-offs across areas of consumption, and environmental impacts, to implement clean transition targets and ambitions by 2030?*

These three scenarios have been simulated with the CF and DF models. The drivers of the CF model scenarios are (i) the projections of annual consumption of products by 2030, and (ii) the environmental impacts of products which are modelled at the unit level and can be parametrised to model the achievement (or not) of clean transition targets. A combination of model adaptations, done by editing these drivers for each target, underpins the scenario analysis proposed in this chapter. In other words, in the CF, the changes in environmental impacts are driven by a combination of changes in the annual consumption by 2030, and/or changes in the parameters that influence the relationships within the life cycle inventory of products.

3.1.3 Consumption Footprint in 2030

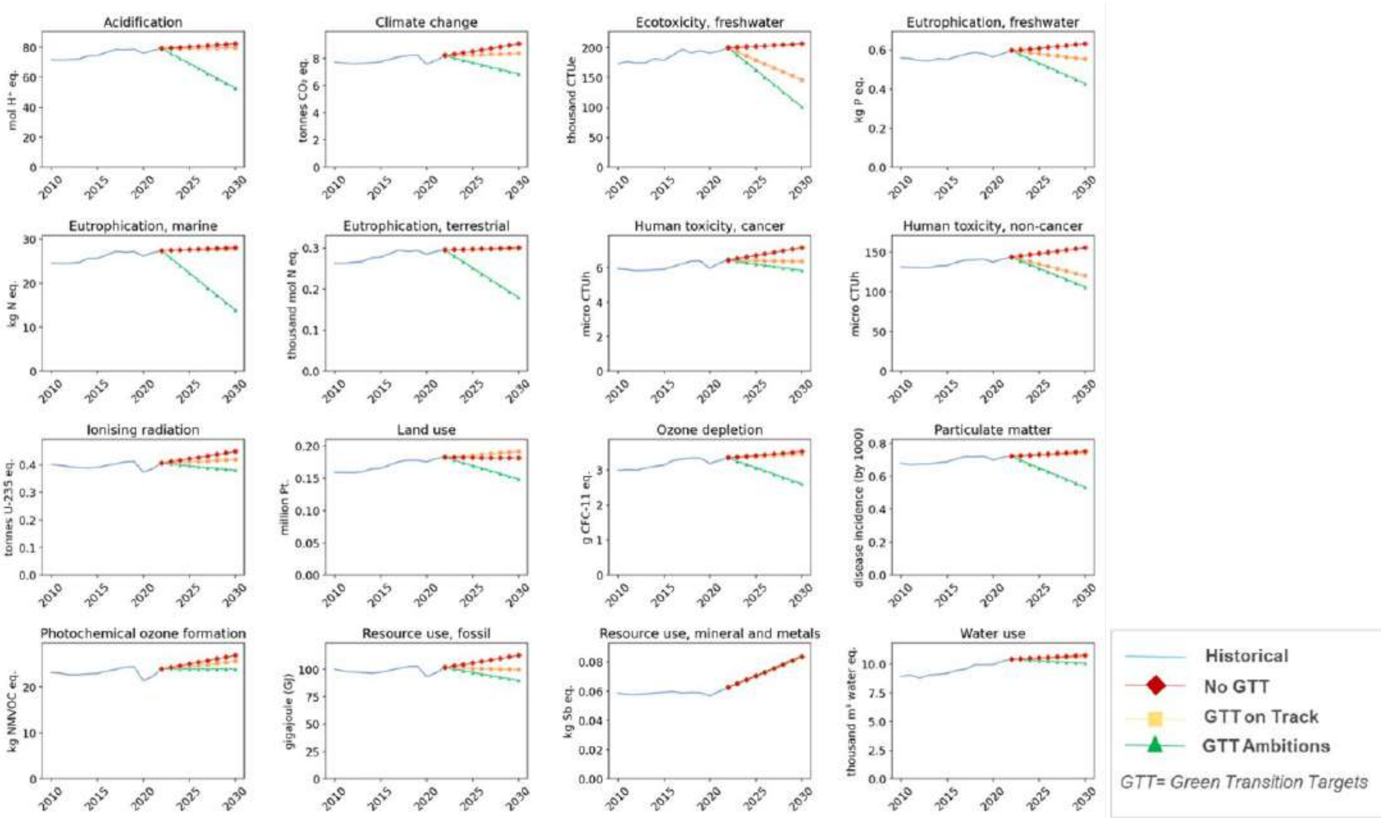
Results indicate that the Consumption Footprint is far **beyond the planetary boundaries for 5 of the 16 environmental impact categories considered**. However, clean transition policies that are on track have significant positive impacts to reduce and mitigate additional increases in the other categories despite economic growth, and the achievement of ambitions could reduce the environmental impacts even further towards the achievement of 2030 clean targets. The areas where the greatest opportunity lies appear to be housing and food while mobility, household goods and appliances are expected to increase their impacts even if GTT ambitions are reached due to increased consumption trends.

How are trends expected to evolve over time?
When adopting an EU territorial perspective, the **DF** shows that environmental impacts are decreasing on EU territory for the period 2010 to 2022, and further reduction is expected even in the **No GTT** scenario thanks to the effects of current macro-economic and political trends including the relocation of industrial plants outside of the EU. These effects are further reduced in the various considered scenarios ([327] for details).

A different perspective emerges with the CF (Figure 12), which considers the full value chain of products by adopting a consumption perspective. As a result, the analysis of this environmental integrated assessment focuses on this area.
Comparing **historical and outlook data up to 2030** of the various impact categories of the **CF**, an upward trend is found. In **GTT on track,** a significant decrease is found in 15 out of 16 impact categories, thus demonstrating the key role of the clean transition policies considered. The effects of fully achieving **clean transition targets and ambitions** provide significant additional contribution to the reduction in environmental impacts. However, the category of mineral and metals resource use would still show a significant increase, with limited impact of clean transition efforts in the three considered scenarios.

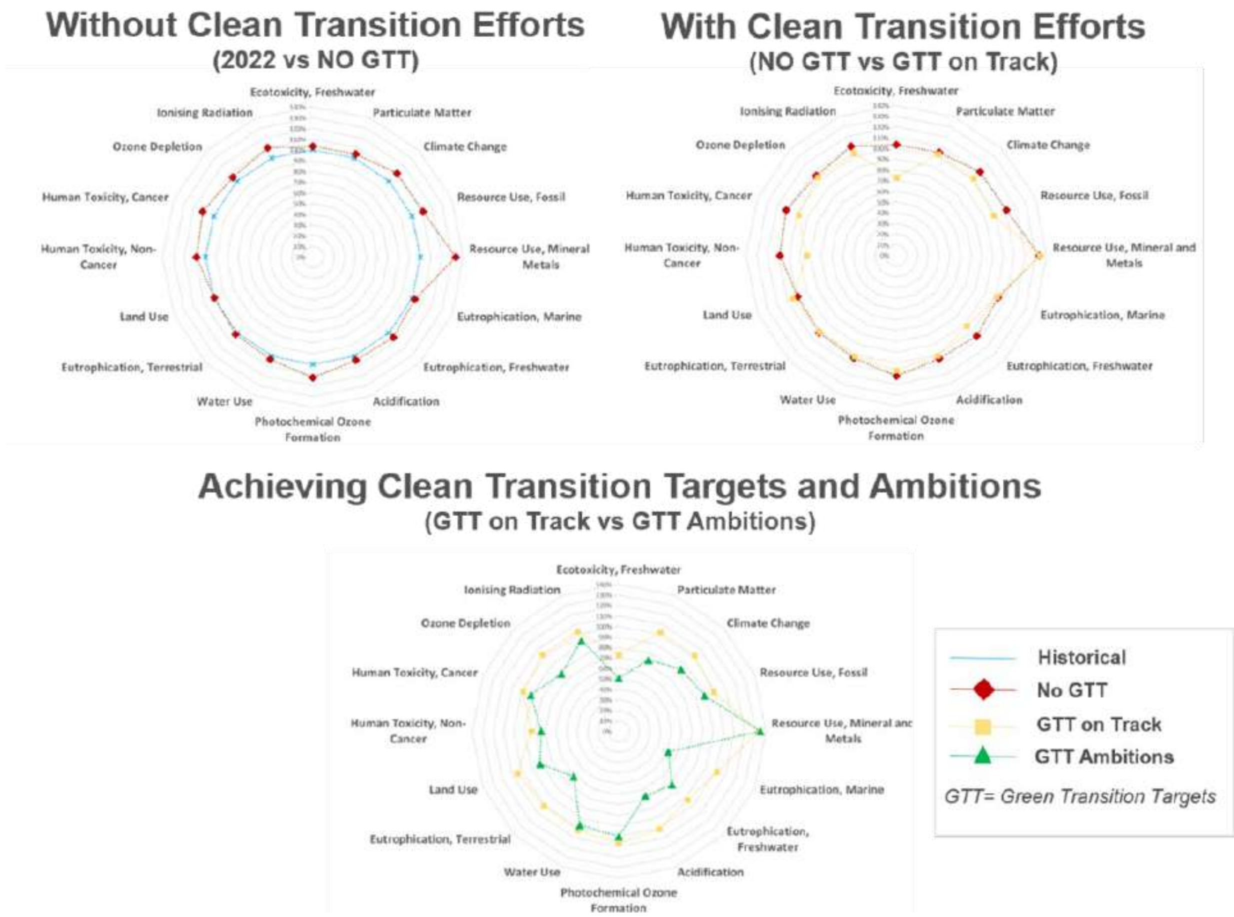
How are scenarios expected to perform in 2030?
Focusing on the situation in **2030** and comparing to the 2022 value (Figure 13), it emerges that **without clean transition efforts** environmental impacts tend to increase mainly due to the growth in consumption. This is true for all areas of consumption taken individually and for all environmental impacts across all 16 EF impact categories (top left quadrant). The greater concern is mineral resource use which is expected to rise by +35% in comparison to 2022. **Clean transition targets on track** (based on [8]) are expected to reduce impacts in particular for toxicity and eutrophication (i.e. from -8% to -30% with regards to **No GTT**, top right quadrant). Trade-offs are visible for land use and mineral resource use due to the strong influence of the energy transition on renewable energy that would require more land for solar and wind power plants, and increased

Figure 12. Consumption Footprint historical data and 2030 outlook in the selected scenarios compared to planetary boundaries



Source: Authors' elaboration based on [327].

Figure 13. Comparison of the three scenarios in 2030 with respect to historical values in 2022.



Source: Authors' elaboration based on [327].
Note: Environmental impact in 2022 =100%.

consumption of motor vehicles and appliances which still require greater consumption of mineral and metal resources. On a positive note, clean transition efforts appear to offset the effects of consumption growth of the **No GTT** scenario, thus **supporting the decoupling of environmental impact from consumption growth** and keeping impacts at a similar level to that of 2022.

On the other hand, there is a large additional opportunity in terms of reduction of environmental impacts that could be generated by **achieving all clean transition targets and ambitions.** This can result in an additional gain of up to -50% (as in the case of eutrophication marine) and generally improve from about 5 to 20% for all the other impact categories. The impact category which remains of concern is **mineral and metal resource consumption**, staying at a similar level in all scenarios (i.e. around +35% against 2022). This indicates that **the shift in the energy transition does not reduce the absolute impact that EU consumption may have on minerals consumption**. Notably, the impact assessment method used for minerals and metals does not take into account material criticality (i.e. considerations related to supply risk or economic importance of the materials) but is based on biophysical resource depletion and potential reduced availability for future generations (for a full description of Environmental Footprint impact categories, see Environmental Footprint Methods - Green Forum - European Commission).

What are the differences between the key areas of consumption?

When looking at the different areas of consumption, it appears that food and housing are the areas where most of the opportunity lies to bring environmental impact towards planetary boundaries, while mobility, appliances and household goods are instead expected to increase their environmental impact.

It proposes these results by area of consumption compared to their relative value in 2022, and in relation to their planetary boundary thresholds. When the environmental impact of an area of consumption is increased, this goes towards the right in Figure 13. When an area contributes to lower impacts, it is shown on the left of the **No GTT** scenario (i.e. no progress towards the clean transition policy), the sum of impacts across the CF areas of consumption is expected to demand between 0.5 to 0.8 additional equivalent planets by 2030 in the context of the five impact categories that exceed planetary boundary thresholds in 2022 (Figure 9).

In the **GTT on track** scenario (based on [8]), the achievement of the targets of reduction in pesticides, alone, could be responsible for substantial reduction of the impact in freshwater ecotoxicity. In addition to this, achieving the targets linked to the expansion of solar and renewables in the energy mix in the housing sector can significantly reduce the impacts (mainly climate change, fossil fuel resource use and freshwater eutrophication) in the use phase (warming or cooling) of houses. Unfortunately, the final results at the CF aggregated level would still result in an increase in the total CF (Figure 12, Figure 13), as the increases in the environmental impact in mobility, appliances and goods would be greater than the reduction obtained by housing.
The **GTT ambition** scenario reveals the greatest impact of achieving ambitions in **housing** via deep renovation (i.e. reduction in energy consumption in buildings), and, most importantly, in **food** via the change towards a more sustainable and healthy diet, modelled as a gradual shift away from high consumption of animal-based products such as beef, pork and dairy towards vegetable-based proteins and higher vegetable consumption overall, based on the EAT Lancet report [340] ([327] for modelling details) - alongside achieving the targets of expansion of organic farming and reduction in nutrient loss.
The latter, assessed as not yet achieved and non-legally binding [8], were included as additional ambitions in the GTT scenario. The sum of these reductions in food and housing areas could reduce significantly the number of times the planetary boundaries are exceeded for climate change, particulate matter and freshwater ecotoxicity, and also reduce the impact generated by fossil fuel.

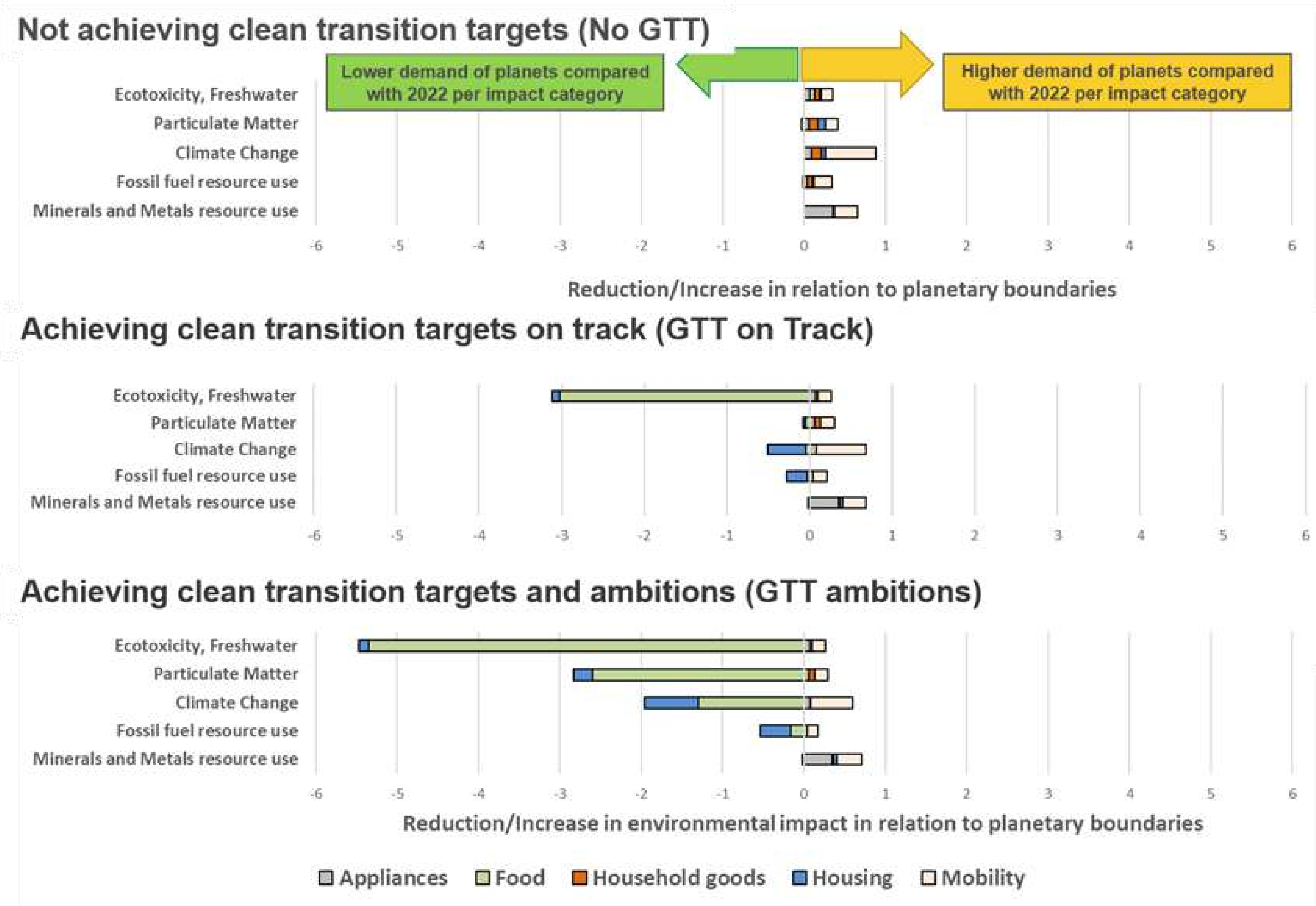
Criticalities remain on the side of minerals and metals resource use, which is expected to increase by a factor of about 0.8 equivalent planets by 2030, even if all clean transition ambitions were to be achieved. It is worth noting that the limited results in terms of appliances, and household goods, are partially due to the fact that product specific EGD requirements are not considered in [8], and not modelled in the present exercise.
These measures, which are specifically addressing circularity economy measures and improved performance of products, could further contribute to the reduction of environmental impacts. However, it should be noted that some of them could be covered by selected modelled targets (e.g. *Renovation Wave* targets modelled in housing, partially consider improved energy efficiency of appliances in use).

An important limitation of this study is that it does not consider the presence of the so-called 'rebound effects', i.e. "induced changes in system behaviour that offset the potential sustainability performance of interventions" [341]. For example, a policy intervention which reduces the impact of a product, may lead to increased demand for that product, thus leading to increased environmental impact in absolute terms. In fact, research shows that 47% of the positive results achieved thanks to sustainability policy are then offset due to rebound effects [341]. **Measures that mitigate rebound effects can be taken along the entire policy cycle**.
The findings of this section are in line with the view that sustainability of production and consumption works in synergy with innovation. On the one hand, moving towards sustainability can drive investments and demand through market differentiation (e.g. being the most sustainable options available in the market). On the other hand, innovation is key to promote sustainability (e.g. R&D) and can generate cascading effects along the entire supply chain. Among these policy interventions, the 2024 *Ecodesign for Sustainable Products Regulation* (ESPR) can promote this shift towards sustainability and innovation in the market.

3.1.4 Assessing bio-based alternatives to the fossil economy

Bioeconomy innovations have been identified as potential contributors to reduce the environmental footprint of the EU consumption, by substituting conventional (mainly fossil) materials, energy and products. A recent analysis by JRC [342] compared the life cycle impacts of fossil- and bio-based alternatives for materials and products, using data collected in an extensive literature review. In general, **bio-based materials** (e.g. plastic packaging or fuel) **show better performance in climate change and fossil resource use impacts, while it can cause higher impacts on other environmental aspects**, such as land use and eutrophication. Generalisations are however hindered

Figure 14. Trade-offs between areas of consumption, by comparison No GTT, GTT on track and GTT ambitions scenarios with 2022 data.



Source: Authors' elaboration based on [327].

by **variability in both scope** (e.g. data from small or laboratory-based experiments) and **modelling assumptions** (e.g. end-of life treatment may not be available for bio-based products) of available studies. Furthermore, bio-based sectors are characterised by **continuous and dynamic innovations**. Available literature is often based on small- or laboratory scale data causing uncertainty for the results related to the **maturity of the technology**. Functional properties of bio-based products, upscaling challenges, and end-of-life fate also need to be assessed.

Illustrative cases were analysed at the **product level** (e.g. by considering the whole packaged product, or vehicle) for bio-based vs. conventional plastic packaging, biofuels, building materials, and plant vs animal-based proteins. Since the **conventional material accounts only for part of the total product life cycle,** impacts are expected to be lower. Further, in case of biofuels, **only a part was assumed to be replaced** considering a possible substitution share of biofuels being always blended with fossil fuels. A considerable exception is plant-based proteins which can decrease the majority of the environmental impact of the animal-based alternative. Finally, potential to decrease environmental impacts **at EU consumption** level by replacing selected materials and products (conventional plastic packaging, biofuels, building materials) was assessed, applying specific replacement rates. Benefits in both **climate change** and **fossil resource use impacts** would occur in all assessed cases which are being relatively greater compared to the impact due to the consumption of other specific material, that is when adding biofuel share in the diesel bus and petrol passenger car fuel mix, as well as when replacing part of the flexible Low-Density Polyethylene (LDPE) packaging film with starch-based packaging film. For the other impact categories, **trade-offs**, such as for land use and eutrophication, would need to be considered.

3.2 Synergies and trade-offs of environmental impacts across thematic areas: key examples

3.2.1 Raw materials production and biodiversity

Raw materials like minerals, metals and biomass provide the foundation for the goods, services, and infrastructure that make up modern socioeconomic systems. They are important for housing, mobility, food, heating, and other human needs, but their extraction, harvesting and processing can generate severe environmental and social impacts. Raw materials are also crucial for the achievement of the EGD targets, including for the *Clean Industrial Deal* and digitalisation objectives; for instance, large amounts of minerals, metals and biomass will be needed for climate-neutral energy generation and storage. According to the assessment performed in Chapter 3.1, resource use is expected to rise by 35% between 2022 and 2035 without considering EGD policy efforts and meeting the EGD targets and ambitions does not appear to help.

In particular, the **demand for minerals and metals intensively present in the renewable energy value chain** is projected to increase sharply. For instance, demand for lithium (which is predominantly extracted in Chile and Australia and processed in China and Chile) could increase by over 150% in a high demand scenario [115].
Concerning the biomass production and uses, resource efficiency is progressing (e.g. increased wood, food and other bio-waste re-use and recycling), but the trend in the biomass used in the EU-27 is increasing from both primary domestic production and secondary sources. The trend is most pronounced for biomass uses for bioenergy, while food uses remain largely constant. Global seaweed biomass production has increased exponentially in the last decades as a result of market demands. The demand for algae biomass has increased because of the development of new algae biomass-based applications (feed and food supplements, nutraceuticals, pharmaceuticals, third-generation biofuel, and bioremediation).
Forest biomass is becoming increasingly relevant for several forest-related policies in the EU, such as the *Bioeconomy Strategy* and *New European Bauhaus*, the *Forest Strategy*, the *Biodiversity Strategy*, the *Renewable Energy Directive*, the L*ULUCF Regulation*, the *Nature Restoration Regulation* and the *Regulation on Deforestation-free Products*.
The use of primary woody biomass has increased, mainly driven by the increased demand for primary woody biomass for material and energy. A slight trend towards an increase in the share of woody biomass used for energy is observed.
The increasing impact of natural disturbances combined with the growing harvest demand may further reduce the marginal share of increment available for wood supply. Moreover, Europe is witnessing an increase in climate variability and climate extremes that have caused a surge of tree mortality and a reduction of productivity. Drought and heatwave interplay with other natural disturbances such as fires and pest outbreaks, multiplying the negative impacts on the forest increment expected in the coming years.

The way forest biomass is produced can have very different consequences for **biodiversity**. For example, removing too much deadwood from forests reduces essential habitats for insects, birds, and fungi, and disrupts nutrient cycles that sustain healthy ecosystems. Similarly, planting trees in areas that were never forests, such as ancient grasslands, often harms species that depend on open landscapes. Even more critical is the conversion of semi-natural or old-growth forests into intensive plantations: these ecosystems host unique species and complex habitats that are largely lost once they are replaced by monocultures. These findings highlight that while forest biomass can support renewable energy goals, certain production practices pose clear risks for biodiversity and should be carefully avoided [343].

The mining sector has **significant environmental impacts**. For instance, there are environmental concerns relating to the mining sector's energy use and emissions of pollutants. Vehicles, dust from explosions and tailing dams can pollute the air and the water. Mine tailings and sulphide-rich waste can lead to water acidification.

Water use for raw materials production, which includes both mining and smelting, is substantial. When operating in regions with water scarcity, mining expansion can exacerbate conflicts for water use and trigger community disputes [344]. About half of the global copper and lithium production, for example, is concentrated in high-water-stress areas [155], [101]. This includes the "lithium triangle", a lithium-rich region with 65% of the world's lithium reserves, in the Andes, encompassed by the borders of Argentina, Bolivia and Chile. In this area, there is a growing

concern that mining activities could significantly impact vital ecosystems and deprive indigenous communities of their essential water sources, exacerbating the desert's arid conditions [345]. The extraction of lithium in Portugal, Europe's biggest potential producer, is expected to degrade freshwater and groundwater quality, and release wastewater and is raising concerns in local communities [346], [347]. **Land uptake** by mining facilities is extensive, as mining areas also include waste dumps, water ponds and industrial processing facilities. Road infrastructure built for mines disrupts natural environments and facilitates accessibility to remote areas for other uses. This causes direct and indirect deforestation, but can also affect other ecosystems such as grasslands, wetlands and aquatic habitats, leading to impacts on **biodiversity that will increase as a consequence of** the increased production of materials needed for the twin green-digital transition.

The site preparation for mine expansion and waste management is a destructive process, changing abiotic and biotic conditions, and in some cases generating region-wide declines in rare and threatened species and ecosystems [348]. Mine tailings - the residue remaining after mineral processing - represent a serious risk to the natural environment, and the failure of tailing storage facilities has caused some of the most serious environmental disasters in history [349]. At the landscapes and regional level, mining can produce direct effects of chemical and physical mining waste discharges, such as dusts and aerosols. These negative impacts can spread over vast distances leaving only the most tolerant species alive.

The impact of mining on **biodiversity** depends on various factors, among them, the mining technique. For instance, the use of reagents to extract and process metal ores often causes greater chemical emissions than the mining of construction materials [350]. Differences also exist between industrial operations and small-scale artisanal mining [351]. Large-scale operations can cause greater harm but equally have greater capacity to minimise damage. Governance is another key factor.
Weak environmental regulations, high levels of corruption and conflict risk are likely to negatively affect biodiversity in mineral extraction areas [352], [353], [354], [355]. Box 1 illustrates the impact of the extractive industry in Africa, and how this can be monitored, using satellite images.
Minimising environmental impacts by improving the circularity and sustainability of critical raw materials supply is a key objective of the EU *Critical Raw Materials Act* [99] (Chapter 4.1).

Box 1. **Protected areas in Africa: pressures from mining**

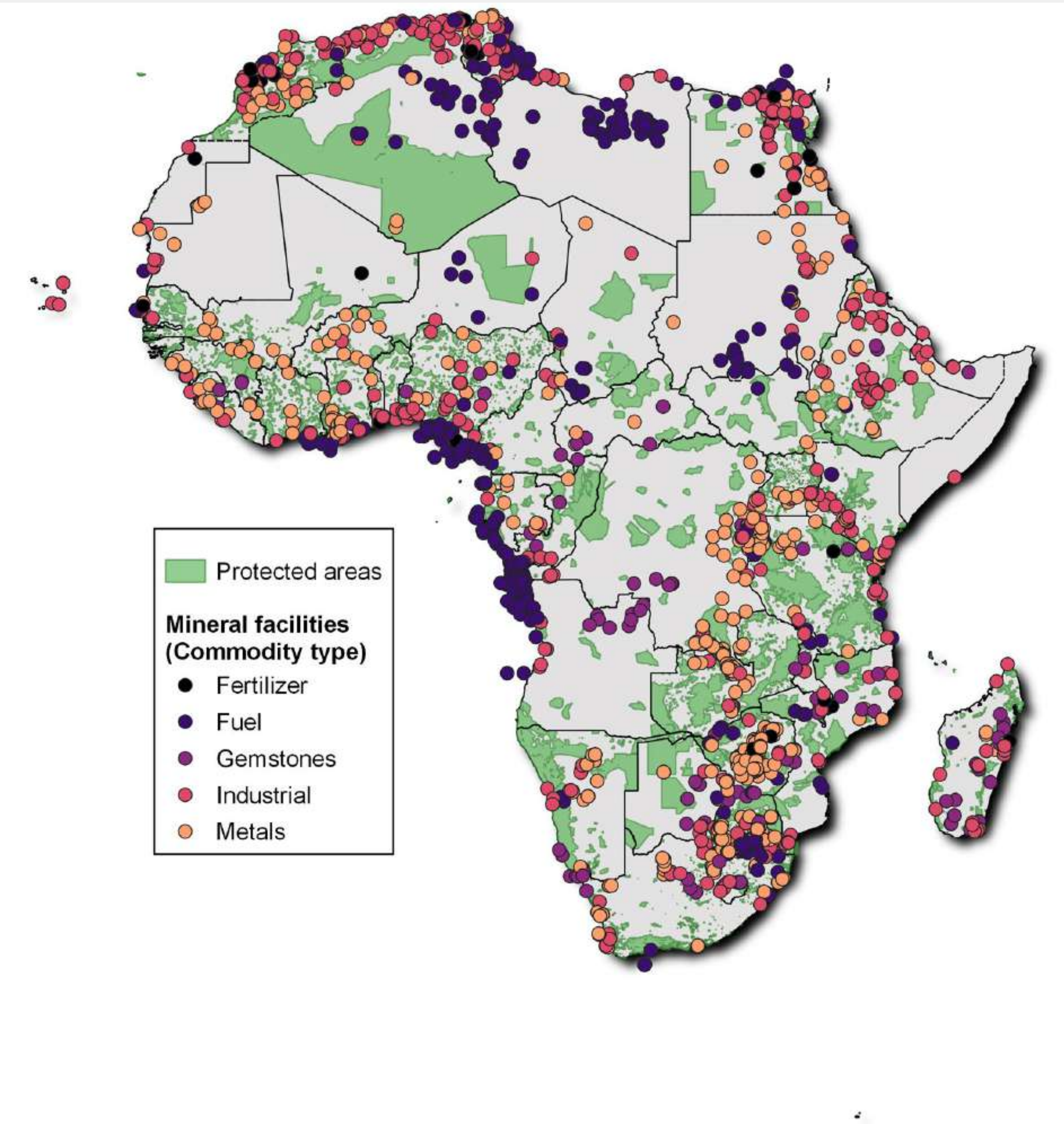
- Mining plays a crucial role in the economies of many African countries, six of which are among the top ten nations on the Mining Contribution Index of the International Council on Mining and Metals. However, the environmental impact of mining is significant at all stages. The discovery of new mineral deposits often leads to increased human settlement and habitat fragmentation. The development of roads facilitates poaching and the spread of invasive species, while excavation and construction during mining operations can destroy habitats and introduce pollutants. Even after mines are decommissioned, they can leave lasting damage, such as unrehabilitated excavation pits and acid mine drainage.
- The global shift away from fossil fuels is driving up demand for the raw materials needed in renewable energy technologies. This has led to mining encroaching on protected areas, key biodiversity zones, and wilderness areas. Many species, including 136 mammals (a third of which are threatened with extinction), have substantial portions of their habitat near mining sites.
- According to the World Resources Institute, the mining-related loss of tropical primary rainforest from 2001 to 2020 impacted 450 000 hectares worldwide, 150 000 hectares were in protected areas, and 260 000 hectares were in Indigenous Peoples' and local community lands. The loss of tropical rainforest is especially concerning because these are some of the most carbon-rich and biodiverse areas of the world. They also help regulate local and regional climate effects like rainfall and temperatures[1].
- African countries, rich in critical minerals, are deeply affected by this trend. For instance, the Democratic Republic of the Congo supplies 60% of the world's cobalt, essential for batteries, with demand expected to increase significantly by mid-century. South Africa produces over 70% of the world's platinum group metals, crucial for fuel cells and digital technologies, with future demand for these metals projected to rise dramatically.

1 see World Resources Institute: Mining is increasingly pushing into critical rainforests and protected areas.

- Mapping the exact locations of African mines is challenging. Official data on mining concessions do not always reflect active sites and often exclude illegal mining. Satellite data tend to underestimate small-scale and underground mining activities. The United States Geological Survey's database indicates that 211 out of 2408 mineral facilities in Africa are located within protected areas. A significant number of facilities are situated very close to protected regions, posing a risk to biodiversity.

- Given the growing global demand for these raw materials, mining in Africa is unlikely to diminish. Therefore, it is imperative to mitigate its environmental impact through integrated spatial planning, enhanced environmental impact assessments, and other measures to protect the continent's biodiversity while supporting its economic engine.

Figure 15. Protected areas in Africa: pressures from mining.



Source: [336].

3.2.2 Land use

According to the integrated assessment results presented in 3.1, the impact on land use is expected to rise by 5% in the current trajectory, mainly due to the expansion of solar energy in the energy mix. The shift towards a sustainable and healthy diet, as well as reduction in energy consumption in housing through the *Renovation Wave* are found to be key potential measures for the reduction of these impacts.

Land management offers significant potential for **advancing EU climate and biodiversity objectives**. However, achieving these goals requires an assessment of trade-offs in land use to avoid unintended negative impacts.

Land performs many vital functions, supporting biodiversity and ecosystem services, including food production, pollutant filtration, natural hazard protection, and carbon sequestration. Changes to land use can thus have diverse impacts.

EU land use is shaped by **several anthropogenic drivers**: food and fibre production, biomass for bioenergy, carbon storage, expanding housing needs, and infrastructure development for mobility. Additionally, land use is influenced by indirect factors, including water needs, fertilisers, and pesticide use for biomass production, each carrying substantial environmental consequences.

"**Marginal lands**," often defined as underutilised or low-yield areas, represent a contentious solution for increased biomass production due to their multiple existing ecological benefits. Marginal lands have been defined in various ways [357], which allows stakeholders to approach these areas as potential solutions for **different purposes**. Primarily, they are considered for industrial biomass production using low-input systems [358] that also improve soil carbon sequestration [359], reclaim saline soils [360], or remediate soils contaminated with heavy metals [361]. Additionally, marginal lands are seen as a potential carbon mitigation strategy, functioning as carbon sinks irrespective of biomass output.

While marginal lands could **provide local biomass**, with minimal competition against food production, altering their use may **reduce the ecosystem services** highlighted in Box 2. For instance, converting marginal lands to biomass plantations may boost carbon sequestration in the short term but could introduce emissions from land preparation and harvesting activities, impacting soil biodiversity and local ecosystem services. Moreover, the use of marginal lands overlaps with high-nature-value and forest areas, adding to the complexity of land use decisions.

Box 2. **Key facts and figures on EU marginal lands**

- **Total area**: 600 thousand km2 (60.7 Mha)
- **Total carbon sequestration**: 28 million tonnes of carbon, which is 11% of the total in EU-27
- Marginal lands **purify** a total of 2.3 million tonnes of water, which is 12% of the total in the EU-27
- Marginal land retains a total of 1.2 billion tonnes of **soil**, which is about 14% of the total soil retention services in the EU-27
- The **pollination** potential includes 61 thousand km^2 of the total 600 thousand km2 marginal lands.
- Marginal lands help to control **flooding** events, offer opportunities for daily outdoor recreation activities and can support pollinator insects.

In conclusion, land use change usually entails trade-offs between different benefits. Alterations to land should consider the pressures that will be put on land systems (which include the environmental, social and economic dependencies on land), as well as the trade-offs in ecosystem services. It is important, therefore, to study land use, land cover and land systems change from a holistic perspective to assess the full and long-term environmental implications of land use policies.

Land use policies should prioritise a holistic, long-term perspective that balances the environmental, social, and economic pressures on land systems. Ecosystem services - ranging from biomass production and pollutant filtration to habitat maintenance - should guide land management, recognising the multifunctionality of all land types. Marginal lands require careful consideration to ensure they are not prematurely earmarked for production without assessing the full ecosystem service trade-offs entailed.

3.2.3 Circular economy and climate mitigation

The **circular economy** contributes to climate change mitigation by redirecting material flows. In particular, it enhances the **recirculation of material into new material cycles**, within production and consumption systems. Drawing from scientific literature, the three main clusters of CE strategies which enhance material loops are [362]:
- **Reduction** (narrowing the material loops by reducing demand, e.g. by demand reduction at production or consumption level).
- **Reuse** (slowing material loops, by e.g. reuse or repair).
- **Recovery** (closing material loops, e.g. by recycling or other forms of recovery).

While reduction and reuse strategies (in all their possible forms), ultimately lead to a reduction of the overall material demand (primary and secondary), recovery strategies decrease primary material demand only under the assumption that a well-functioning market for secondary raw materials exists (i.e. secondary materials are absorbed by the market to displace primary materials).
The 2040 EU Climate Target Impact Assessment showed that around 25% of EU GHG emission reductions by 2050 relative to 1990 levels can be achieved through the more efficient use of resources in production, such as reducing demand for primary production by extending the lifetime of products, encouraging their sharing, reuse and recycling, and substituting primary raw materials with secondary raw materials [363], [364]. In addition, by successfully applying EU waste legislation [365], [366] across the EU27+UK, the cumulative reduction in GHG emissions could be up to 139 Mt CO_2eq per year from 2035 onwards [367], i.e. an additional reduction of 3.2% relative to 1990 levels. These could increase up to 171 Mt CO_2eq per year, around 4% relative to 1990 levels, if even more ambitious waste legislation is enforced in the future [367].

More **ambitious measures** could further increase the **potential of the circular economy to cut global emissions by 39%** [368] and in the **EU by up to 50%** [369]. Other studies confirm these estimates or show even larger potential (based on a literature review conducted as part of the JRC RecalibrateCE project). For instance, Material Economics [370] has found that up to 234 Mt CO_2eq can be saved per year in the EU by 2050 (compared with a baseline scenario of no action), when combining material recirculation, product material efficiency and circular business models and applying these to steel, plastics, aluminium and cement industries across two major end-use sectors (passenger cars and buildings). Demand-side measures could contribute more than half of the emissions savings to net-zero and, in the majority of cases, the circularity measures applied to these sectors are economically attractive.

In their report "ReShaping Plastics", SYSTEMIQ [371] assessed six different scenarios with different CE actions in the plastics sector covering packaging, household goods, automotive and construction, which represent around 75% of the total EU plastic demand in 2022. The scenarios range from a business-as-usual scenario without policy intervention and a current policy scenario, to a circular scenario (78% circular), a retrofit scenario assuming carbon capture and storage and renewable energy sources, and a net zero emission scenario. The authors estimated that the plastic 'circular scenario' can reduce GHG emissions by 67 Mt CO_2eq in 2040. GHG emission reductions in the plastic can reach up to 60% in 2050, relative to 2020. Le Den et al. [372] focused on steel and cement, concluding that the combined effects of CE actions for steel and cement can bring an overall reduction potential of 130 Mt CO_2eq per year, a reduction of 61% relative to 2015. Furthermore, Zibell et al. [373] investigated the impacts of hypothetical CE measures[2] across nine end-use sectors (textiles, construction, packaging, electronics, automotive, aeronautics, food, furniture and batteries) and five intermediate sectors (cement, steel, aluminium, chemicals and plastic) against a baseline scenario [374]. The study concluded that CE measures can save up to 509 Mt CO_2eq per year on average in the period 2020-2050.

Therefore, implementing existing policies related to CE strategies is anticipated to yield significant climate change reductions in the future, relative to a no-action scenario. However, significant margins for improvement remain. It can be argued that the first circular economy cluster, material reduction at production level, may potentially be tackled in the context of energy efficiency and decarbonisation policies, as well as company-driven process optimisation. By contrast, behaviour-oriented demand reductions (by consumers), along with reuse and recovery strategies, require legislative interventions, since benefits incurred at environmental (or societal) level most often do not correspond to economic benefits for the different actors involved in product

2 Hypothetical CE measures classified as: i) reduction of the service level, e.g. smaller house; ii) reduction of the stock of assets (increase usage intensity, e.g. via longer life); iii) reduction of the flow of primary non-renewable materials – e.g. substitution of material by more efficient one, reduction of max, increased share on renewable material or recycled content).

(thus material) supply chains. Several examples could be cited here, a prominent one being the externalised costs of waste management incurred by society, as exemplified by UNEP [375]. Correcting for these external costs or market failures requires measures that span entire material life cycles, from the design phase to use and end-of-life.

Additional potential of circular economy to mitigate GHG emissions in steel, aluminium, cement and plastic sectors

The **JRC RecalibrateCE** project [362] assessed the impact of **CE levers on the environment** (pollution, resource use) beyond **climate change, economy** (e.g. investment and other costs, economic output, industrial competitiveness), and **employment** across **four** carbon intensive material sectors - **steel, aluminium, cement and concrete, and plastics**. Results show that the *additional* potential of the CE to mitigate GHG emission - on top of what would result from the implementation of CEAP and from the contribution of the energy transition towards a cleaner energy mix, including carbon capture and storage of hard-to-abate industrial emissions - is significant. For example, in the **steel** sector, enhancing quality recycling can abate up to an additional 3Mt CO_2eq per year relative to no-action. Implementing more ambitious CE levers (a combination of **Reduction, Reuse, and Recovery**) can lead to **GHG emissions reductions of 64-81Mt CO_2eq per year** [362]. In the **cement and concrete** sector, reducing the use of clinker as well as the overuse of cement and concrete offer the highest reduction potential.

About **29Mt CO_2eq per year can be avoided** when implementing **CE reduction strategies**, whereas the total savings of additionally implementing **Reuse and Recovery** strategies are between **38-47Mt CO_2eq per year**. The combination of all CE strategies can lower GHG emissions by 38-45% in the cement and concrete sector by 2050, on top of the reduction stemming purely from decarbonisation efforts [362]. Considering spillover effects in other sectors and countries, annual emissions can be reduced by 52 Mt CO_2eq In the **aluminium** sector, levers focused on **Reuse** show the greatest reduction potential. Applying this bundle of levers would result in additional abatements **up to 11Mt CO_2eq per year** relative to business-as-usual (defined as the continuation of historic CE trajectory with decarbonisation of energy), with **recovery levers** still representing an easily accessible reduction with potential additional **reductions of 6Mt CO_2eq per year** relative to business-as-usual. An additional abatement can be achieved when simultaneously implementing levers **on reduce, reuse, and recovery** - between **12-14 Mt CO_2eq per year** -, on top of the reduction related to decarbonisation only [362].

Reducing the final demand for **plastic** packaging and extending the life of plastic products and components (e.g. in construction and vehicles) could deliver a reduction of 29 Mt and 15 Mt CO_2eq per year, respectively. At the plastics end-of-life stage, increasing recycling capacities and yields for chemical and mechanical recycling can deliver GHG emission reductions of up to 48 Mt CO_2eq per year. Finally, by applying a combination of ambitious measures of **plastic demand reduction, reuse and recycling**, a **GHG emission decrease of 45% can be achieved by 2050**, on top of the reduction achieved by the anticipated energy decarbonisation efforts [362]. Overall, when compared to current emissions, the **savings from the circularity scenario are almost double** those of the future decarbonised baseline (noting that savings are not summative, as there may be overlaps across sectors).

04

Section C
Compass Pillar: Reducing dependencies and increasing security

Reducing excessive dependencies and increasing resilience

Key messages (1)

The availability of **biological and mineral resources** and the restoration of sustainable and regenerative ecosystems are essential elements for a successful clean transition. Strategies to ensure sustainable and resilient economies include, nature-based solutions, agroecological and regenerative farming systems, climate adaptation, and international cooperation.

The EU's increasing demand for **Critical Raw Materials** (CRMs) poses significant challenges, as CRMs are often supplied by a limited number of countries and companies, making the EU vulnerable to supply disruptions and price volatility.

The ***Critical Raw Materials Act*** (CRMA) aims to address supply risks and strategic dependencies. Its effective implementation will require attention to: recycling; material-disaggregated data for the entire value chain; stakeholder engagement and social considerations; the promotion of sustainable practices and competitiveness; and global partnerships and due diligence to ensure sustainable practices within and outside the EU.

Many **bioeconomy solutions** rely on **biomass**; careful assessment of sustainable biomass availability is therefore essential to avoid environmental degradation and ensure long-term supply sustainability.

Nature-based solutions and **agroecosystems regeneration** hold significant potential for sustainable development and are fundamental to the clean transition. Carbon farming and ecosystem restoration, for example, can help address societal challenges such as food insecurity and inequality while mitigating environmental challenges including climate change.

Agroecological and **regenerative farming** approaches can help reduce agriculture's environmental footprint while maintaining food security.

Reducing greenhouse gas emissions remains urgent to avoid crossing the **critical climate thresholds**. However, as the climate is already changing, adaptation is equally a matter of public health and social resilience, and standardised assessment of adaptation needs and benefits is needed.

Key messages (2)

The EU's clean transition has a strong external dimension: as a major **importer** of energy, raw materials, food and manufactured goods, it must strengthen its resilience to **external shocks** while reducing, rather than shifting, environmental and social burdens along global value chains.

Effective multilateralism and EU external instruments are essential to address global challenges: delivering on the Paris Agreement, the Kunming–Montreal Global Biodiversity Framework and the 2030 Agenda depends on international cooperation supported by tools such as NDICI–Global Europe, Global Gateway and Team Europe Initiatives.

Clean energy and transport partnerships with third countries can enhance security and competitiveness, but they must be designed to avoid new strategic dependencies and a "decarbonisation divide", where benefits and burdens are unevenly shared.

Global value chains for raw materials and circular economy activities, including waste and secondary material exports, need to be managed carefully to prevent shifting pollution and health risks to countries with weaker regulatory and enforcement capacity.

Highly globalised **food systems** require both **resilience and fairness**: reducing reliance on high-impact feed imports, ensuring that stricter EU standards do not exclude smaller producers, and aligning agricultural support with climate, environmental and development objectives are key priorities.

Biodiversity loss and pollution are cross-border problems that require shared solutions; EU measures such as the *Deforestation-free Product Regulation*, support for deforestation-free value chains, biodiversity partnerships and global chemicals and pollution agreements seek to lower the EU's external footprint while supporting sustainable development in partner countries.

The clean transition requires a holistic approach that integrates multiple strategic cross-cutting areas to achieve a sustainable, regenerative, and resilient economy that prioritises the well-being of both people and the planet, restoring natural resources and preserving the environment. To succeed, **the potential of innovation, technology, and sustainable practices and their integration must be fully leveraged to drive growth, create jobs, and improve well-being**.
This chapter examines some of the essential cross-cutting enablers for a successful clean transition in all the thematic policy areas involved in enhancing EU strategic autonomy and resilience, including the availability of raw materials (minerals and metals, as well as sustainable biomass), and a resilient, sustainable and regenerative environment. Ensuring resilient supply chains also needs to go hand in hand with strengthening international collaboration on global challenges and the domestic development of climate adaptation solutions.

4.1 Critical Raw Materials for the clean and digital transition

The EU needs to prepare for an increase in demand for Critical Raw Materials (CRMs) as a key enabler of its future competitiveness, in relation to both its digital transition and green transition.

The **EU's energy transition**, the decarbonisation of strategic sectors (e.g. industry and transport) and digitalisation are increasing demand for raw materials, including many that are already classified as 'critical', i.e. provided by a limited number of countries or companies, and therefore carrying a high risk of supply disruption.

Demand for CRMs (such as germanium, gallium, lithium, cobalt and graphite) is expected to increase in the coming decades. For instance, future demand for several rare-earth elements (neodymium, praseodymium and dysprosium, among others) will grow as a result of their use in permanent magnets for EV motors and wind turbines [376] which, in turn, are key components of several major EU policies away from imported fossil fuels. CRMs are also linked to supply chains in the EU and beyond, associated with key economic sectors, including for the **digital transition**. The digital transition is also a major driver of CRM demand, as materials such as gallium, germanium, rare earth elements and tantalum are essential for semiconductors, data centres, telecommunications infrastructure, consumer electronics and other digital technologies underpinning the EU's digital transformation.

The EU's hydrogen industry faces some key challenges associated with limited EU resource supply, global dependence both for raw and processed materials and precious metals constraints (e.g. iridium supply is a bottleneck for large-scale deployment). **Electrolyser production** requires more than 40 raw materials (including CRMs, such as iridium and palladium) and 60 processed materials. Trade restrictions (e.g. Chinese trade restrictions on tellurium, tungsten, molybdenum, bismuth and indium in 2025) can disrupt supplies and increase prices, whilst geopolitical tensions can intensify as a result of both rising demands and trade restrictions. The exact implications for EU industries are being examined, considering both direct use and uses outside of the EU that could affect key strategic sectors in the EU.

To help address supply risks and dependencies, in 2024 the EU adopted the ***Critical Raw Materials Act*** (CRMA) [99]. It promotes sustainable raw materials production and enhances circularity, while aiming to mitigate adverse impacts within the EU and in third countries with respect to labour rights, human rights and environmental protections. This chapter explores major challenges linked to CRM extraction and processing, highlighting enablers for meeting the targets under the CRM Act to increase resource security and enhance EU competitiveness.

Key insights are presented in the *Critical Raw Materials Navigator* (p. 139).

Geopolitics and autonomy

Several **key risks linked to CRM supply** can impact global trade and security, such as the concentration of resources among a few countries and companies, potential disruptions in global supply chains, and geopolitical tactics. First and foremost, the EU relies heavily on third countries for the supply of CRMs and/or for components containing them. For instance, 77% of the world's lithium supply is extracted in Australia and Chile, whilst 56% is processed in China and 32% in Chile. China also dominates the extraction and processing of praseodymium, terbium, neodymium, dysprosium (used for permanent magnets used in EVs and wind turbines) and gallium (used in electronics and solar panels). 73% of global boron reserves are concentrated in Türkiye, and are used in glass and fiberglass, alloys and metals, fertilisers and insecticides. China (37%), South Africa (11%) and Russia (7%) are major suppliers of raw materials for electrolysers, whilst the EU only produces 2%. Even though the EU increases its share in the steps towards the final product in the electrolyser value chain, it does not go much beyond a fifth of the global shares for processed materials and a third of the necessary components. **Natural resource shortages**, like water scarcity, are also seen as threats to CRMs production [377].

Recovery and recycling of CRMs

Circularity can play a key role in enhancing resilience and reducing dependencies on CRM imports.

Secondary raw materials currently only meet a modest fraction of EU demand, and this will take time to change. Whenever it happens, it will depend on several factors, including technology issues, the feasibility of separating/recycling and economic advantage. Certain value chains/sectors, such as automotive, batteries, consumer electric and electronic goods are key for the recovery of CRM. Even though the CRMA contains various articles to increase circularity and other legislative measures aim to increase CRM recovery and recycling from end-of-life vehicles [378] and batteries [160], CRMs recovery from WEEE is still characterised by high losses during collection, pre-processing and recycling processes (e.g. absence of recycling processes at industrial scale for neodymium) [165].

Several opportunities for enhanced circularity and increased strategic autonomy arise. For instance, waste generation from PV modules is expected to grow exponentially (i.e. from 45,000 tonnes in 2016 to 1.7-8 million tonnes globally by 2030). PV modules contain CRMs, precious metals (e.g. silver) and highly energy intensive materials (e.g. silicon wafer) that are worth recovering and/or reusing [379]. These are listed under the *Waste Electrical and Electronic Equipment Directive 2012/19* and are, therefore, subject to recovery and preparation for re-use and recycling targets (85% and 80%, respectively). However, these targets are mass based and, in the case of PV modules, do not encourage the development of efficient recovery of materials present in smaller traces [380], thus missing an opportunity for the recovery and recycling of critical and precious materials (e.g. silicon). Furthermore, **waste legislation** should be coupled with **product design considerations**, as it is necessary to know the material composition of the PV modules placed on the market [158], [381].

Recycling requires high upfront investments (Chapter 2.3), and the low profitability of CRM recycling can act as a major barrier. Nevertheless, the increasing value of some scarce metals, such as indium or tellurium, may eventually justify the investment in large-scale recovery and in the recycling of certain electronic items (e.g. touch screens) [165].

CRMs extraction capacity in the EU

In addition to setting an extraction capacity benchmark, the CRM Act also aims to provide "strategic projects" with expedited approval processes to boost CRMs production. This can raise environmental and social concerns, as the opening of new mines can lead to impacts on **ecological systems** and conflict with environmental protection policies, such as the *Nature Restoration Regulation* (Chapters 2.6 and 3.2.1). On the other hand, if demand is met by supply from third countries, impacts might be even greater. In the case of metals, exploiting lower grade deposits of minerals (i.e. mineral deposits with lower concentrations of the desired mineral or metal) will require increased processing and might result in the risk of partially offsetting the climate change targets and other environmental targets as well as vital ecosystem services. Furthermore, **energy consumption** for extraction and processing of CRMs is a major environmental consideration. Shifting towards more efficient operations based on best technological practices and using renewable energy sources in the production processes could reduce related impacts; offsetting increases in energy use associated with increased demand, including for raw materials that require additional processing. This can also be a competitiveness opportunity, facilitating costs reduction through efficiency and use of lower cost energy sources. Lastly, **social opposition to mining** activities and a lack of **public acceptance** or impacts on local communities can delay or derail projects. This might be due to the limited public awareness of the social and environmental impacts associated with increased CRM extraction and processing in extra-EU regions, which usually have lower standards. At the same time, society wants renewable energy, digitalisation, and healthcare devices, among others. Equally, this demand will be met, even if extraction and processing are not based in the EU, thus increasing exposure to potential supply risks, lowering competitiveness (hence, reducing jobs and welfare in the EU), and potentially exacerbating other global issues (such as climate change).

Ensuring that materials imported from thirdcountries are produced in a sustainable and responsible manner

Given the growing materials' demand, a certain level of **international supply** will continue to be essential to fulfil the EU's materials needs. Some imports come from developing countries with low governance capacities. In these regions, the extractive sector can have severe environmental and social impacts, such as deforestation, pollution, and violation of human rights, particularly in artisanal and small-scale mining (ASM) sectors. ASM, while providing livelihoods to millions, operates largely informally, increasing vulnerabilities to exploitation, resource mismanagement, and the perpetuation of conflicts in resource-rich areas [382], [383].

For some CRMs, the extraction sites are in areas of conflict and political tensions. Materials extraction in such areas can further contribute, directly or indirectly, to armed conflict, gross human rights violations and barriers to socioeconomic development. Regulations, such as the ***Conflict Minerals Regulation*** and the ***EU Batteries Regulation*** [160], enforce **due diligence in sourcing**, emphasising transparency, risk management, and sustainability. Both regulations mandate third-party audits and public reporting to enhance accountability and support responsible sourcing practices. The *Corporate Sustainability Due Diligence Directive* [384] extends these principles across corporate value chains, aiming to foster responsible business practices globally. Enhanced international cooperation is key (Chapter 4.5).

4.2 Sustainable use of Biomass

Biomass plays a central role in achieving the clean transition and EU political priorities, supporting economic growth, and addressing pressing environmental and climate challenges [385].
As a fundamental resource, biomass underpins the EU's environment, economy and society, providing energy, food, materials and a wide range of products, while also supporting essential ecosystem services [385]. However, biomass is a **finite resource**, primarily sourced from ecosystems that require careful maintenance and protection to ensure their long-term health, resilience and regenerative capacity. Because the bio-based economy brings together all activities that produce, transform and use this finite resource, Europe's clean transition recognises it as both a driver and an outcome of a greener, fairer European economy.
As indicated in Chapter 5.3, the *EU Bioeconomy Strategy* defines the bioeconomy as activities that 'deliver sustainable solutions to create added value'. Therefore, through the deployment of bioeconomy solutions, biomass can contribute to reducing greenhouse gas emissions, strengthening ecosystem services, creating jobs and improving wellbeing, notably through the sustainable management of resources, the use of resource and energy-efficient innovative technologies, the application of circular economy models and the valorisation of organic residues and waste streams.

Biomass is 'renewable', but the quantity of renewable biomass is limited by the **regenerative capacity of ecosystems**. The sustainability of biomass depends further on the extractive activity not impairing the healthy state of ecosystems, or on their capacity to return to a healthy state. Therefore, careful consideration of how biomass is used is central [386]. Furthermore, the EU's dependence on biomass

CRITICAL RAW MATERIALS Navigator

The implementation of the CRM Act requires a multifaceted approach that addresses recycling, production, stakeholder engagement, and international collaboration. Below are considerations and potential enablers that can support the achievement of the targets as well as key Competitiveness Compass flagship actions.

If we go like this, we will secure EU competitiveness!

Legend

- Challenges
- Path from challenges to enablers mixes
- Path from enablers to policy ambitions
- Potential intervention areas
- Final milestones

challenge

GEOPOLITICAL TENSIONS AND STRATEGIC AUTONOMY

Several key risks linked to CRM supply can impact global trade and security, such as the **concentration of resources** among few actors, potential **disruptions** in global supply chains, and **geopolitical** tactics

Enablers' mix

Global partnership and due diligence

Strong **due diligence protocols** in key supply chains (see batteries) can mitigate risks and enhance transparency throughout the supply chain

Strengthening **capacity-building efforts** in resource-rich developing countries through **training**, improved **infrastructure**, and strategic **partnerships**. Collaboration under initiatives like the EU Raw Material Partnerships can complement these efforts, demonstrating a commitment to ethical and sustainable resource management

challenge

RECOVERY AND RECYCLING OF CRITICAL RAW MATERIALS

CRMs recovery from waste electrical and electronic equipment (WEEE) is still characterised by **high losses during collection**, **pre-processing** and **recycling** processes (e.g., absence of recycling processes at industrial scale for neodymium)

Enablers' mix

Enhancing sustainable practices

Policies to promote sustainable mining practices and processing, prioritizing **sustainable materials** to maintain EU competitiveness

Analysis and support of existing operations for **base metal CRMs** should be prioritized. Optimizing these operations can enhance **resource security**

Acknowledging and communicating **societal and environmental risks** of relying on politically sensitive regions for raw material supply is key for informed and strategic policy

Enablers' mix

Enhancing recycling and data transparency

The overall **recycling capacity benchmark** within the CRM Act should be disaggregated into **specific, non-binding targets** for each strategic raw material

Establishing standardized **calculation methods** for comparing **recycling capacity** against EU demand to boost recycling

Comprehensive data provision for individual raw materials, rather than aggregated material groups, is necessary for imports, exports, production, and recycling metrics

This will support our strategic autonomy!

EU COMPETITIVENESS

Pillar 3 **Strategic autonomy and security**

POLICY TARGETS

Extraction capacity of at least **10%** of the Union's annual consumption of strategic raw materials

Processing capacity of at least **40%** of the Union's annual consumption of strategic raw materials

Recycling capacity of producing at least **25%** of the Union's annual consumption of strategic raw materials

Diversify imports [so that] no third country would account for more than **65%** of the Union's annual consumption [...]

challenge

SUSTAINABLE AND RESPONSIBLE PROCESSING OUTSIDE THE EU

Some imports come from developing countries with **low governance capacities** and where the extractive sector can have severe **environmental and social impacts**, such as deforestation, pollution, and violation of human rights.

Let's bridge the gaps!

Enablers' mix

Stakeholder engagement and social considerations

Meaningful **engagement** with local stakeholders from the onset of mining projects promotes social acceptance and **community buy-in**

Analysis of **social** and **environmental trade-offs**, within the EU and globally, is imperative. This includes assessing socio-environmental impacts and gauging public opinion to inform decision-making.

Encouraging the use of **Best Available Techniques** reference documents (BREFs) under the ***Industrial Emissions Directive***

challenge

INCREASING EXTRACTION CAPACITY IN THE EU

The CRM Ac also aims to provide **"strategic projects"** with expedited approval processes to boost CRMs production imports raises significant environmental, social, and economic concerns, highlighting the need for a balanced and sustainable approach to biomass trade. As the EU navigates the complexities of biomass utilisation, it is imperative to adopt a holistic perspective that reconciles the competing demands on this vital resource, ensuring its sustainable use and management to support a thriving environment, economy and society.

There is clear evidence on the **steady increase** in the use of biomass in the EU, increasingly driven by demand for bioenergy and for materials, while trends in use of biomass for food and feed remain fairly stable [387]. Although recycling of biomass has increased over the past decade, sourcing of virgin biomass has also risen, resulting in an increasing impact on ecosystems. Ecosystem conditions are **deteriorating** in many areas in Europe, with particularly high pressure on forests [389], [390]. These trends reinforce the need for clear prioritisation regarding natural resource management, and for policy approaches that explicitly address trade-offs between economic, environmental, climate and social objectives.

A **holistic approach** to scientific assessments for policy support is therefore essential. This approach is exemplified by the Integrated Bioeconomy Land Use Assessment project to which the current assessment contributes.
Across EU policies, biomass is expected to fulfil multiple and sometimes competing roles, ranging from environmental protection and ecosystem restoration to energy generation, food production and materials manufacturing. These policy roles often overlap: environmental protection policies may promote certain uses of biomass, while policies centred on biomass use may incorporate environmental safeguards. At the same time, growing demand, limited biomass availability and competition with other sectors raise challenges for implementation, particularly in transition pathways for resource-intensive industries [385], [387], [391].

Analysis of EU policies reveals two dominant roles for **biomass in EGD policies**: i) *protection and enhancement of the environment* and ii) *biomass use*.
Protection policies focus on conserving and restoring primary production systems such as forests and agricultural land, which are crucial for water regulation, carbon sequestration and biodiversity. Policies more focused on biomass use regulate its use primarily from an economic perspective and the potential of bio-based products to 'substitute' products based on fossil or other harmful materials, using a "win-win" policy discourse. Examples include the *RED III* and the *REPowerEU Plan*, which promote biomass use to reduce fossil fuel dependence while supporting climate goals, and the *Circular Economy Action Plan*, which encourages biomass use for material production and waste reduction. Other policies, such as the *EU Algae Initiative* and the *Farm to Fork* strategy, also emphasise the dual benefits of biomass for economic growth and environmental sustainability.
While biomass is a central component in several thematic areas of the EGD, including climate ambition, biodiversity preservation, greening the agriculture sector, and fostering circular economy, there is still a lack of comprehensive and harmonised **quantification of biomass uses across all sectors**. This is especially the case for woody biomass use sectors. This gap hampers the assessment of whether policy ambitions are feasible within a broader policy context and complicates policymaking, particularly at the implementation stage. For instance, wood for bioenergy is now reported under the Regulation (EU) 2018/1999 on the *Governance of the Energy Union and Climate Action* in Eurostat, but there are many issues with this dataset (as discussed in [391]). Although the bioeconomy provides an essential framework for policy coherence, limited knowledge of current biomass uses and clear understanding on the share of 'sustainable' biomass, constrains informed debate.

Unlocking Biomass for Europe's Competitiveness: Priority Levers from the 2025 JRC Biomass Report

The 2025 ten-year anniversary edition 'Biomass Report', one of the outcomes of the JRC Biomass Mandate, presents sectoral challenges and actionable opportunities that can make biomass a true accelerator of the *Competitiveness Compass*.
Four priority levers stand out:
1. Prioritisation and cascade-use for bioeconomy. Developing a genuinely circular bioeconomy is indispensable for meeting the EU's climate-neutrality and fairness goals. By funnelling biomass and, crucially, organic residues into its *highest-value* uses first, and by maximising environmental and economic value added through cascading uses, valorisation strategies can raise resource efficiency, curb waste and keep materials circulating in the economy.
Real progress hinges on sustainable biomass management, systematic input reuse and cross-sector cooperation among governments, industry (as e.g. in industrial symbioses), researchers and civil society.

Yet significant hurdles persist, including high upfront investment needs, technological uncertainty and unavoidable trade-offs between economic returns and environmental or social safeguards, particularly as global demand for bio-based products expands. Successful implementation therefore depends on making these trade-offs explicit and balancing them.

2. Biomass for the energy transition.
Crop-based biofuels are a *transitional* option, capped at 7% of transport energy, in line with RED sustainability safeguards, until more sustainable alternatives scale up. Over the next 15 years, *advanced biofuels and low-ILUC fuels, biomethane and bio-hydrogen* are expected to shoulder much of the biomass-based decarbonisation effort in sectors that are difficult to electrify, where a full technology switch is not yet realistic.
- **Transport:** Sustainable aviation fuels (*ReFuelEU*) and renewable marine fuels (*FuelEU Maritime*) are expected to absorb a large share of future demand, primarily through advanced and waste- and residue-based feedstocks, while legacy heavy-duty road, rail and off-road vehicles will still need drop-in renewable fuels well beyond 2040. Simple "check-and-fix" retrofits (such as adjustments to fuel-line gaskets, injector nozzles, pump calibration) are essential to ensure that existing fleets can safely and reliably use these fuels, allowing continued operation while avoiding premature asset replacement.
- **Industry:** Energy-intensive industrial processes that require very high temperatures or long lead times for plant replacement can rely on biomass-derived fuels during the transition, in parallel with other renewable or low-carbon options.
- **Feedstock dynamics:** Electrification of buildings and light-duty road transport is expected to gradually release some solid biomass. In addition, occasional surpluses from storm-damaged or pest-infested forests may provide supplementary feedstock, although this supply is inherently unpredictable. Both streams can support hard-to-abate sectors, yet material and non-energy uses will continue to structurally compete for the same resources until the cascading principle is fully enforced.

3. Biomass and wood for construction.
New housing absorbs about one quarter of all timber used in construction, and renovation steadily increases the wood share in façades and interiors, helping to reduce reliance on carbon-intensive mineral materials such as concrete and steel. The New European Bauhaus (NEB) has grown into a 1 500-member community spanning culture, research, forestry and construction. Its *Academy* will mainstream expertise in wood durability, fire performance, moisture management, species diversification, modular design and disassembly, helping SMEs scale skills from small houses to large developments, where skill gaps remain a key challenge to wider uptake.
Harmonised EU statistics on structural material mixes are needed to reflect the prevalence of hybrid construction systems and capture the true flow of timber and to inform life-cycle benchmarks for Eco-design, public procurement and forthcoming Construction-Products rules. The integrated NEB approach urges developers to prioritise upgrading the existing building stock - three quarters of which are energy-inefficient - over erecting new structures. Pairing the *Renovation Wave* with cascading use, reclaimed timber and business models that preserve value in energy, labour and materials can turn Europe's buildings into a long-term carbon store while cutting embodied emissions.

4. Novel foods, food waste and dietary shifts.
Diversifying the protein portfolio and cutting waste are essential levers.
- **Novel foods as complementary sources.** Plant-based, insect-based, precision-fermented and cell-cultured products can broaden supply, ease land pressure and lower GHG emissions - provided that potential trade-offs such as resource competition, invasive-species risk and impacts on rural income are monitored through robust assessment and monitoring frameworks.
- **Consumer trends and market coexistence.** European consumers are increasingly motivated by environment, health and animal-welfare concerns. Plant-based sales have surged, while overall meat demand remains broadly stable, signalling that animal- and plant-protein markets can coexist, even as consumer acceptance varies across novel food categories. Policy must therefore integrate livestock's economic and cultural role while promoting balanced, healthier diets and addressing key acceptance barriers such as perceived naturalness, trust and labelling.
- **Food-waste prevention as a system lever.** Roughly half of EU food waste occurs at the consumer stage; halving it requires multi-stakeholder action including clearer labelling, right-sized retail portions, donation networks, local composting schemes and data-driven targets. Accelerated R&I for alternative proteins, footprint labelling that reflects true impacts including energy use and production methods, and behaviour-change programmes can together make dietary shifts and waste reduction a cornerstone of the circular bioeconomy.
- **Governance, market and territorial considerations.** The contribution of novel foods

to sustainable diets will also depend on coherent EU-level governance, evolving regulatory approval processes and geographically uneven patterns of innovation and production, calling for policy coordination to avoid fragmentation and unintended market distortions.

Cross-cutting enablers: pricing externalities and accounting for ecosystem services

The effective implementation of the priority levers identified above also depends on appropriate economic and analytical frameworks. The application of the polluter pays principle, through targeted taxation and subsidisation, can help internalise environmental externalities and steer biomass uses towards options that deliver higher net societal benefits, while discouraging practices associated with higher environmental costs.

In parallel, integrated environmental and economic accounting frameworks can support more informed decision-making by capturing the multiple contributions of biomass and ecosystems beyond market value alone. By linking biomass use to ecosystem services, carbon sequestration and environmental risks, such approaches can improve policy coherence, support prioritisation across sectors and strengthen the evidence base for long-term sustainability and competitiveness objectives.

4.3 A sustainable and regenerative environment

Addressing the multiple ecological, social and economic crises means moving beyond resource conservation towards a **regenerative environment** that can restore and revitalise natural and human ecosystems and increase their resilience. Such a system can provide numerous benefits for climate change mitigation, resource efficiency, biodiversity conservation, human health and well-being, and economic development. Creating a sustainable and regenerative economy and environment requires a multi-faceted approach that involves various sectors. As key examples, nature-based solutions and agroecosystems regeneration hold significant potential for climate change mitigation, sustainable development and regenerative growth.

Nature-based solutions (NbS) involve working with and enhancing natural ecosystems to address societal challenges, such as climate change, biodiversity loss, and human well-being. NbS can be applied in various contexts, including agroecosystems, forests, wetlands, and urban areas, to promote ecosystem services, biodiversity, and ecosystem resilience. Integrating NbS with bioeconomy and the blue economy supports the regeneration and restoration of degraded ecosystems in a holistic manner, promoting sustainable land use and resource management.

Agroecosystems regeneration and resilience involve the restoration and regeneration of degraded agricultural landscapes to promote ecosystem services, biodiversity, and soil health. Agroecosystems regeneration can be achieved through the adoption of sustainable agricultural practices, such as agroforestry, permaculture, and regenerative agriculture, which prioritise soil conservation, efficient water use, and integrated pest management.

4.3.1 Nature-based solutions

Nature-based solutions are considered 'win-win' strategies, based on natural processes, which can help to address major environmental and societal challenges. As defined at the 5th United Nations Environment Assembly (UNEA 5.2), nature-based solutions (NbS) are "actions aimed at protecting, conserving, restoring, and sustainably managing natural or modified terrestrial, freshwater, coastal, and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits". Examples of win-win strategies are the enhancement of urban green networks, multifunctional forestry and the enhancement of ecosystems such as the restoration of wetlands.

In the EGD, NbS are part of the Climate Ambition (for their mitigation potential) as well as adaptation to climate change (as green infrastructure and management of natural areas and landscapes can reduce climate risks). Specifically in the *Communication on Sustainable Carbon Cycles*, NbS are expected to play a role in carbon removal (so-

called "**carbon farming**"), as well as in ecosystem restoration. The enhancement of the CO_2 removals can be achieved by proactively managing terrestrial ecosystems to enhance carbon storage or minimise GHG emissions [392]. These are some of the so-called Nature-based Solutions for climate mitigation considered in the *Carbon Removals and Carbon Farming* regulation (Box 3).
The concept of ecosystem restoration also features in the *EU Biodiversity Strategy* and the *EU Forest Strategy*. Apart from land, with notable examples in agroecology and forestry, NbS are encouraged for the restoration of coastal and marine environments as well. **Synergies** between ecosystem and biodiversity conservation and climate change adaptation **can be leveraged.** A few examples are listed below:

- **Ecosystem based adaptation** to climate change is more cost-effective than engineered measures.
- **Nature-based solutions** in line with the UNEA definition, contribute to climate change mitigation and adaptation, while providing co-benefits for biodiversity, agriculture and urban planning.
- **A shift to more sustainable diets and agricultural practices** may clear suitable areas for reforestation with benefits for biodiversity and climate.
- Identifying and protecting natural "sanctuaries" supports biodiversity restoration.
- **Reforestation** of formerly forested land can create a large carbon sink in its early decades and, in the longer term, store considerable amounts of carbon. Further, it couples carbon sequestration with other adaptation benefits, notably floodwater impedance.
- Restoring natural ecosystem functions, such as hydrology and carbon dynamics, enhances resilience to climate change.
- **Catchment restoration** protects simultaneously from floods and droughts, while contributing to carbon storage and sequestration.
- Restoring **grassland** ecosystems and agroforestry, drylands and tree-grass ecosystem (e.g. removing trees and reinstating natural fire regimes) increases resilience and supports soil carbon storage.

4.3.2 Towards agroecosystems regeneration and resilience

Industrial agriculture is dominated by chemical and mineral inputs, typically obtained by extractive (non-circular) processes and aimed at a commodity-production model. **Agroecological and regenerative approaches** are designed to maximise the efficiency (circularity, sustainability) of natural inputs in terms of resource use (water, soil, biodiversity) and favour the regeneration of ecosystem functions and services. **Healthy ecosystems**, managed for continuous regeneration, can in turn provide a multitude of services to farmers and society, from ecological inputs (such as clean water, fertile soil and pollination) to natural protection against flooding and extreme weather.
For decades, mainstream agriculture has been extractive without directly accounting for the depletion of natural capital. Consequently, agriculture has become one of the main drivers of environmental degradation, biodiversity loss and climate change. For example, the agricultural sector in Europe is responsible for an estimated 11% of total GHG emissions, most of which (66%) is due to livestock production through enteric fermentation (49%) and manure management [77].

Two EU guiding strategies (the *Biodiversity Strategy* for 2030 and *Farm to Fork*) include targets aiming to reduce the impacts of the food system on the environment, fostering the transition to healthier, more sustainable and fairer food systems. Targets include significant reductions in the use of mineral fertilisers and pesticides, as well as the increased uptake of more environmentally sustainable farming practices and farm management systems (Chapter 2). The challenge is to **decrease environmental impacts while guaranteeing food security and social standards**, in a supportive economic environment that aligns with broader sustainability goals. Such shift involves acting on different parts of the food system, with a system approach (Chapter 2). Changing human diets (consuming fewer animal products and more plant-based proteins) coupled with reducing food waste are pre-conditions for shifting production towards increased environmental sustainability to avoid exceeding the planetary boundaries, while enhancing regenerative capacity of natural capital [398], [399], [400].
In this frame, ecological approaches to farming such as agroecology are possible solutions for food systems transformation, enhancing food security, nutrition, health and well-being, livelihoods, soil health, biodiversity, sustainability, and ecosystem services [401], [402]. Building on the key principles of agroecology [403], five key farm management principles can be identified:

- Build-up and maintenance of **soil health**.
- Decrease of total **input intensity**.
- Increased **reliance** on self-produced inputs.
- Avoidance of **most harmful inputs**.
- Presence of **semi-natural elements** on farm.

Box 3. **Nature-based climate solutions**

Nature-based Solutions for climate mitigation (NbS) have the potential to **increase CO_2 removals** through the proper management of terrestrial ecosystems to enhance carbon storage and minimise greenhouse gas emissions. NbS such as conserving and restoring carbon-rich forests and wetlands, and optimising the use of land for agriculture, forestry, and grassland management can offer not only environmental and climate benefits, but also economic incentives, and social benefits such as the potential diversification of income for farmers and land managers.

The carbon sequestration capacity of ecosystems largely depends on how they are managed. Examples of management practices and NbS to enhance carbon sinks and bring biodiversity benefits are:
- **Afforestation/reforestation** and improved forest management: Enhancing carbon sequestration and resilience through reforestation, silvicultural practices (including diversifying tree species, extending the rotation period between harvest cycles, and reducing harvest intensity) and agroforestry, while maintaining biodiversity and ecosystem services [393].
- **Agricultural soil management**: Increasing soil organic carbon (SOC) through sustainable practices such as conservation agriculture, the use of cover crops, minimum tillage, introduction of legume/rotation crops and shifting annual cropland to other uses, and agroforestry[1].
- **Peatland rewetting**: Restoring carbon sequestration and reducing GHG emissions by rewetting drained peatlands[2].
- **Grassland management**: Converting cropland to grassland or maintaining continuous grasslands to increase SOC.

Co-benefits and trade-offs
NbS can yield co-benefits such as biodiversity enhancement and biophysical climate adaptation impacts, but may also involve negative trade-offs, including biophysical impacts, nutrient cycle changes, and methane emissions. Afforestation, for example, can increase precipitation [394], but may also lead to negative effects on water availability [395].

The following key considerations should therefore be taken into account:
- **Water availability**: Afforestation is only sustainable in areas with sufficient water availability, and in regions where this is not jeopardised by climate change; alternatively, it can be designed with a species mixture adapted to future climatic conditions.
- **Leakage**: Harvest intensity reduction is one of the NbS with higher potential for carbon sequestration enhancement. However, reduced timber harvesting intensity can lead to leakage, such as increased wood import from other regions [396].
- **Afforestation of drained peatlands** might not be a viable option due to trade-offs between carbon sequestration of the trees at the cost of enhanced soil respiration, leading to likely negative feedback of soil emissions [397].
- **Regional context**: NbS must be tailored to regional contexts, taking into account local conditions, species niches, and potential trade-offs.

Overall, NbS offer a promising approach to climate mitigation, but require careful consideration of co-benefits, trade-offs, and regional contexts to ensure effective and sustainable implementation.

1 Maqbool, Z., M. S.Farooq, A.Rafiq, M.Uzair, and Q.Hussain. 2025. “Utilisation of Climate-Smart Conservation Agriculture Practices for Improved Soil Carbon Sequestration, Greenhouse Gas Mitigation and Sustainable Crop Productivity.” *Soil Use and Management,* 41, no. 2: e70103. https://doi.org/10.1111/sum.70103.

2 Buma, B., Gordon, D.R., Kleisner, K.M. et al. “Expert review of the science underlying nature-based climate solutions”. *Nat. Clim. Chang.* 14, 402–406 (2024). https://doi.org/10.1038/s41558-024-01960-0

The benefits deriving from an enhanced supply of ecosystem services are manifold. Supporting agricultural production, protecting agricultural fields against extreme events, supporting ancillary activities, such as those based on food and wine tourism, also bring economic benefits. The value of seven ecosystem services (crop provision, pollination, soil retention, flood control, habitat and species maintenance, water purification and nature-based recreation) for the EU-27 in 2018 is estimated to be EUR 56.7 million per year for cropland and grassland [404], [405].
In addition, the Gross Ecosystem Product (GEP), which aggregates the contribution of ecosystem services to the economy, shows that in a macroeconomic scenario driven by changes in consumer preferences towards greater consumption of plant-based protein, the shift in the EU agricultural sector generates an increase of 1.5% (equivalent to approximately EUR 2.3 billion) [406].

The provision of these **ecosystem services** could mitigate the economic exposure of the agricultural sector, thereby reducing the potential for nature-related financial risks and ultimately increasing the resilience of the sector. To illustrate, the decline in pollinators, the intensification of soil erosion and the occurrence of flooding events have the effect of increasing the operating costs of agricultural businesses and reducing their profitability. For banks that extend credit to these agricultural enterprises, lower profitability may result in elevated default rates, which are indicative of **credit risk**. Also, the **insurance sector** may be under pressure to cover claims due to an increased exposure to hazards, which relates to liquidity risk. Furthermore, a reduction in production levels will result in a decline in demand for activities associated with the transformation of primary production. This will have an impact on the value chain, which is linked to credit and market risks.

4.4 Climate adaptation and resilience

Climate adaptation is a crucial component of building a resilient society (Box 4). The frequency and severity of extreme weather events, rising temperatures, and altered ecosystems underscore the urgent need for proactive measures to resist the effects of climate change. Climate adaptation is essential for safeguarding human well-being, economic stability, and environmental sustainability, preparing communities to respond to the inevitable changes that are already unfolding.

An "European Climate Adaptation Plan" is signaled as flagship action of the *Competitiveness Compass*, to help the EU, Member States, and sub-national authorities to improve their preparedness. The Compass also highlights the urgency to "*improve critical infrastructure resilience by design*", ensuring EU infrastructure is equipped for current and future shocks. In 2024, the EU completed its first *Climate Risk Assessment (EUCRA)* and launched a dedicated *Monitoring, Evaluation and Learning (MEL) framework* to better track adaptation progress across governance levels [41]. However, while the *European Climate Law* sets legally binding targets for emissions reductions, **adaptation lacks concrete, enforceable goals** [407].
Some of the major **challenges,** documented by the European Environmental Agency (EEA) [408], [409], for a climate resilient society are outlined below:

- **No standardised and clear assessment of adaptation needs and adaptation benefits:** Investments for climate adaptation differ from those in climate mitigation in several aspects, which have a bearing on incentives to raise private funding [395]. There are **no uniform standards and methodologies to assess multi-dimensional risk** and its reduction from adaptation investments. This hinders the definition of any clearly quantified and internationally agreed targets for adaptation, as well as the assessment of its economic benefits. Additionally, market actors suffer from **information asymmetries and knowledge gaps**, which reduce their incentive and ability to invest in adaptation. As a result, many companies are underestimating the threat of physical climate risks, leading to a potential increase in the costs and risks resulting from the delayed adoption of adaptation plans [410].
- **Financial challenges** extend beyond initial investment costs. The EIB and EEA identify uncertain returns and limited private sector engagement as key obstacles [411], [412]. EU funding tools like the *Recovery and Resilience Facility* (RRF) help Member States align public investment with resilience goals.

- **Sectoral Vulnerabilities**: Climate impacts create interconnected challenges across sectors. **Water stress** will affect 89.6 million Europeans by 2030 according to EEA forecasts [413]. **Agricultural productivity** faces severe threats, with yields potentially declining by up to 50% in southern Europe by 2050, which are not expected to be compensated by increased yields in northern countries [414], [415]. The **Mediterranean region** particularly exemplifies these compound risks, facing doubled **wildfire risk** by the century's end while also managing increased drought frequency and intensity [416], [417].
- **Institutional fragmentation** complicates coordination, highlighting disparities between governance levels [408], [418].
- **Implementation Status**: The current response shows mixed progress. All 27 Member States have adopted national adaptation strategies, and most have developed National Adaptation Plans (NAPs), yet the **quality and implementation of these plans vary significantly** [41]. Some policy areas demonstrate more advanced mainstreaming, for example the Water Framework Directive and the CAP now incorporate climate resilience considerations. However, critical sectors such as **energy, transport and health still lack consolidated and forward-looking adaptation planning**, limiting preparedness for escalating climate risks. The EEA states that current adaptation actions must increase in both **pace** and **scale** to match growing climate risks [407], [409].
- Information gaps persist in **climate projections at local-level**, even though local and Regional Authorities are directly responsible for the implementation of most EU climate mitigation and adaptation policies (Chapter 8). Behavioural barriers include resistance to transformative changes in traditional practices [399], [403].

These multi-faceted challenges demand shared efforts and common understanding. In fact, several opportunities might rise from increasing adaptation in the EU.
- **From a cross-sectoral perspective,** adaptation to climate change can advance multiple EU priorities simultaneously.
- **Nature-based solutions** demonstrate clear co-benefits; [392] such as enhanced carbon sequestration alongside adaptation benefits [392], [419]. In urban areas, **green infrastructure** – directly supported by the new *Nature Restoration Regulation* – delivers quantifiable improvements in air quality and public health [420], [421].
- There is a significant **potential** for **job creation** through adaptation projects, particularly in vulnerable regions [421], [422].
- **From an innovation and economic perspective,**

Box 4. **The Tipping Points**

Earth System Tipping Points (ESTPs) are critical thresholds beyond which components like land/water ecosystems, glaciers, atmospheric elements, and ocean currents can move to new equilibrium states. Increases in GHGs and the consequential global warming are the major forcers toward tipping points, although a growing number of co-drivers such as deforestation, ocean acidification, pollution, water eutrophication, albedo, extreme weather events, ecosystem fragmentation, and overfishing, are known to contribute to pushing the Earth Systems into irreversible, self-sustained new equilibria.

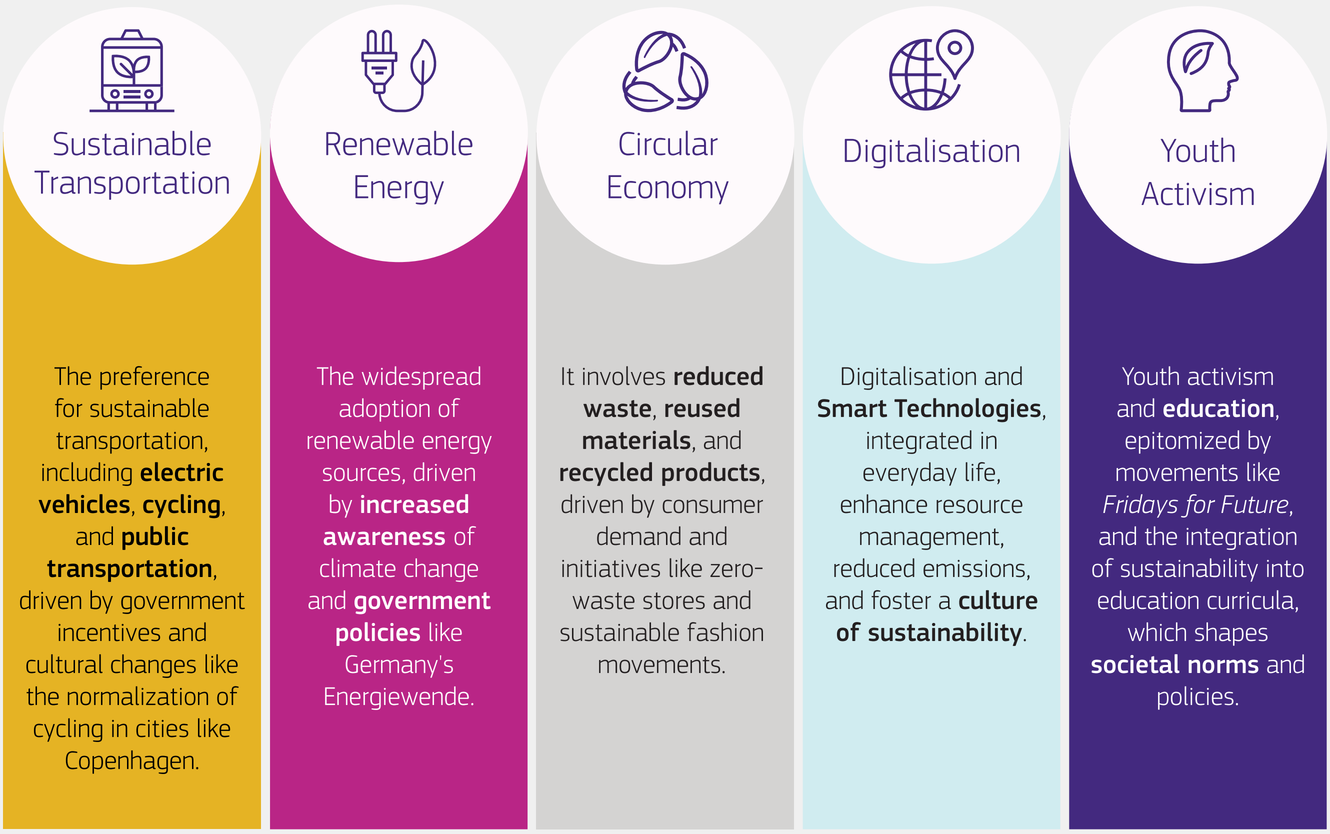
The latest **Global Tipping Point Report** [439] identified more than 50 potential Tipping Systems. Empirical evidence suggests that at least 15 Tipping Systems are now actively responding to global warming [440], [441]. Six out of them have their expected Tipping Points close to 1.5 °C: the Greenland Ice Sheet, Western Antarctic Ice Sheet, Coral Reef Systems, Boreal Permafrost, Barents Sea Ice, and Labrador Sea-Subpolar Gyre Convection. Tipping Points for regional Coral Reefs are feared to be unavoidably crossed. Tipping Points are now becoming high probability high impact events, for which Europe is not sufficiently prepared.

Global tipping points present major climatic and biophysical impacts that can affect Europe in various ways. From the melting of Arctic ice and the Greenland ice sheet to disruptions in the Atlantic Meridional Overturning Circulation (AMOC), boreal forest dieback, permafrost thaw and Mediterranean desertification, the continent faces numerous challenges. These impacts represent a security threat for Europe [442], risking environmental, economic, and social instabilities.

Addressing these challenges requires an understanding of the risks and impacts of Tipping Points to support discussions around **precautionary and anticipatory strategies**, including innovative adaptation strategies. The *Preparedness Union* strategy recognises a strong interlinkage between climate, environment and security, and identifies the urgent need to prepare for natural disasters and increasing climate extremes, but anticipatory governance addressing the systemic risks of TP is missing. Early warning monitoring systems and improved integration of ESTPs in socio-economic governance. A fundamental anticipatory strategy remains the **urgent commitment to reducing greenhouse gas emissions to avoid crossing these critical thresholds**.

Positive societal tipping points receive increasing attention as they can drive substantial and rapid progress towards sustainability and remaining within the safe limits of planetary boundaries (Figure 16). The mathematical analogy with ESTP is that these transformational societal shifts can become self-reinforcing and accelerated, and have the potential to catalyse changes in behaviour, norms, and practices that collectively drive fast progress towards a more sustainable future [443].
Leveraging these **positive social tipping points** is crucial to driving systemic change and accelerating the transition towards a more sustainable future. By harnessing the collective power of renewable energy adoption, sustainable transportation, circular economy practices, youth activism, and digitalisation, Europe can drive the systemic change and achieve the clean transition.

Figure 16. Positive Social Tipping Points



Source: Authors' elaboration.

the adaptation challenge presents opportunities for EU leadership. In the new *EU Strategy on Adaptation to Climate Change*, the European Commission identifies emerging markets for adaptation technologies and services [423].

- **Cross-border cooperation** on shared climate risks can strengthen EU cohesion, while **technological innovation** in areas like early warning systems shows benefit-cost ratios exceeding 1:10 [142], [424].
- From an **assessment perspective**, reducing the information gap needs data and clear methodologies to evaluate climate risks. The EC is already engaged in providing better access to climate risk data and assessment, as proved by the 2024 European Climate Risk Assessment (a report from the EEA regarding the identification and evaluation of climate risks) [409] and the JRC Risk Data Hub (a multi-hazard geo-portal mapping climate risk into the EU territories) [425]. More and better climate-related risk and loss data are also advocated by the new *EU Strategy on Adaptation to Climate Change* (2021) [426]. At the same time, the EC recognises the need for a comprehensive framework for climate risk adaptation assessment [427], so further efforts will be necessary to extend data coverage and access and to diffuse harmonised risk assessment methodologies and standards.

To address these challenges, Member States can help by increasing the availability of data to assess localised climate risk and vulnerability.
While all EU Member States have adaptation strategies, their effectiveness varies significantly, particularly in critical sectors like energy and transport. Moving forward requires a fundamental challenge to be addressed: the lack of standardised methods to evaluate adaptation needs and benefits [428], [429], [430]. This gap affects both policy design and the capacity to mobilise private investment [411], [431], [432], [433].

The *EU Adaptation Strategy* provides a framework to address these challenges through three complementary approaches [434], [435]: financial innovation to overcome investment barriers, policy integration to mainstream adaptation across sectors, and capacity building to address regional disparities. While the mechanisms for effective adaptation exist, accelerating implementation requires better coordination between governance levels and clearer methods for assessing progress.
Current evidence demonstrates that early, strategic action delivers multiple returns across EU policy objectives [436], [437], [438]. The mechanisms and frameworks for effective adaptation exist - the critical task is **accelerating implementation** at scale.

4.5 International collaboration on the global challenges

The EU's clean transition is deeply **intertwined with global dynamics and with the Union's own resilience**. Europe depends on imports of energy, raw materials, food and many manufactured goods, so disruptions, price spikes and geopolitical tensions in global markets directly affect its economy and security.
At the same time, Europe's demand is embedded in international value chains, and its climate, biodiversity and pollution footprints extend well beyond its borders. A genuine clean transition therefore cannot simply decarbonise and clean up within the EU while **shifting environmental burdens** and externalising environmental and social costs elsewhere: it must both strengthen resilience and reduce, rather than shift, pressures along global supply chains and in partner countries, especially those with lower regulatory capacity and higher vulnerability.

Effective responses to these shared challenges rely on a rules-based multilateral system and strong international institutions. **Global frameworks** such as the Paris Agreement under the UNFCCC, the Convention on Biological Diversity and its Kunming–Montreal Global Biodiversity Framework, and the 2030 Agenda for Sustainable Development provide a common direction for climate action, biodiversity protection and sustainable development.
The EU is a **key proponent and negotiator** in these processes, working to raise ambition, translate global commitments into concrete measures and support partners in implementation. However, eroding trust in multilateralism, rising geopolitical tensions and the growing use of trade and energy policy as strategic instruments risk fragmenting this rules-based order and make it harder to design and implement coordinated responses to global challenges, including

the timely implementation of existing agreements. This makes the external dimension of the EU's clean transition and of its new competitiveness agenda a core part of the transition, not an add-on. Through instruments such as the *Neighbourhood, Development and International Cooperation Instrument – Global Europe* (NDICI–Global Europe), the *Global Gateway* strategy and *Team Europe Initiatives*, the EU seeks to align its external action with climate, environmental and social objectives. These frameworks aim to support partners' own green and just transitions, promote sustainable and resilient infrastructure and value chains, and uphold high environmental and social standards, while also addressing excessive dependencies and strategic vulnerabilities for the EU.

Against this backdrop, this section examines where the clean transition has a strong global and external dimension, the main risks of burden shifting and excessive dependencies, and how EU international cooperation and external instruments seek to address them in a coherent and resilient way.

Global climate ambition and cooperative carbon pricing

While the EU's climate targets are defined in terms of domestic emissions reductions, the climate risks, economic impacts and distributional effects it faces also depend on how mitigation and adaptation progress **globally**. The EU works through multilateral frameworks such as the UNFCCC and the Paris Agreement, to raise ambition, translate global commitments into concrete actions and support partner countries. Global Europe (NDICI–Global Europe) gives this a dedicated financial backbone, with around 30% of EU development aid earmarked for climate action and a mandate to help countries most in need achieve the SDGs and Paris goals. Climate and energy is also one of the five key areas of partnership under the Global Gateway.

A further pillar is cooperation on **carbon pricing** and markets: through initiatives such as the International Carbon Action Partnership and the Partnership for Market Readiness, the EU helps partners design and implement emissions trading systems and related instruments, supporting more compatible carbon pricing frameworks, reducing the risk of carbon leakage and competitive distortions, and contributing to a more coherent global response to climate change, even though coverage and price levels still differ significantly across countries.

Together with international financial support, technical assistance, technology cooperation and trade relations, these instruments are central to enabling low-emission, climate-resilient development pathways and to avoiding a clean transition that shifts costs onto partners outside the EU.

Securing clean energy supply without shifting impacts abroad

The EU's clean energy transition has a strong external dimension: reducing reliance on Russian fossil fuels to around 3% has required rapid **diversification** of suppliers, with the United States, Norway and Kazakhstan emerging as key partners. At the same time, **hydrogen** partnerships (e.g. *Global European Hydrogen Facility* and import plans for hydrogen) will deepen energy interconnections with neighbouring regions and Africa, creating both opportunities for partners' transitions and new strategic dependencies. Global Gateway supports partner countries in expanding renewable energy, grid infrastructure and energy efficiency while strengthening secure and sustainable energy links with the EU.

Biofuel and feedstock imports have surged in recent years, highlighting the risk of externalising land-use change, biodiversity loss and social impacts when production is located in countries with weaker regulatory frameworks.

Renewable energy projects can also raise environmental justice concerns, particularly in developing countries with weak governance: the uneven distribution of benefits and burdens, coupled with limited involvement of local communities in decision-making, is often described as the "decarbonisation divide" [444]. This is evident in projects that displace agricultural land and biodiversity for biofuel production or raw material extraction for clean energy technologies [445], and in renewable energy and mining projects that interfere with Indigenous territories (including in the Arctic), where "free, prior and informed consent" as established by the UN Declaration on the Rights of Indigenous Peoples is essential [446].

In this context, instruments such as the *Carbon Border Adjustment Mechanism* can help maintain fair competition, but the lack of globally standardised environmental regulations underlines the need for international cooperation, due diligence and rights-based approaches to ensure that environmental and social costs are not simply shifted outside of the EU.

Curbing waste exports to support fair circular value chains

Global waste and secondary material flows directly link **EU circular economy** efforts to environmental and social conditions abroad. Material-rich products at end-of-life are often shipped out of the EU, and

an estimated 15–30% of waste shipments evade controls, increasing environmental risks through improper disposal or treatment and representing a lost opportunity for reuse and recycling within the EU. This can shift pollution and health impacts to countries with weaker regulatory and enforcement capacity, rather than reducing them overall. The *Waste Shipment Regulation* aims to reduce waste exports, particularly to non-OECD countries, with potential benefits including savings of around 14 million tonnes of CO_2eq, job creation and decreased ocean litter. Revisions to the *Waste Framework Directive* and the *Waste Shipment Regulation* also seek to limit textile waste exports, ensuring that only reusable materials are sent to low- and middle-income countries, while promoting higher resource efficiency and value retention within the EU.
In parallel, the EU engages in international cooperation and multilateral frameworks on waste and circular economy to help **partner countries strengthen** waste legislation, enforcement and recycling capacity, although weak enforcement and data gaps continue to hamper effective control of waste flows.

Greening international transport while safeguarding fair competition

International transport and **trade routes** are central to Europe's competitiveness and a major source of cross-border emissions. Decarbonising aviation, maritime shipping and long-distance freight depends on coordinated rules, interoperable infrastructure and common standards for alternative fuels and cleaner technologies.
The EU works through international organisations such as ICAO and IMO, and through bilateral and regional agreements, to promote higher ambition on sustainable fuels, vessel and aircraft efficiency and emissions monitoring, even if progress in some international fora remains slower than required to meet climate goals.

Global Europe (NDICI–Global Europe) and the Global Gateway also support sustainable connectivity with partner regions, including cleaner ports, corridors and urban mobility systems, helping partners align with higher environmental and safety standards.
At the same time, ensuring **undistorted competition**, **reciprocity** and a **level playing field** is essential as companies invest in greener fleets and logistics chains. The *Foreign Subsidies Regulation* complements existing trade and competition instruments by addressing the distorting effects of foreign subsidies in the internal market, including in public procurement, helping to ensure that European and partner companies that invest in cleaner technologies are not disadvantaged by unfair support elsewhere. Through this combination of international cooperation on standards, external investment and instruments to tackle distortions, the EU aims to advance low- and zero-emission mobility and strengthen sustainable connectivity with partners, while safeguarding fair competition and avoiding lock-in to high-emitting technologies.

Global food interdependencies and sustainable trade

EU food production and consumption are closely intertwined with **global land-use and trade flows**. Reliance on imported soy and maize for livestock feed raises questions about the resilience and self-sufficiency of EU food systems and about the externalisation of environmental pressures to producer countries. Changes in EU **dietary habits** and the progressive tightening of sustainability standards can also reshape import demand, affecting exporters' domestic supply chains and potentially driving up prices as they adapt; smaller suppliers in developing countries may face particular challenges in maintaining access to the EU market under stricter requirements. Sustainable food import policies are therefore crucial to **prevent biodiversity loss**, deforestation and higher greenhouse gas emissions linked to lower sustainability standards in exporting countries, while ensuring fair competition for European farmers.

At the same time, **agricultural support schemes** in advanced economies, including the EU may risk contributing to market distortions, which underscores the importance of ongoing reforms to better align support with environmental and climate objectives and with partners' development needs.
Trade and development cooperation (e.g. support under NDICI–Global Europe) can help partner countries comply with higher standards, diversify value chains and strengthen food security. The EU also concludes international **fisheries** agreements with non-EU countries, under which EU fleets are granted access to surplus fish stocks subject to sustainability criteria, while the EU provides financial support to partner countries' fisheries management and local development, linking European consumption more closely to the long-term health of shared marine resources.

Global biodiversity commitments and deforestation-free value chains

EU consumption and investment patterns influence

land use, species exploitation and ecosystem health in other world regions, through land-use change, overexploitation and the degradation of terrestrial, freshwater and marine ecosystems.
Agricultural expansion for commodity production is a primary driver of deforestation and forest degradation, and as a major consumer of these commodities the EU recognises its responsibility. The *EU Deforestation-free Product Regulation* seeks to ensure that products consumed in the EU do not contribute to these pressures by mandating **traceability** and **accountability** for key commodities: operators and traders placing them on the EU market or exporting them must demonstrate that their products do not originate from recently deforested land or contribute to forest degradation.
In line with the *Global Gateway* strategy, the *Team Europe Initiative* on deforestation-free value chains aims to help partner countries transition to sustainable, legal and deforestation-free agricultural value chains, including by strengthening forest governance and supporting producers, although implementation will require sustained support, especially for smallholders.

At the multilateral level, the *Kunming–Montreal Global Biodiversity Framework*, adopted in December 2022, sets global goals and targets for protecting and restoring nature across all ecosystems, supported by monitoring, reporting and review mechanisms, and the EU contributes to its implementation through financing commitments and policy alignment. Initiatives such as **NaturAfrica** promote biodiversity conservation in Africa through a people-centred approach, with programmes designed and implemented in consultation with national and regional governments, local communities, civil society and the private sector, with particular attention to Indigenous communities and women. Together, these efforts seek to reduce the EU's global nature footprint while coupling conservation outcomes with local development benefits, rather than shifting conservation burdens onto partner countries.

Tackling transboundary pollution through international cooperation

Many forms of **pollution**, including **marine litter**, hazardous **chemicals** and **air pollutants**, are transboundary in nature and cannot be tackled by countries acting alone.
International efforts are therefore essential to achieve, for example, the EU's 50% reduction target for marine plastic litter by 2030 [447]. Domestic measures such as bans on single-use plastics are not sufficient, as only around a quarter of macro-litter found in EU seas originates domestically.
The Mediterranean Sea illustrates these challenges: it faces pressures from pollutants, marine litter, unsustainable fishing, underwater noise, invasive species and seabed disturbance.
To respond, the contracting parties to the UN Barcelona Convention adopted a 2022–2027 strategy to restore the sea's ecological health and agreed to support the designation of a sulphur emissions control area requiring ships to use low-sulphur fuels. Beyond marine pollution, the *Chemicals Strategy for Sustainability* aims to set a global benchmark by promoting high chemical safety standards and phasing out the production and export of hazardous chemicals banned in the EU.
Other forms of transboundary pollution, such as air pollution and long-range transport of hazardous substances, are likewise addressed through international conventions and cooperation frameworks (e.g. *Convention on Long-range Transboundary Air Pollution*, *Stockholm Convention on Persistent Organic Pollutants*, *Minamata Convention on Mercury*), yet **implementation** and enforcement remain uneven across regions.
Together, these efforts seek to ensure that progress towards zero pollution within the EU does not simply shift hazardous substances and waste streams abroad but contributes to higher protection standards globally.

Across all these areas, international cooperation is a precondition for the success of the clean transition. The EU's efforts to reduce excessive **dependencies**, strengthen **resilience** and raise environmental and **climate ambition** will only be effective and durable if they go hand in hand with fair partnerships, higher standards and just transitions in partner countries, rather than with burden shifting and new asymmetries.
Clear **commitments** to international frameworks, followed by meaningful action towards their implementation, are also essential to uphold multilateralism as an effective instrument for international cooperation in addressing global challenges. This requires a coherent mix of domestic regulation, external action instruments, trade and investment policies, and development cooperation, underpinned by effective multilateral frameworks and adequate financing, as well as closing remaining implementation and enforcement gaps.
By working with partners to align standards, support capacity and governance, and address the distributional impacts of change, the EU can help ensure that the clean transition reinforces rather than undermines global stability, prosperity and the protection of the global commons.

05

Closing the innovation gap

Key messages

The EU must close its **innovation gap** to meet clean transition objectives, prioritising R&I investment, public-private collaboration, and startup scaling, especially in clean technologies.

Structural **challenges** - including fragmented regulation, insufficient private capital, limited risk appetite and talent shortages - continue to slow innovation diffusion and scaling across Member States.

Strengthening Europe's innovation ecosystems requires **enabling conditions** such as adaptive regulation, long-term policy direction, mission-oriented partnerships, and improved coordination across governance levels.

Closing the innovation gap demands systemic **alignment** of finance, regulation, governance and societal engagement to translate research excellence into competitive, market-ready solutions.

Scaling innovation requires progress across multiple scaling dimensions – **up** (*institutionalisation*), **out** (*replication*), **big** (*market uptake*) and **deep** (*cultural and behavioural change*) – to translate breakthroughs into durable transformation and sustain Europe's green innovation cycle.

The EU remains a leader in **clean energy** R&I and public investment, but lags in private investment, smart technologies, and manufacturing, risking competitiveness against global competitors.

Bioeconomy innovations support the EU's clean transition by reducing fossil fuel reliance, promoting resource efficiency, and boosting rural economies, while contributing to sustainability and circularity goals.

Biotechnologies, applied in health, industry, agriculture, and environmental management, can drive sustainable solutions in waste management, biomanufacturing (including biopharmaceuticals), bioremediation, and carbon sequestration, supporting EU competitiveness and green job creation.

The EU **Blue Economy** supports over 3.5 million jobs and generates EUR 171.1 billion in GVA, with significant potential for innovation in areas like marine renewables, biotechnology, and robotics.

The EU's **twin green and digital transitions** are deeply interconnected; digital technologies can reduce emissions but also consume significant energy and generate e-waste, requiring a balanced approach to digitalisation that minimises resource consumption and waste.

Major **data gaps** hinder monitoring in areas such as land use, climate action, food systems, biodiversity, waste, critical raw materials, and pollution, demanding improved data collection, sharing, and interoperability, as well as greater use of advanced technologies such as AI and Earth observation.

Innovation stands at the core of Europe's capacity to deliver a competitive clean transition. However, as highlighted in the '*Draghi report*' on European competitiveness [5] and the Letta Report on the Single Market [3], the EU faces persistent innovation gaps that undermine its strategic autonomy and ability to lead in emerging technologies. Both reports converge on the urgency of strengthening Europe's innovation ecosystems, scaling up disruptive technologies, and aligning research and industrial strategies to maintain global competitiveness.

The *Competitiveness Compass* builds on these analyses, aligning EU policy priorities with the recommendations of Draghi and Letta to revive Europe's innovation cycle. The EU's performance in clean energy technologies remains strong, yet vulnerabilities persist in digitalisation, biotechnologies, and industrial manufacturing. Structural challenges - such as regulatory fragmentation, insufficient private investment, and limited access to risk capital - continue to hinder the scaling of startups and the diffusion of innovation across Member States. These obstacles create what the Draghi report terms "valleys of death" where promising research struggles to transition into market-ready products and scale to global markets. This chapter explores how closing these gaps can accelerate Europe's green and digital "twin transitions" with a focus on sectors that are central to systemic transformation. It examines the role of research and innovation (R&I) as a driver of technological and social solutions, analyses the specific challenges and opportunities for clean energy technologies, the bioeconomy and biotechnologies, and the blue economy, and considers the critical interplay between digitalisation and sustainability, ultimately outlining pathways to strengthen competitiveness and advance a clean transition.

5.1 The role of Research and Innovation

Research and innovation (R&I) are central to Europe's strategic objectives, especially the EU's ambitions for decarbonisation and the transition to a net-zero economy. However, despite considerable efforts, the EU has consistently fallen short of its target of **3% of GDP for R&I investment** [448], a crucial figure for long-term progress. EU leaders [449] have recently re-affirmed this target, calling for an innovation-friendly environment based on excellent science, aiming to accelerate market adoption and the industrial scaling of innovations.

Currently, the EU's research and development (R&D) intensity stands at **2.2% of GDP** [450], lagging behind global competitors such as the US, China, Japan, and South Korea. While public investment in clean energy technologies has grown, notably through Horizon Europe and national funding, private sector contributions remain insufficient. Europe excels in **clean technologies** like wind, energy and hydrogen, but faces increasing challenges in **digital sectors**, where countries like the US and China are advancing rapidly. This growing technological gap undermines Europe's global competitiveness.
A key issue is the underutilisation of Europe's R&I ecosystem, with significant innovation divides across Member States, particularly in southern and eastern Europe. Although public R&I investment is rising, **regional disparities** persist, impeding progress and hindering Europe's ability to compete in emerging technologies [450]. Addressing this gap requires coordinated investments and stronger public-private collaboration. Moreover, the decline in government support for private R&D, which fell by 3.4% in 2020, further deepens the issue [450].

To bridge the innovation gap, the EU needs more robust **public-private partnerships**, especially in clean technologies, and to focus on scaling up green startups, which face high costs and limited funding. The EU faces challenges in bringing innovation to market and scaling up in the field of clean technologies. The EU *Start-up and Scale-up Strategy* [451] aims to address these barriers by strengthening university-business collaboration, supporting talent mobility, improving patent commercialisation, and enhancing access to risk capital.
Complementing these efforts, the European Innovation Council (EIC) has emerged as the EU's flagship instrument for supporting breakthrough innovation and deep-tech entrepreneurship. Through an integrated portfolio spanning frontier research (EIC Pathfinder), technology maturation (EIC Transition), and blended grant-equity support for startups and SMEs (EIC Accelerator), the EIC has supported more than **800 innovative startups** and SMEs and mobilised over EUR 5 billion in co-investment through the EIC Fund (see the EIC 2026 Impact Report), demonstrating the potential of blended finance approaches to crowd in private capital for high-risk innovations.
The newly established Scaleup Europe Fund complements the EIC Fund by targeting the **late-stage financing gap**, providing growth capital to fast-growing European companies seeking major investment at the growth and scale-up stage. Targeting a total size of approximately **EUR 5 billion**, anchored by a EUR 1 billion contribution from the European Commission, the Fund is rooted in public-private co-investment bringing together the European Commission and major institutional investors to support the scaling of European companies in strategic technology domains, including artificial intelligence, quantum technologies, semiconductors, robotics, energy technologies, biotechnology and advanced materials.

In his report [3], Letta suggests introducing a "**fifth freedom**" to complement the traditional four - people, capital, goods, and services [452]. This new freedom would focus on the unrestricted movement of research, innovation, knowledge, and education, strengthening the single market [453].
The '*Draghi report*' [5] recommends an annual investment of **EUR 750-800 billion**, primarily from the private sector, for boosting EU competitiveness. This strategy puts the emphasis on reinforcing Europe's leadership in areas where it excels, while advancing in emerging technologies. It also calls for better **alignment** between R&I efforts and **industrial policies**. To boost competitiveness, the EU must prioritise R&I at the core of its economy. The proposal for the next Horizon Europe Programme (2028-2034) included a budget of EUR 175 billion, nearly doubling from the current EUR 95.5 billion, and will be tightly linked with the *European Competitiveness Fund* for a more integrated approach from research to industrial deployment, making the programme simpler, faster, and more impactful [454].

While the decrease in R&D productivity is a global phenomenon, EU-based firms show lower R&D

productivity than their US and Asian counterparts, particularly in generating sales and **new ideas** [455]. Simply increasing R&D investments is not enough: the EU needs to improve R&D processes, attract and retain top talent, and develop more effective policy instruments to drive impactful innovations.

Looking ahead, Europe must also strengthen **international scientific cooperation** to maintain its global relevance. A critical goal will be to attract and retain talent in Europe to ensure a sustainable and innovative future for the continent [456]. The recent "Choose Europe for Science" initiative, launched in 2025 with a €500 million funding package for 2025-2027, takes a step in this direction by attracting and retaining research talent through extended grants and long-term career prospects.

Without a strategic reassessment of funding priorities and improved policy coordination, Europe risks falling further behind in achieving its 3% R&D target [5]. However, by leveraging initiatives like Horizon Europe, improving access to finance for startups, and strengthening international collaborations, the EU can accelerate progress toward its goals. The key will be ensuring that R&I serves not only as a driver of technological innovation but also as a catalyst for economic resilience and sustainability.

To close the R&I gap with global competitors and successfully transition to a sustainable economy, the EU must prioritise R&I investments aligned with the clean transition's objectives. By fostering collaboration, increasing funding, and addressing regulatory barriers, Europe can maintain its leadership in clean energy technologies and achieve the clean transition's ambitious targets.

Driving innovation: EU startups and scale-ups

Startups and scale-ups are crucial for the EU's competitiveness. They often bring breakthrough innovations to market that address key societal challenges. However, their growth is still hindered by difficulties in accessing private capital and in selling seamlessly across the single market. JRC research shows that while Europe creates a similar number of startups as the United States, it **underperforms at scaling** them [457]. The EU accounts for just 8% of global scale-ups, and nearly 30% of European unicorns have moved their headquarters abroad, mostly to the US, in search of better funding and market opportunities. This reflects not a lack of innovative firms, but **structural weaknesses** in financing conditions at the scale-up stage, particularly the shallow and fragmented nature of European capital markets.

The constraint is most acute at the **scale-up phase**. Evidence from the European Investment Bank shows that EU scale-ups raise 50% less capital than their US counterparts ten years after establishment, a gap that persists regardless of industry, year of establishment or business cycle. Greentech is a notable exception, with EU venture capital investment broadly comparable to that of the United States, driven by strong policy demand and an ambitious decarbonisation agenda. Even so, financing constraints remain more binding in that sector than elsewhere, given its capital intensity and longer time to market [458].

Understanding these dynamics across sectors requires **robust data and forward-looking analysis**. Data-driven insights, sectoral analyses, and forward-looking foresight can define and track key performance indicators, monitoring the growth of startups and mid-caps by sector and geography [459]. Sectoral research spans automotive [460], advanced manufacturing [461], digital, clean energy [462], [463], nuclear, biotech [464], the blue economy [465], and healthcare [466], identifying innovation trends, investment challenges, and competitiveness gaps. **Technology foresight** contributes to shaping policy and innovation funding priorities [467] to guide the European Innovation Council, particularly in emerging deep-tech [468] and strategic fields [469]. Analysis of funding gaps, investment flows, and financing models underscore the importance of government-backed venture capital [470], [471], blended finance instruments, and international investment. Governmental venture capital in the EU remains important and accounted for over 30% of total VC funding in the 2007-2021 period.

Studies of **investment drivers and venture capital** syndication reveal structural challenges that limit scale-up success in Europe [457], [472]. For instance, the top European automotive corporates invest disproportionately more in the US than in European startups. Additionally, research explores corporate venture capital trends [473], the complementarity of public-private financing [474], and the role of crowdfunding as an alternative funding channel. Research on sustainability innovations in the EU food supply chain also highlights how startups respond to regulatory pressures and market demands [475].

The **fragmentation of regulatory frameworks** across Member States increases costs and slows market entry, limiting the ability of businesses to scale within the Single Market. In addressing regulatory and administrative burdens, JRC work evaluates how innovation-friendly mechanisms [476], such as regulatory sandboxes [477], can support startup growth, as well as the effects of corporate taxation on small firms [478], identifies barriers in accessing public procurement opportunities [479], and advocates for harmonisation of sustainability regulations [480].

By simplifying **public procurement**, the EU could increase startup participation in public tenders and therefore unlock significant additional funds. Sector-specific studies reveal persistent regulatory and administrative challenges in biotech [481] and the blue economy [465], calling for targeted reforms to reduce burdens and improve competitiveness.

In the area of **advanced manufacturing**, the EU was an attractive market for startups between 2009 and 2019. In this period, their number grew faster than the global average, ensuring a higher share in the global industry. This share has remained stable at around 15% since 2019. In the same period, the EU demonstrated its ability to attract large strategic deals, enabling the scale-up and growth of battery and hydrogen-based steel manufacturers [482].

The *'Draghi report'* [5] highlights two major "valleys of death" in Europe: the transition from research and innovation to **marketable products**, and the **scaling phase** where firms struggle to secure late-stage funding and access international markets. JRC work on market access barriers, both within the EU and globally, identifies the obstacles that startups face in entering public procurement markets and proposes strategies to increase their participation.

Recent firm-level analysis confirms that the scale-up gap stems primarily from structural features of European capital markets rather than from a **shortage of innovative firms**. The EU venture capital market remains shallow and fragmented, with far fewer large-scale funds capable of writing the ticket sizes that scale-ups require. This constraint is particularly acute for capital-intensive sectors such as clean and green technologies, where scaling requires significant upfront investment, longer time horizons, and the ability to navigate complex regulatory environments making the "valley of death" longer and deeper than in other industries. Addressing this requires not only more capital, but better-designed financing instruments, stronger public-private collaboration, and deeper integration of EU capital markets [458].

In contrast to the US, where deep capital markets and institutional investors provide abundant late-stage funding, European startups receive only a fraction of equivalent growth capital. GovTech holds potential as a channel for startups to deliver digital solutions to public administrations [483]. In biotech, healthcare, and marine sectors, the JRC highlights challenges related to intellectual property, regulatory approval, and financing that limit market entry and expansion.

Nearly four in five SMEs in the EU cannot find the talent they need. The Union of Skills [484] aims to address skills and labour shortages, ensuring that European companies have access to the workforce they need to remain competitive. In 2021, there were 2.8 million startups in the EU, which employed around 14.3 million persons. Within this pool of firms, 260 000 startups (with 1.7 million employees) carried out R&D activities, of which around 45 000 can be considered as innovative startups, employing approximately 280 000 people [485].

Analysis of workforce gaps, training needs and talent mobility shows how crucial they are for startup success. The analysis highlights the rural-urban innovation divide and proposes strategies to attract talent to less-developed regions, for example through initiatives like the Startup Village Forum [486]. It also highlights different sectoral needs: the analysis for biotech identifies critical workforce needs, including regulatory expertise, R&D capabilities, and specialised training [481].

Finally, limited access to research and technology infrastructure significantly hampers startup growth - particularly in Deep Tech and biotech. Research and Technology organisations are essential in providing access to labs, pilot-scale facilities, and regulatory guidance. Despite their role, persistent infrastructure gaps and high costs remain major barriers, underscoring the need for improved shared services and targeted support to help startups to scale effectively [487].

Scaling green innovations – challenges, enablers and policy levers

While Europe continues to strengthen its research base and increase R&I investments, the effective translation of knowledge and technology into marketable, scalable, and socially accepted solutions remains a core challenge. Progress depends not only on more funding or scientific excellence, but on the *systemic conditions* that allow innovation to take root and spread. To better understand these conditions and identify practical pathways to scale, the JRC convened an expert workshop on *Scaling Green Innovation in Support of the EU Green Transition* (Milan, February 2025, co-hosted with Bocconi University) [489].

Findings show that Europe's innovation system is not primarily hindered by a lack of ideas or technologies, but by *structural frictions* that slow the diffusion and

Box 5. **Advancing transformative research for a greener Europe**

The **European Research Council** (ERC) is the EU's premier funding body for investigator-driven, high-risk, and high-gain research. Established in 2007, it supports ambitious ideas across all disciplines, aiming to strengthen Europe's knowledge base and competitiveness. Recognising the urgency of tackling climate change, biodiversity loss, and resource degradation, the ERC carried out a *Mapping Frontier Research* exercise to assess how the research it funds can drive transformative impact [488]. Over 300 ERC projects receiving more than EUR 650 million in total grants were identified as contributing to a greener Europe. These initiatives highlight the potential of advanced science and interdisciplinary collaborations to help shift towards net-zero emissions, sustainable resource use, and resilient socio-ecological systems. The highlights below illustrate how ERC-funded research contributes to the longer-term scientific foundations of the clean transition.

- **Alignment with clean transition objectives:** A significant group of ERC-funded projects focuses on areas such as renewable energy, biodiversity conservation, sustainable agriculture, circular economy, zero pollution, and climate resilience.
- **Frontier research across disciplines:** ERC projects demonstrate deep interdisciplinarity, bridging natural sciences, social sciences, and the humanities. Achievements range from rethinking circular production processes to pinpointing 'social tipping points' for sustainable lifestyles. Projects further emphasise the need for systems thinking to balance environmental, economic, and social priorities. This breadth enables ERC-funded research to address the complex interdependencies underpinning systemic change.
- **Structural constraints in research and innovation:** Despite promising technological and social solutions, insufficient deployment of renewable energy infrastructure, regulatory complexity, and funding mechanisms favouring incremental over transformative investments still hinder rapid progress. Many ERC projects specifically investigate why such solutions are not more widely adopted, identifying hurdles to be overcome and enabling factors that could catalyse deeper systemic change.
- **Advanced technologies supporting Europe's clean transition**: Examples include next-generation photovoltaic cells and innovative wind turbine materials, CO_2 flux models and high-resolution climate simulations, precision farming with plant stress sensors and soil restoration techniques, methods for recovering critical materials from waste and bioplastics using engineered microorganisms, renewable-powered charging networks for electric vehicles and vehicle-to-grid technology, digital twins to monitor ecosystems and AI tools for tracking pollution and biodiversity changes.

Focusing on the transformative impact of research helps identify initiatives with the greatest capacity to produce system-wide benefits, guiding funding bodies to align support with systemic transitions and ensuring that investments deliver real-world outcomes. Successful innovation ecosystems also require **collaborative research**, **industrial partnerships** and **scale-up mechanisms** capable of translating scientific advances into societal and economic impact.

While frontier research generates the scientific breakthroughs that enable future transformations, collaborative research - laying at the heart of Horizon Europe - plays a crucial role in translating these advances into practical solutions through cooperation between academia, industry, public authorities and other societal actors to co-develop, test and validate solutions, helping bridge the gap between scientific discovery and real-world deployment. European Partnerships play an important role in this context, bringing together the European Commission, Member States, industry, research organisations and other stakeholders around shared strategic objectives. Their focus on **long-term collaboration**, demonstration activities and ecosystem-building complements frontier research by strengthening the links between scientific excellence, industrial competitiveness and societal impact.

These insights emphasise that Europe's competitiveness hinges on its ability to bridge the "valleys of death" between research, innovation, market deployment and scaling. Nurturing collaboration, risk-taking, and societal engagement is essential, as these factors determine the uptake of new solutions and help translate bold ideas into widespread adoption - ultimately advancing Europe's clean transition.

adoption of new solutions. **Financial constraints** remain pervasive, as green innovators often face risk-averse markets, fragmented support schemes and complex access procedures. The absence of fit-for-purpose blended-finance instruments and neutral intermediaries limits the ability of smaller actors to attract capital or navigate regulatory and administrative hurdles.

Social and cultural factors also play a decisive role. Behavioural inertia, perceived unaffordability and uneven distribution of costs and benefits can weaken societal support for innovation. When change is not perceived as fair or inclusive, social acceptance declines, creating resistance even to technically sound solutions.

Knowledge and capacity gaps persist along the innovation chain. Europe's strong research performance does not always translate into application, partly due to limited interfaces between academia, industry and the public sector. Skills shortages, disciplinary silos and weak systems thinking in education and governance reduce the capacity to manage cross-sectoral transitions effectively.

Regulatory frameworks often evolve more slowly than technology. Misaligned permitting processes, fragmented standards and limited opportunities for experimentation delay implementation and increase investor uncertainty. Anticipatory and adaptive approaches, including regulatory sandboxes, pilot zones and iterative standardisation can help balance innovation speed with accountability and safety.

Governance and coordination challenges persist across institutional levels. Dispersed responsibilities, short policy cycles and insufficient alignment between EU, national and local actions reduce coherence and slow cumulative learning. Strengthening institutional capability and feedback mechanisms is key to enabling consistent progress.

These challenges illustrate that Europe's innovation challenge is systemic rather than sector-specific, rooted in the interaction between financial structures, institutions, regulation and culture. This is borne out by recent firm-level evidence, which points to structural features of European capital markets as the primary driver of the scale-up gap, rather than a shortage of innovative firms [458]. Yet the same systems perspective also reveals entry points for progress.

Across different domains, experts and practitioners highlighted a number of **enabling conditions** that could significantly strengthen the environment for green innovation. Public–private collaboration and mission-oriented partnerships can provide legitimacy and risk-sharing. Clear policy direction and stable long-term targets help reduce uncertainty for investors and innovators. Adaptive regulation, knowledge-sharing infrastructures and education reforms enhance learning and diffusion. Inclusive governance and citizen engagement build trust and social acceptance, embedding innovation more deeply within communities. Many of these enabling factors rely less on additional resources than on improved coordination, transparency and institutional capacity (Figure 17).

Scaling innovation also requires recognising its multidimensional nature: **scaling up** (institutionalisation through policy and regulation), **scaling out** (replication across geographies and sectors), **scaling big** (market penetration and industrial uptake) and **scaling deep** (cultural and behavioural embedding). Successful transitions advance across all these dimensions simultaneously, combining technological progress with social and institutional transformation.

Several **policy levers** emerge as priorities for the next phase of the EU's innovation agenda:

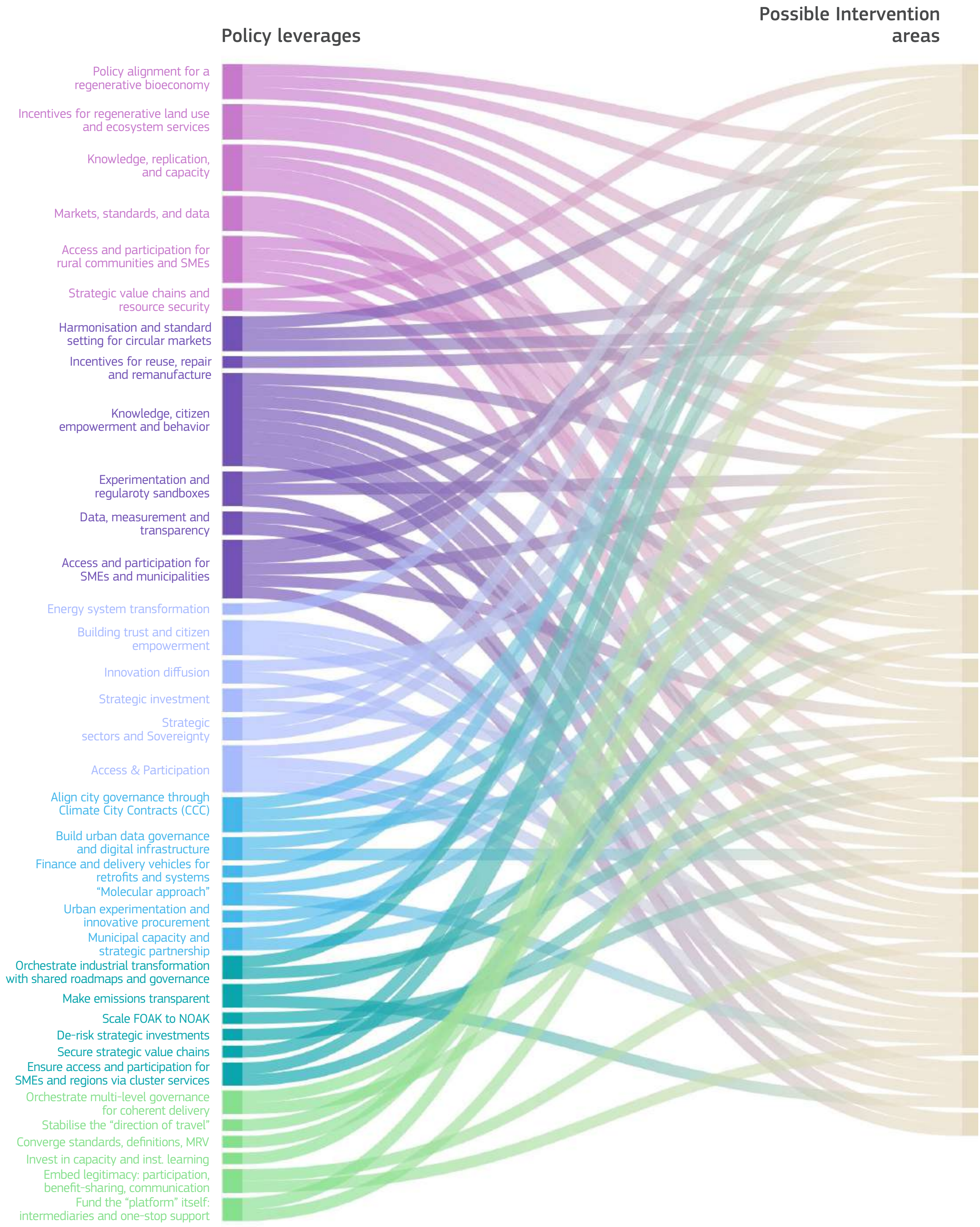
- Provide long-term **regulatory clarity** and investment signals aligned with EU climate and competitiveness goals.
- Combine grants, guarantees and equity in **blended-finance instruments** to de-risk early deployment and crowd-in private capital.
- Strengthen multilevel **innovation ecosystems** by linking local experimentation with EU-wide missions and industrial alliances.
- Promote ***policy as a platform*** for collaboration between administrations, industry, academia and citizens.
- Invest in **learning infrastructures** - policy labs, demonstration programmes and shared facilities - that turn experimentation into institutional knowledge.

Integrate fairness and inclusion as guiding principles to ensure that innovation benefits are distributed across regions and social groups.

Building the systemic capability to scale innovation - through coherent regulation, adaptive finance, institutional competence and societal engagement - will be essential to revitalising Europe's innovation cycle and ensuring that the clean transition strengthens both sustainability and strategic autonomy.

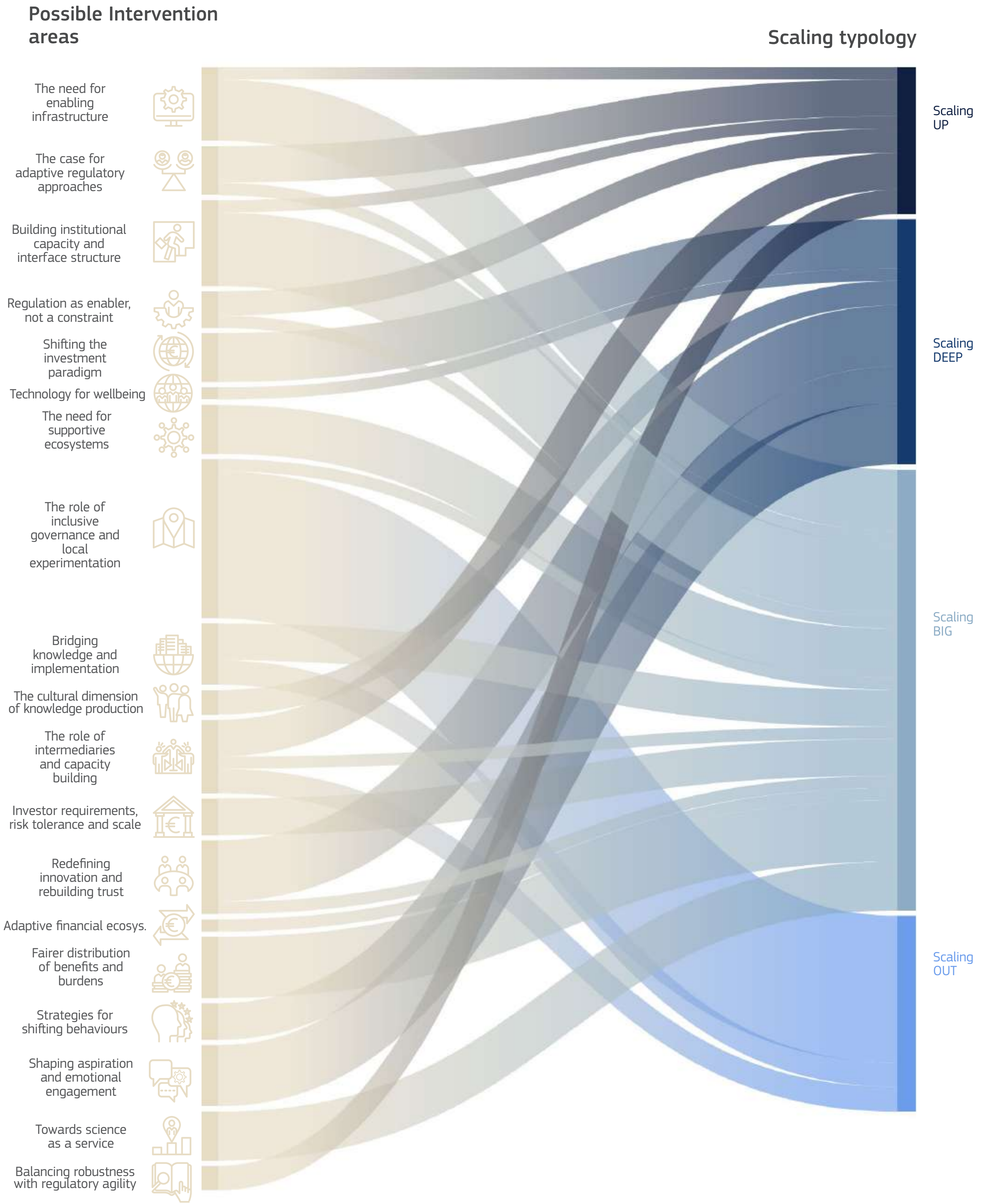
From frontier research to collaborative innovation ecosystems, institutional support for research and innovation plays a critical role in developing the knowledge base, capabilities and transformative solutions needed to achieve the clean transition (Box 5).

Figure 17. Possible intervention areas, based on policy leverages, per scaling typology.



Source: Authors' elaboration [490].

Figure 17. Possible intervention areas, based on policy leverages, per scaling typology.



Source: Authors' elaboration [490].

5.2 Innovation in the Clean Energy sector

In recent years, the EU has achieved market success in the clean energy sector through technological excellence. The JRC Clean Energy Technologies Observatory and Strategic Energy Technology Information System assessment of the clean energy sector innovation landscape in support of the Research, Innovation and Competitiveness dimension of the Energy Union, the annual State of the Energy Union Report [490] and the Progress Report on Clean Energy Competitiveness [491] shows that this advantage is slipping.

The EU still leads in global high-value patent filings in renewables (29%) and energy efficiency (23%) but falls behind in digital and smart applications related to clean technologies. While the EU continues to perform well, China is increasingly leading in research outputs on clean technologies. In terms of scientific publications, the EU is more specialised than the US but stagnating behind China on smart, green and integrated transport as well as secure, clean and efficient energy. Nonetheless, it is still leading in specialisation, when scientific output is grouped under the headline of the SDG 7 for affordable and clean energy [456].

The EU leads globally in public R&I spending in clean energy technologies both in absolute terms and as a share of GDP. Public investment in research and innovation in the Energy Union R&I priorities [492], [493] has been steadily increasing, with EU Member States reporting a 23% rise in 2022 compared to the previous year. Combined with Horizon Europe funds, public investment in clean energy technologies has surpassed EUR 9 billion, and is set to increase more based on the latest preliminary figures which indicate a further 9% increase in public R&I spending [462]. Nevertheless, the *Commission's assessment of draft National Energy and Climate Plans* in December 2023 [492] highlighted a lack of national objectives and funding targets.

Despite the EU's lead in public R&I, private R&I investment, which accounts for over three quarters of clean energy R&I funding, remains significantly higher in major Asian economies. To keep pace with global leaders, Europe should **accelerate private sector investments in critical areas like solar PV and electrolysers**. Targeted measures, such as **green public procurement rules** [494] and reduced **regulatory burdens**, aim to further support EU-based startups and scale-ups [495]. Anti-subsidy measures, such as the investigation into Chinese electric vehicle imports, help safeguard EU industries from external market distortions [496].

The 2024-2029 Commission political guidelines recognise R&I as a key driver of competitiveness, with measures to increase research spending and support strategic technologies [2].
The EU must adopt a more coordinated approach to R&I funding, focusing on critical areas of the clean transition such as renewable energy, energy efficiency, and green hydrogen. Frameworks like Horizon Europe and the Strategic Energy Technology (SET) Plan represent progress, but greater action is needed. For example, the Horizon Europe programme has not prioritised manufacturing processes, showing that the EU's research and innovation policy is not sufficiently linked to its industrial policy.

In 2023, the EU captured a growing share (28%) of global venture capital investment in clean energy technologies, but lower activity in 2024 has led to the first decline in investment in a decade, and access to finance remains an issue [462]. The EU should also **streamline regulatory processes** to reduce lock-ins for clean-tech startups and ensure that Europe remains a hub for green innovation. Public-private partnerships, such as the *European Battery Alliance* and the *European Clean Hydrogen Alliance*, are crucial to scaling up transformative technologies.
In 2023, the Commission revised the SET (Strategic Energy Technology) Plan and integrated it into the *Net-Zero Industry Act*. This strengthens its role in advancing R&I within the Energy Union and boosting the EU's manufacturing capacity for net-zero technologies. Through coordinated national research efforts, the SET Plan helps to lower the cost of new technologies, foster cooperation across EU countries, companies, and research institutions, and align national R&I programmes with its objectives. The annual SET Plan implementation progress reports published by the JRC [497], provide an overview of activities focusing on strategic research agendas that align public and private priorities and investments with those at EU, national and regional levels to accelerate the development and deployment of low-carbon energy technologies.

5.3 Innovation in the Bioeconomy

A **sustainable and circular bioeconomy** is essential for a green and fair transition in Europe (Chapter 4). The *EU Bioeconomy Strategy* defines the bioeconomy as activities that 'deliver sustainable solutions to create added value'. As such, it is a key enabler to address the interconnected environmental, societal, and economic challenges. Additionally, the bioeconomy can ensure both greater resilience and strategic autonomy in securing sustainable food, energy, and materials. By reducing dependency on fossil-based and non-renewable resources, the bioeconomy can help tackle the intertwined crises of climate change, pollution, and biodiversity loss.

Bioeconomy policies take a **holistic and cross-sectoral perspective** to improve policy coherence and identify and resolve trade-offs across the entire bio-based value chain, embracing a system perspective from ecosystem services to end-of-life of bio-based products and including sustainable management of natural resources, land and biomass supply and demand, product manufacturing, food, energy production, cascading and circular use of resources. This makes it possible to identify win-win solutions that generate economic gains, preserve the environment, and increase resilience and capacity for recovery. In essence, a sustainable, circular bioeconomy offers opportunities to support the EU's strategic priorities by:

- Reducing reliance on fossil fuels and other harmful materials and advancing a circular economy through the use of biomass, biomass residues, side streams, and circular product designs.
- Promoting regenerative practices in agriculture, forestry, and aquaculture to diversify income sources and improve sustainability.
- **Strengthening rural and coastal economies**, particularly in central and eastern Europe, rich in biological resources.
- Enhancing sustainable biomass conversion through biotechnologies (Chapter 5.4).

The bioeconomy depends on the competitiveness and sustainability of primary sectors such as sustainable agriculture, forestry, and water and waste management. By **aligning scientific and technical innovations**, such as alternative proteins, biomanufacturing, and sustainable construction, with environmental and climate policy goals, the bioeconomy can drive prosperity, competitiveness, and environmental restoration while supporting net-zero emissions, ecosystem restoration, and resilience. **Biomass** offers a viable alternative to fossil-based materials; however, while being a renewable raw material, its availability is limited by the capacity of ecosystems to regenerate it while preserving or restoring healthy conditions. The **biomass supply gap** is already a reality today and is projected to widen under business-as-usual scenarios as sustainable biomass supply struggles to meet demand for materials and energy. Addressing this requires **significant research and innovation efforts** but also a holistic, cross-sectoral approach and coordinated policies to manage competition for sustainable biomass resources and ensure the availability of feedstock.

The bioeconomy offers opportunities for greater benefits by leveraging numerous **technologies and innovations** that enhance the production, processing, and use of biomass with reduced environmental impact. **Biotechnologies, social innovations, and nature-based solutions** contribute not only to a circular economy but also to creating new markets and adding long-term value. These advancements are fundamental in transitioning toward a sustainable bioeconomy that benefits both people and the planet. As global demand for bio-based products grows, the EU's bioeconomy holds the potential to **boost competitiveness and unlock significant growth opportunities** through sustainable and innovative production methods. While still heavily reliant on research, increased investment in the bioeconomy can enhance biomass production, position Europe as a leader in green technologies and high-value bio-based manufacturing, and support the development of competitive, resilient value chains.
Assessing the **environmental impacts** that bioeconomy solutions can play is crucial, and particularly regarding the potential of bio-based products to reduce environmental impact in comparison with their conventional counterparts.

It is of particular interest to understand the potential trade-offs and shifting of impacts among different products, the various lifecycle stages (e.g. reducing impacts of raw materials but requiring additional manufacturing steps) or environmental impacts (e.g. reducing climate change while increasing land use impacts). In this respect, to monitor the environmental implications of bio-based products consumed in Europe, the JRC proposed a first life cycle assessment (LCA)-based '**Bioeconomy Footprint**' model [498]. In addition, further ongoing analysis is exploring, both at the product and at the aggregate level, the potential of bio-based products to reduce environmental impact in comparison with their conventional counterparts.

In April 2023, the Council of the European Union provided recommendations for the European Commission to further integrate the bioeconomy into all policies, to facilitate knowledge transfer to rural areas and finally to update the *EU Bioeconomy Strategy* and associated *Action Plan*. These conclusions explicitly highlighted the need to reinforce the bioeconomy's contribution to competitiveness, innovation and regional development, while ensuring sustainability and coherence across policy domains. Responding to these recommendations, the European Commission adopted in November 2025 a new strategic framework, ***A Strategic Framework for a Competitive and Sustainable EU Bioeconomy.*** The framework positions the bioeconomy as a core pillar of the EU's green and industrial transitions, emphasising its role in reducing strategic dependencies on fossil-based and imported raw materials, strengthening resilience and supporting long-term economic competitiveness.

The strategy marks a shift towards industrial scale-up and market creation, with a strong focus on biotechnology and biomanufacturing as key enablers of cost-competitive and scalable bio-based solutions. It prioritises accelerating innovation from lab to market, closing investment gaps and developing lead markets for bio-based materials, chemicals and technologies. At the same time, it underscores that growth in the bioeconomy must remain within planetary boundaries, placing renewed emphasis on the sustainable sourcing and efficient use of biomass, circularity and ecosystem resilience.
The Knowledge Centre for Bioeconomy (KCB), managed by the JRC, develops and maintains knowledge on the bioeconomy to support EU policymakers. As part of the KCB knowledge base, the EU Bioeconomy Monitoring System (EU-BMS) was developed by the JRC to track progress towards the bioeconomy strategy objectives. The latest trends in the EU bioeconomy observed with the EU-BMS are illustrated in a recent report [499].

5.4 Biotechnologies

Biotechnology is increasingly recognised as a technology that can strengthen Europe's industrial base, enhance strategic autonomy and resilience, support innovation and help address environmental and societal challenges, including climate change, food security [500], nature restoration [501], human health [502], and marine applications [503]. Over the last two decades, the EU biotechnology industry has grown steadily, reaching an average growth rate higher than the total economy and a gross value added of €38.1billion in 2022 [504].

Biotechnologies are an important enabler of the clean transition, **fostering competitiveness within Europe's innovation** landscape, as also highlighted in the Competitiveness Compass [4]. The EU has since advanced this agenda through the *Life Sciences Strategy* [38] and the new *Bioeconomy Strategy* [505], which identify biotechnology as key driver in for scientific excellence and industrial innovation. Furthermore, the legislative proposal for the first *Biotech Act* has been recently published, with the aim to incentivise biotechnology and **biomanufacturing** in the **healthcare** sector, as it is the sector in which biotech has the most significant economic impact (40% of all medicines sold in the EU are bio-medicines) [506]. A second initiative, the *European Biotech Act II*, is listed in the Commission Work Programme 2026 [507] and is also expected to address the wider biotechnology landscape beyond the health and pharmaceutical sectors.

Biotechnology and biomanufacturing rely on **living organisms** (e.g. microorganisms such as bacteria, fungi, and microalgae) to convert biological resources into a wide range of consumer products through different bioprocesses (e.g. precision fermentation). The new *EU Bioeconomy Strategy* identifies biorefineries, advanced fermentations (including using engineered microorganisms) and permanent storage of biogenic carbon technologies as **lead biotechnologies** to scale up the European bioeconomy and support EU industrial base.

As previously mentioned, the biotech sector encompasses a wide range of applications across multiple fields, however the largest contribution is concentrated in the healthcare (e.g. vaccines, gene/cell therapies), industrial (e.g. chemicals) and agricultural (e.g. crop engineering) sectors [481]. Other areas of interest for biotechnological applications include **food** (e.g. production of proteins, lipids and other food components), and **energy** (e.g. biofuels production). In fact, biotechnologies can be classified according to the sector in which they are primarily used [481], [508]: **"red" biotechnology** is referred to applications in the healthcare and pharmaceutical sectors; industrial and environmental applications are labelled as **"white" biotechnology**; **"green" biotechnology** refers to applications in the agri-food sector and **"blue" biotechnology** refers to applications using marine and aquatic resources, including algae production and using aquatic living organisms [481].

Environmental biotechnology plays a key role in boosting the clean transition by enabling a more sustainable use of resources. For instance, bioremediation uses living organisms to remove or neutralise contaminants from polluted environments. This makes it particularly relevant for **soil and water remediation**, **pollution control and ecosystems restoration**. Biotechnological approaches such as bioleaching and phytomining also enable the recovery of technology-critical and rare earth metals from electronic waste and biomass used from phytoremediation in contaminated sites, supporting both circularity goals and strategic raw materials supply.
Biotechnologies are in fact key instruments to reach a more circular bioeconomy. **Wastes and by-products from several sectors (e.g. agri-food system) can be valorised and converted into high value-added products (e.g. bio-based fertilisers, bio-based plastics, bio-based chemicals) and energy**. This approach can contribute to reduce EU dependency on fossil-based inputs and support a higher resource efficiency. Carbon storage using biotechnological processes is also increasingly recognised as a promising approach to support climate mitigation and the transition towards a circular economy [46].

Strengthening biotechnologies can support both environmental sustainability and industrial competitiveness. Actions to close innovation gaps should target the main biotechnological players and processes. Microorganisms are central to numerous biotechnological applications as they possess the capacity to convert raw materials, side streams and wastes into valuable products through bio-chemical processes. The full exploitation of microbial potential is far from being reached, as the vast majority of environmental microorganisms have yet to be fully characterised.

The biotech sector is currently facing several challenges: (1) ensuring **feedstock availability** (at competitive cost) and its inherent heterogeneity; (2) optimisation of **production efficiency** despite intrinsic biological variability; (3) high costs and limited access to **funding and investments**; (4) techno-economic complexity of **scaling up** from pilot to commercial scale; and (5) **commercialising** (legislative burden and public opinion); all while maintaining high level of safety and protection.

A number of actions can help to fill knowledge and innovation gaps in the biotech sector, some examples are outlined below:
- The Commission has launched a new *Biotech and biomanufacturing Hub* to promote exchanges among stakeholders and to support companies, particularly start-ups and SMEs, in bringing innovative products to the EU market and increase their competitiveness.
- The promotion of innovative **research** on biotechnology applications (e.g. through Horizon Europe calls).
- Support a secure deployment of **AI** and use of data, also in light of the ongoing **digital transformation**.
- The development of targeted **communication** and engagement efforts on biotechnology, building on existing initiatives. This is particularly important to address public concerns and misconceptions, while avoiding fragmented or duplicative messages across the growing number of policy initiatives in this area.

Finally, the forthcoming *Biotec Act II* will build on the already in place policy framework for the biotechnology sector, closing current gaps and addressing hurdles and challenges faced by the sector. This initiative aims to streamline the regulatory framework, [2], [479], strengthen R&D and investment to scale up innovative solutions, and build public trust, thereby unlocking the full potential of biotechnology in the EU to drive sustainable growth and competitiveness while creating job opportunities. To remain competitive, Europe must leverage its advanced knowledge and regulatory frameworks to close the innovation gap through the strategic use of biotechnology [481]. This means moving beyond research excellence and creating the conditions for biotechnology solutions to be tested, approved and deployed across sectors.

5.5 The Blue Economy

Socioeconomic relevance of the EU blue economy

The blue economy, encompassing all economic activities based on or related to oceans and seas, directly **employs over 4.9 million people** in the EU and accounts for **1.7% of EU Gross Value Added** (GVA) [465]. Established blue economy sectors, including fisheries, aquaculture, coastal tourism, maritime transport, port activities, shipbuilding and marine extraction of oil and gas, generated a GVA of EUR 255.9 billion in 2023 (see data reported on the EU Blue Economy Observatory), up by 35% compared with 2020, when most blue economy sectors – particularly Coastal Tourism – suffered from the restrictions imposed by the COVID-19 pandemic, making the lowest contribution to the EU economy since 2009. These figures do not include the **marine defence industry** and other emerging sectors for which data is not fully available in the public domain. The contribution of the blue economy to the entire EU economy extends well beyond the above-mentioned sectors. It also supports a wide range of related industries and services across multiple supply chains, leading to considerable spill-over effects and economic benefits, further amplifying its economic impact. Furthermore, the blue economy has the **potential to drive innovation and technological advancements in a wide range of sectors**, such as marine renewable energy, aquaculture, desalination, robotics, and marine biotechnology.

Seas and oceans remain largely unexploited compared to land, holding vast potential for economic growth and development. Their exploitation requires careful management to ensure a sustainable, resilient and competitive blue economy.

In turn, marine ecosystems require conservation and restoration activities, thereby creating new opportunities for sustainable management practices, nature-based solutions and green employment.

Enablers, solutions and way forward

A broad range of economic activities and sectors depend on marine resources, natural capital and ecosystem services. This includes the primary sector (e.g. fishing and aquaculture), the marine extractive industry (e.g. oil, gas, and other minerals), manufacturing industries (e.g. shipbuilding, nautical equipment, sport goods, apparel), and services (e.g. food, beverage, accommodation and recreational activities in coastal areas, maritime transport, finance, insurance, defense).

For some of the more "established" blue economy sectors, EU Member States regularly share comparable statistics about their socioeconomic performance, mainly via Eurostat. This includes economic activities in the Marine living resources, Marine non-living resources, offshore wind energy, Port activities, Shipbuilding and repair, Maritime transport, and Coastal tourism sectors. Economic activities of other sectors, such as emerging business applications harnessing innovative technologies and nature-based solutions, are less available in Eurostat statistics. This includes economic activities in sectors such as blue biotechnology, desalination, ecosystem restoration, innovative marine infrastructure, research and robotics.

The European Economic and Security Council (EESC) calls for an *EU Blue Deal* [509] that would recognise water as a strategic priority for the upcoming planning period, equipped with a *Blue Transition Fund* combining public investment with innovative (private sector) financing.

Table 2 provides an overview of some of the most promising enabling solutions for the sustainability transition under implementation in the blue economy, sector by sector. Based on good practices and sectoral policies inspired by the EGD, the solutions presented in this table offer leverage points towards the establishment of a regenerative environment in the EU.

Table 2. Challenges, enablers, good practices for the EU Blue Economy.

ENABLING THE BLUE ECONOMY

Challenges	Enablers and good practices
Blueconomy as a whole	
Knowledge gaps about marine resources, ocean health and sustainability, economic value of marine ecosystem services, etc.	The European Economic and Security Council (EESC) calls for an EU Blue Deal [509] that would recognise water as a strategic priority for the upcoming planning period, equipped with a Blue Transition Fund combining public investment with innovative (private sector) financing. Since 2018, the JRC publishes annual EU blue economy reports [465] monitoring the socioeconomic performance of established and emerging EU blue economy sectors. In 2021, in collaboration with DG MARE, the JRC established an EU Blue Economy Observatory [510] to act as a knowledge gateway facilitating access to information about the socioeconomic performance of EU blue economy sectors and their progress in decarbonisation and energy transition [511] using best available data.
Climate adaptation and mitigation	
Methodological challenges and data gaps may hamper the estimation of socioeconomic impacts of climate change and ocean warming on the blue economy sectors, as well as the effects of potential mitigation strategies. *The Economics of Climate Change, the impact of flooding in terms of economic damages in coastal areas, currently amounting to approx. EUR 1 billion per year, could reach between EUR 137 billion and EUR 814 billion by 2100 under alternative emissions and mitigation scenarios. The impacts are particularly severe in Overseas Countries and Territories (OCT) and Outermost Regions (OR) of the EU, where potential increase in flooded areas is estimated to reach up to 0.5% of the total OCT/OR landmass by 2150, more than 2 800 km² (EU blue economy report 2024 [512]).*	Coastal ecosystems store carbon at the highest rates per unit area. For this reason, the IMF and World Bank promote public and private investments in Blue Carbon as part of countries' blue economy efforts [513]. The climate change mitigation potential of blue carbon deserves to be further assessed, as well as the benefits and drawbacks of nature-based solutions (e.g. boosting algae and shellfish production). Marine Carbon Capture and Storage (MCCS) [514] offers potential complementary solutions to mitigate climate change by reducing the amount of CO_2 in the atmosphere and reducing ocean acidification. MCCS technologies and approaches that are being researched include ocean afforestation (e.g. kelp forests), direct air capture and deep sea storage, ocean alkalinity enhancement, ocean fertilisation (e.g. iron or nitrogen inputs to stimulate the growth of phytoplankton), among others [515]. Given the potential risks and ecological impacts associated with these technologies [515], more research is needed before large-scale deployment.
Marine living resources	
Financial barriers to fleet renewal, decarbonisation, sustainability transition, and overall compliance with relevant policies and targets	In the EU Blue Economy Observatory, the Guide on Financing opportunities for the Green Energy Transition of Fisheries and Aquaculture contains a database of financing opportunities to support innovation projects in the EU fisheries and aquaculture sector (including energy transition) and an online platform for knowledge sharing on the Energy Transition Partnership with best practices and case studies.

Challenges	Enablers and good practices
The extraction of non-living resources has a major impact on fishing activities and on the marine environment. Extractive activities can discharge contaminants, such as crude oil spills or contaminated water, and generate underwater noise pollution. *It is estimated that around 50% of newly discovered deposits are in the deep-water (between 400 and 1 500 metres) and ultra-deep-water (more than 1 500 metres) range. The ocean's seabed is considered one of the biggest carbon sinks, absorbing around a quarter of the CO_2 emitted yearly by humans [516].* *To date, 24 countries have announced their support for a moratorium, a precautionary pause, or a ban on deep-sea mining [517].*	It is estimated that over 200 platforms and 2 500 wells will be in decommissioning phase by 2025 in the North Sea, the EU's main oil and gas production area. There is potential for the sector to transition towards more sustainable practices, such as exploring and exploiting renewable energy sources, as well as contributing to the development and deployment of low-carbon technologies. Additionally, there is an increasing focus on oceanographic research and the extraction of raw materials from Europe's seas and oceans, which could play a crucial role in the transition to a sustainable blue economy. Liquefied Natural Gas (LNG) is a main solution, facilitating the import of natural gas from countries lacking a direct pipeline connection. LNG serves as a transition fuel for vessels, cleaner than diesel and meeting current IMO emission standards. Between 2021 and 2023, LNG imports within the EU experienced a surge from 20% to 40% of total gas imports [510]. Robotics have high potential in the fields of exploitation and maintenance. Oil and gas companies are exploring the development and use of subsea completion systems managed by underwater robots. These systems are particularly beneficial for deep-water exploitation, as they reduce the need for offshore infrastructure, minimising environmental impacts and cost.
	Marine non-living resources
Despite progress in tapping renewable ocean energy, challenges such as high costs and technical limitations persist. *It typically takes about 11 years to get from the early stage of a wind farm development to its full completion. Annual installation rates need to increase from 7 GW in the late 2020s to over 20 GW in the late 2030s.* *Concerns include environmental impact, visual aesthetics, and potential conflicts with other marine activities.*	Renewable ocean energy (i.e. offshore wind, tidal, currents and wave energy) contributes to progress towards the ambitious targets set in the offshore renewable energy strategy. Furthermore, the sector offers significant potential for job creation and sustainable growth, warranting an enabling policy environment and financial support. Initiatives like the REPowerEU Plan aim to accelerate the deployment of renewable ocean energy solutions.
	Ocean energy
Recent disruptions of global maritime trade routes, together with the fuel price increases registered in the past three years, reveal the counter-cyclical performance of maritime shipping, compared to other Blue Economy sectors, as well as the limited efficiency of regulatory measures and policy-driven incentives to counteract (energy) market dynamics and consumer demand. *The issue of carbon pricing is particularly complex, as carbon prices affect the demand and supply side in multiple ways [518].*	The Renewable and Low-Carbon Fuels Value Chain Industrial Alliance (RLCF Alliance) [519] focuses on boosting production and supply of renewable and low-carbon fuels in the aviation and waterborne sectors. Besides renewable fuels and energy sources, there is a portfolio of complementary decarbonisation options available to the shipping industry which can be pursued via a "ship lifecycle approach": - up to 20% of GHG reductions can be achieved in logistics and digitalization (e.g. speed reduction, vessel utilization, vessel size, alternative routes), - 5-15% in hydrodynamics (e.g. hull coating, hull-form optimization, air lubrication, cleaning), - 5-20% from machinery (improvements, waste-heat recovery, engine de-rating, battery hybridization), and - up to 30% from after treatment measures (e.g. MCCS) [520]. According to observers and market analysts, the current cost of carbon is too low to drive the energy transition of the maritime shipping industry at the scale and pace required to meet the carbon neutrality goals [520].
	Maritime transport

Challenges	Enablers and good practices
Main challenges include congestion, infrastructure upgrades, and technological barriers, requiring sustainable solutions to ensure resilience and meet energy transition goals. *The sale of companies and infrastructures in port to third countries may weaken the EU position in controlling trade and supplies.*	The Alternative Fuels Infrastructure Regulation (AFIR) sets mandatory national targets for the rollout of infrastructure. Many European ports have launched initiatives to reduce their carbon footprint, such as investing in shore power facilities to enable vessels to connect to renewable energy sources while at berth, as well as adopting alternative fuels and technologies to minimise emissions from port activities. Onshore Power Supply (OPS) allows ships docked in port to connect to electrical power derived from renewable sources. With a 2030 target, the EU Horizon Mission "Restore our Ocean and Waters" aims to protect and restore the health of our ocean and waters through research and innovation, citizen engagement and blue investments. Under this Mission, cross-cutting enabling actions are implemented for investing in digitalisation and automation technologies to improve efficiency, reduce emissions, and enhance overall port operations (Digital Twin Ocean) [58]. In January 2024, the European Parliament adopted a resolution on building a comprehensive European Ports Strategy (EPS), which aims to ensure the future competitiveness and resilience of European ports and limit foreign dependency in this sector. The resolution foresees limits on foreign investment that could undermine security in the EU [521]. **Port activities**
The EU houses approx. 300 shipyards and leads in niche markets like cruise ships and superyachts. However, challenges such as high production costs, competition from Asia, and cyclical demand patterns persist. *The demand of this segment of the shipbuilding industry is often cyclical and seasonal and influenced by factors such as tourism trends, travel restrictions, bans, etc., as caused recently by COVID-19 and the Russian invasion of Ukraine.*	The EU Regulation on ship recycling (or "scrapping") aims to reduce the negative impacts linked to the recycling of EU-flagged ships and to ensure that, as of 31 December 2020, ships calling at EU ports or anchorages either possess an inventory certificate or a certificate of compliance. Ship recycling in the EU registered a peak in 2017; however, that amount was reduced to less than a fourth in 2019. Observers expected a substantial growth of (regulatory-driven) ship recycling over the coming years, as numerous fleets are approaching their end of life [520]. Since 31 December 2018, the EU Ship Recycling Regulation has been requiring all large sea-going vessels sailing under an EU Member State flag to use an approved ship recycling facility included in the European List of ship recycling facilities. Several yards on the European List are also capable of recycling large vessels [522]. New business opportunities for the shipbuilding industry arise from emerging trends like expedition cruising and vessel refurbishment, urging European shipbuilders to adapt and innovate in a rapidly evolving landscape. Order books for new buildings of large container vessels and tankers have registered a significant growth over the past 3 years, mainly benefiting Asian shipyards (China, South Korea, Japan), while the EU secured a relatively minor share of global demand (7%) [510]. **Shipbuilding and repair**
Tourism demands are typically concentrated in a limited number of months – usually July and August. *The sector was hit hard by the COVID-19 pandemic in 2020 and did not fully recover.* *Tourism can consume large quantities of energy, water, and plastics, which degrade the environmental quality of destinations and ecosystems, affecting the lives of residents.* *Unsustainable tourism and over-tourism create strong pressures and impacts on fragile marine and coastal ecosystems. European biodiversity is declining at an alarming rate, with 57% of Atlantic marine habitats, and 75% and 40% of Baltic and Mediterranean marine species respectively, in bad condition [523].*	The high sensitivity of the sector to exogenous shocks, and its vulnerabilities to climate, nature and geopolitical events highlights the importance of both supply-side and demand-side measures to promote sustainable practices in the sector and a responsible tourist behaviour. The Nature Restoration Regulation has the potential to be a game-changer for the ocean, by supporting the restoration of damaged marine habitats to support biodiversity and resilience to climate change [524] [525]. According to a recent study, adopting clear environmental goals, circular economy principles, energy efficiency and fuel flexibility, and collaboration across the ecosystem are no-regrets measures that can be taken now to facilitate the sustainability transition of the sector. Good practices in this sense have been identified across a range of cruise tourism-related activities, ranging from Onshore Power Supply (OPS), LNG bunkering, sustainable cruise terminals, food waste reduction and waste treatment to a holistic approach to destination management [526]. Travel and tourism actors can both act as enablers of circularity in a wider economic context, and at the same time benefit from circularity models in other industrial value chains. **Coastal tourism**

Challenges	Enablers and good practices	
It is predicted that many regions in the EU will face severe water scarcity by 2050, when water demand is expected to increase by up to 30% [527]. *Desalination can help tackle issues of water scarcity. However, this technology is energy-intensive, costly and can have significant environmental impacts both in terms of GHG emissions and in terms of brine discharge in marine ecosystems, which accumulates on the seafloor, threatening species that are sensitive to the level of salinity [528].* *Approximately 1.5 litres of brine (salt-saturated water) are produced as waste for every litre of fresh water.*	Augmenting freshwater supply through seawater desalination is already a cornerstone of drinking water security policies, as well as a source of complementary freshwater for agricultural, industrial and municipal uses in some EU countries [512]. A recent review of the largest vendors shows that EU companies represent a significant share of technology providers. Efforts to mitigate its impacts combined with technological advancements are enabling a transition to sustainable desalination. There is a substantial innovation potential to i) significantly reduce the currently high and costly energy consumption, ii) reduce the greenhouse gas emissions of installations (by using renewable energies), and iii) reduce the impacts on the environment through the reduction and appropriate disposal of brine discharges, ideally combined with the recovery of valuable minerals and energy from salt water. Desalination must be framed in an integrated water management approach, with rigorous application of the "efficiency first" principle and with a sustainable balance between water supply and demand.	**Desalination**
Maritime defence, security and surveillance sectors are gaining relevance and expanding with many technological innovations and applications for military and civilian uses (dual-use). Maritime security is affected by transnational crime, piracy, territorial disputes and threat of seabed warfare. *Building and maintaining a state-of-the-art military complex is complex and expensive. In the EU there is a wide diversification of military equipment.*	Maritime defence has important relations and synergies with other blue economy sectors such as maritime transport, shipbuilding and port activities. Securing transport routes and creating book orders in shipyards for new vessels is essential. Technological innovation for the maritime defence industry steers innovation in other marine sectors, i.e. military innovations (e.g. radars and sonars) often ending in civil sectors after some time. To prepare against seabed warfare, the industry is developing Autonomous Underwater Vehicles and Unmanned Underwater Vehicles, with a focus on advanced navigation and communications, efficient energy and propulsion systems.	**Defence**
Algae aquaculture faces challenges like reduced domestic demand, fierce Asian competition and regulatory hurdles. Also, the industry depends on unpredictable conditions at sea, which may lead to increased yield variations. *Despite around 30% of algae-related companies located in Europe, the EU (including EEA countries) still has less than 1% of global algae production.* *Europe is lagging behind on cellular aquaculture and has not yet regulated any cell-based product.* *Beyond algae and cellular aquaculture, the broader potential of marine living organisms, including aquatic microorganisms from extremophilic environments with unique biosynthetic properties, faces common bottlenecks across applications: long development timelines, high capital requirements, difficulties in scaling biological processes, limited characterisation of relevant organisms, and fragmented regulatory pathways at both EU and Member State levels [510].*	Harnessing marine living organisms for the development of pharmaceuticals, nutraceuticals, cosmetics and personal care products, and biomaterials (e.g. biofuel and bioplastic) can help tackle global challenges such as disease, food security, and climate change, but also bioremediation and environmental monitoring of pollutants (e.g. bacteria and fungi able to degrade organic pollutants and detoxify heavy metals). Innovation in seaweed and microalgae production, supported by initiatives like the EU's Algae Initiative, is essential for unlocking its potential and overcoming scalability and market acceptance obstacles. Addressing persistent data and knowledge gaps on macroalgae production, flows and uses will also be critical to support both policy development and sector growth (Box 6: Closing the data gap for macroalgae). Cellular aquaculture, also known as cell-based or cultured seafood production, represents a revolutionary approach to aquaculture that involves the cultivation of seafood products from animal cells in a controlled laboratory setting.	**Blue Biotechnology**

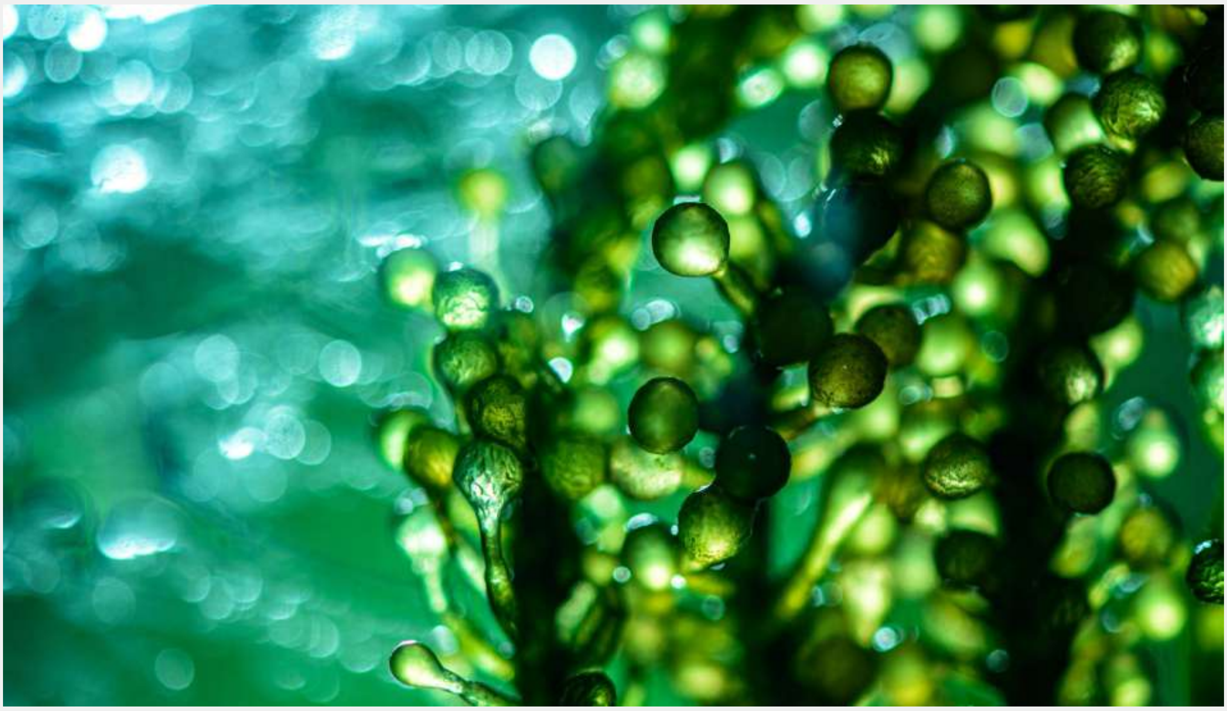
Source: Authors' elaboration.

Box 6. **Closing the data gap for Macroalgae**

Algae play a crucial role in marine ecosystems, supporting complex food webs and contributing to global primary production. In recent decades, global macroalgae, i.e. seaweed biomass production, has grown rapidly due to increasing market demand for algae biomass in various sectors, including feed and food supplements, nutraceuticals, pharmaceuticals, third-generation biofuels, and bioremediation [529]. While global macroalgae production mostly comes from aquaculture cultivation, wild-stock harvesting is the primary method (99.3%) in Europe [391]. The *European Green Deal*, the *Farm to Fork Strategy*, and the *Sustainable Blue Economy Communication* highlight the potential of farmed seafood as a low-carbon source of protein for both food and feed, and advocate for its expansion [530].

Despite the potential of macroalgae biomass production to contribute to a sustainable clean transition, **data and knowledge gaps continue to hinder its deployment as a source of biomass for the blue economy**. The low quality and availability of data on macroalgae production, flows, and uses prevent an overarching approach to assess the potential utilisation of this biomass. National reporting systems vary yearly and across countries, leading to mistakes and errors in the data, and some countries do not regularly report data or stop reporting for some time, leading to large data gaps.

To address these gaps, recommendations include **implementing specific harvest recording approaches by species, training programmes for harvesters, producers, and personnel recording and processing the data** to ensure the right identification of the species and aligning national reporting systems across Europe to ensure harmonisation. Particular focus should be put on the time continuity of the national reporting systems [391]. Additionally, the implementation of the action plan, *Strengthening a sustainable EU Algae Sector* [530], to tackle the lack of robust and reliable data on the algae sector, is crucial to improve data quality and coordination with the EU Data Collection Framework. The action plan also cautions against replicating the environmental mistakes historically made on land in water in terms of over-exploitation of biomass, which underlines the importance of the collection of sound and continuous data. In addition, Macias Moy et al. [391] point out that the environmental and socioeconomic aspects of an expansion of algae use would need to be assessed and surveyed carefully.
Enhancing the quality and quantity of available information is crucial to support both policy development and the algae sector in Europe. For more comprehensive and detailed insights concerning macroalgae production and supply, the reader is referred to [391].



5.6 The Digital Transition

The digital and clean transitions have been bundled together as 'twin challenges' because they interact with – and influence – each other and also they are deemed **equally important for the future**.
While digital solutions can support a shift toward less carbon-intensive by reducing travel or implementing smart energy efficiency measures, they also consume energy. Digital technologies account for 8-10% of total energy consumption and 2-4% of greenhouse gas emissions [531]. Research by the World Economic Forum estimates that digital technologies have the potential to reduce GHG emissions by up to 20% in sectors otherwise difficult to decarbonise [532]. Nonetheless, the digital transformation can inadvertently also encourage unsustainable practices such as resource intensity and electronic waste. The increasing complexity and pervasiveness of artificial intelligence (AI), and in particular of generative AI models, have significant environmental implications, including high energy consumption, water usage, and mineral extraction [533]. As such, progress in digitalisation has to be in balance with potential environmental impacts and seek to minimise the latter (Box 7).

The JRC study "*Towards a green and digital future - Key requirements for successful twin transitions in the European Union*" [534] examined the opportunities and pitfalls in the green and digital transitions in achieving the climate neutrality goals. The Focus 5 summarises the report findings on the key requirements for the twin transition as presented in [534]. Building on these findings, the 2022 *Strategic Foresight Report* [535] identified 10 areas of action for a successful twin transition:
1. **Strengthening resilience and open strategic autonomy** in sectors critical for the twin transitions via, for instance, the work of the EU Observatory of Critical Technologies.
2. **Stepping up green and digital diplomacy**, by leveraging the EU's regulatory and standardisation power, while promoting EU values and fostering partnerships.
3. **Strategically managing supply of critical materials and commodities**, by adopting a long-term systemic approach to avoid a new dependency trap.
4. **Strengthening economic and social cohesion**, by reinforcing social protection and the welfare state.
5. **Adapting education and training systems** to match a rapidly transforming technological and socioeconomic reality as well as supporting workforce mobility across sectors.
6. **Mobilising additional future-proof investment** in new technologies and infrastructures.
7. Developing monitoring frameworks for measuring **well-being beyond GDP**.
8. Ensuring a future-proof **regulatory framework for the Single Market**, conducive to sustainable business models and consumer patterns.
9. Stepping up a **global approach to standard-setting** and benefitting from the EU's first mover advantage in competitive sustainability.
10. **Promoting robust cybersecurity and secure data sharing framework** to ensure, among other things, that critical entities can prevent, resist and recover from disruptions.

Through *Europe's Digital Decade* [536], the EU is pursuing a human-centric, **sustainable** vision for digital society that will empower citizens and businesses. The *Digital Decade Policy Programme*, in its objectives and targets, includes ensuring the sustainability and resource efficiency of energy infrastructures and technologies.
The *Multiannual Financial Framework* (MFF) for 2021-2027 allocates around €207 billion, or about 21% of the total budget, for digital initiatives, including Digital Decade targets and broader digital objectives. This funding is mainly distributed through five key instruments: the *Recovery and Resilience Facility*, *Cohesion Policy*, *Horizon Europe*, *Digital Europe Programme*, and *Connecting Europe Facility-Digital* [537, pp. 2021–2027].
The 2025 report on the State of the Digital Decade also highlights the opportunities of harnessing digitalisation for the clean transition, acknowledging that both transitions are strongly coupled with EU competitiveness.

The **ICT industry** (Information and Communication Technology) has already committed to supporting the **twin transition** through the *European Green Digital Coalition* [539] and – supported by **EU funding** – researching and publishing methodologies to measure the **net impact of digital solutions on the climate** [540]. There is also continuing work on the part of the *European Commission* to develop **common indicators** for measuring the **environmental footprint of electronic communications networks** for the provision of electronic communications services [541]. Indicators relating to **energy**

Focus 5 Key requirements for the twin transition

Social

Ensure just transitions
Society at large has to benefit from the twin transitions, for example by overcoming the digital divide and avoiding subsidies that do not benefit vulnerable groups of society.

Increase societal commitment to the need to change
Awareness and inclusive societal debates are needed to change common behaviours and values in favour of the twin transitions.

Ensure privacy and ethical use of technology
Create willingness to share (strictly necessary) data by protecting privacy through anonimization, empowering end users to understand how data is used.

Technological

Ensure data availability and security
Data governance regulations must ensure clarity about who owns data and who has access to it. It must protect stakeholders and make sure data is secure.

Build a coherent and reliable technology ecosystem
Technology interoperability and reliability will be crucial in an increasingly complex and interconnected ecosystem.

Implement innovation infrastructure
Research ecosystems are needed for the development and improvement of green-digital technologies. Furthermore, enabling technologies require an adequate infrastructure for their roll out.

Environmental

Avoid rebound effects
Awareness raising, adequate governance systems, and market mechanisms that avoid market failures can mitigate unintended side effects of the implementation of green-digital solutions

Reduce the environmental footprint of green-digital solutions
Reduce consumption, emissions, and pollution of green-digital solutions throughout their entire life cycle.

Economic

Create enabling markets
Markets have to internalize the environmental costs of products to give long-term investment incentives for green-digital solutions.

Ensure diversity of market players
The market for green-digital solutions should not be dominated by a few players but should be a healthy ecosystem that also includes SMEs and start-ups.

Equip labour with relevant skills
Education and training have to ensure that workforce is equipped with the skills they need to handle green-digital technologies and drive innovation.

Political

Implement adequate standards
Standards should ensure interoperability, keep entry barriers low, and avoid that technologies become obsolete before their end of life.

Ensure policy coherence
Regulations should be consistent in the long-term across different government levels and regions to have a stable framework that facilitates cooperation while avoiding unnecessary complexity.

Channel investments into green-digital solutions
Regulations have to unlock public and private investments into green-digital solutions.

Box 7. **The increasing relevance of AI in the twin transition**

The increasing demand for computational resources and data storage is driving the growth of data centres, which are **projected to increase their energy consumption by 50% by 2027 and more than double by 2030** [552]. This has significant consequences for greenhouse gas emissions and climate change, mainly driven by the development and adoption of **Artificial Intelligence** (AI), and in particular of generative AI models. The environmental pressure posed by this emerging technology is due to the **high energy consumption of data centres** and the extraction of raw materials for manufacturing AI-related hardware. The estimated 5,000 data centres in the US and 2,000 in Europe are expected to increase their power demand by 50% by 2027, contributing to greenhouse gas emissions and climate change. While it is challenging to identify the exact share of energy consumption attributable to AI, it is estimated that it currently accounts for 14% of data centre energy consumption, projected to rise to 27% by 2027. On the one hand, these estimates may not be taking into account the possible **widespread adoption of reasoning models** such as OpenAI's o1, which yield better capabilities at the expense of an increased demand in computational resources. On the other hand, these estimates were made before the release of DeepSeek-R1, which showed that it was possible to compete with OpenAI for a fraction of the energy consumption.

Additionally, the production of AI-related hardware, such as graphical processing units (GPUs) and tensor processing units (TPUs), requires the extraction of **rare earth minerals**, leading to environmental degradation and pollution. Data centre hardware has a short lifespan of around 3.5 years, and therefore implementing circular economy measures could help **increase the longevity of data centre hardware and reducing e-waste**. In addition, it is critical to contemplate sustainable data centre design and operation, including the use of renewable energy sources and efficient cooling systems. Specific measures such as mandatory tracking of energy consumption, better planning of data centres in water-rich areas, and recycling programmes could help reduce the impact of AI on the environment. Recent advancements in new transistor design and new model designs allow for AI computations directly on devices that could dramatically reduce energy consumption across AI-powered devices.

AI models can also help mitigate climate change by supporting applications like **pollution tracking, weather monitoring, and energy optimisation**. Moreover, emerging technologies like energy-efficient transistors, neuromorphic chips, and specialised edge AI chips are enabling on-device intelligence and reducing energy consumption, which can help achieve a more sustainable and environmentally friendly AI ecosystem. Ongoing and future research into the use of novel materials and innovative algorithmic design might reduce reliance on cloud computing and data centres will be key to enabling a sustainable use of AI and its long-term development and uptake. Policymakers must therefore consider measures to foster RDI, as well as industrial scalability, hardware standardisation and supply chain security, ensuring a true twin transition where energy-efficient technologies meet growing adoption and performance demand. In this respect, the recently published *Apply AI Strategy* recognises the complexity of the interplay between AI and the efforts supporting the climate targets adopted by the EU, and puts forward future initiatives such as the Strategic Roadmap on Digitalisation and AI for the Energy Sector that will further elaborate on the use of AI in the energy system and, together with the *Cloud and AI Development Act*, will address strategies to ensure the sustainability of the AI ecosystem in terms of energy consumption [553].

Overall, a balanced approach is needed to harness the benefits of AI while minimising its environmental impact. This requires a combination of technological innovation, sustainable design and operation, and effective policies and regulations, as well as digital competences including the critical understanding of the environmental impact of the use of AI. The fifth edition of the European Digital Competence Framework (DigComp 3.0) [554], announced under the European Commission's Union of Skills [484], includes competences to foster an informed, balanced and sustainable approach to the use of digital technologies, and an awareness of the large environmental impacts of data centres and digital technologies such as generative AI. Prioritising sustainability across all elements of AI ecosystems would ensure that AI development and deployment support a climate-neutral future.

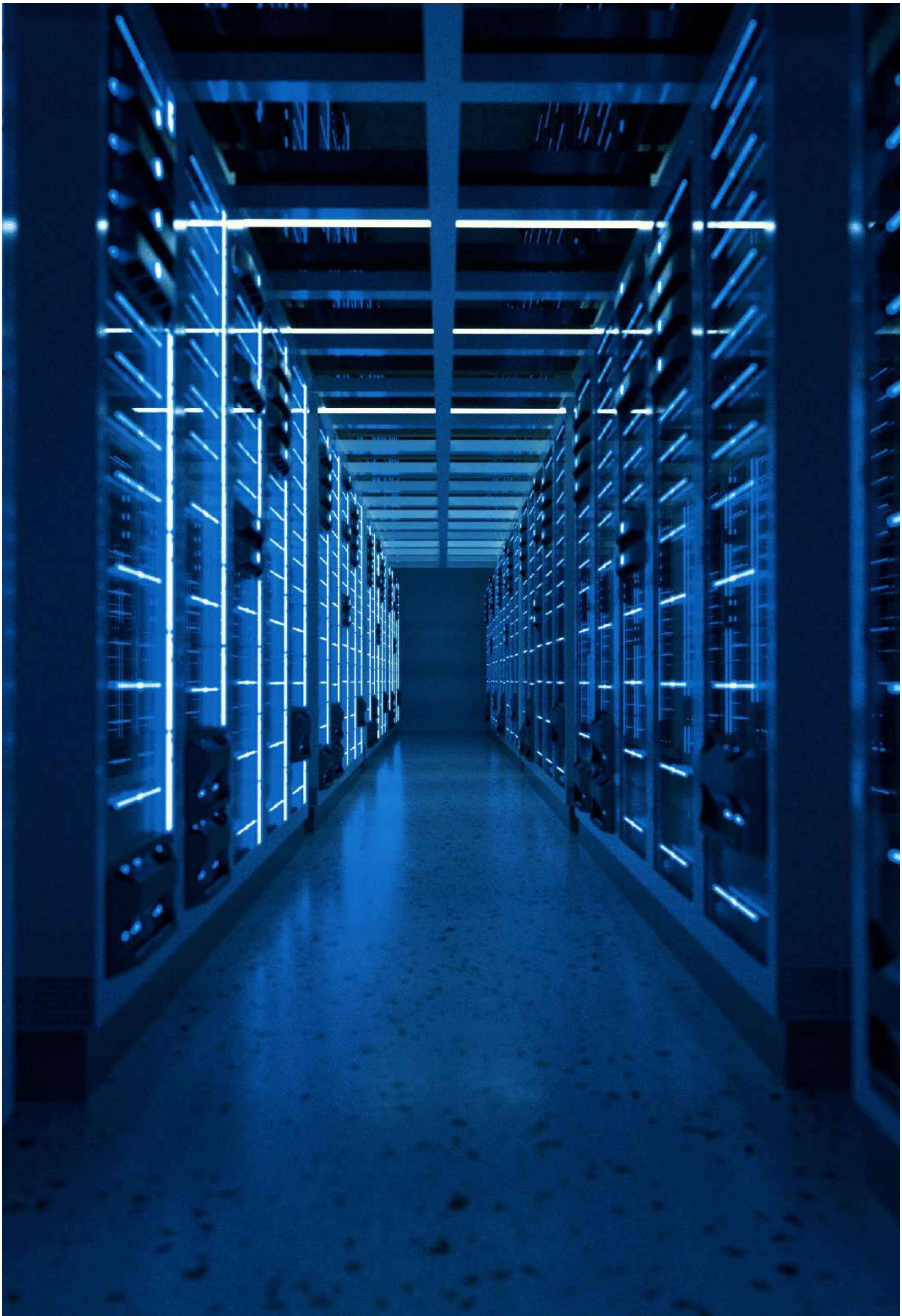
consumption, **energy efficiency**, **GHG emissions**, **e-waste**, **renewable energy use** and **circular economy** will be used to track the impact of **ICT on climate**.
Nonetheless, JRC work indicates that **EU businesses may be falling behind** in the **global digital innovation race**.

Patents on the **twin transition** grew exponentially over the last decade, with **China emerging as the lead applicant**. The EU international collaborations in **twin innovation initiatives** are strongest with the US and China. However, while the EU has a strong reciprocal collaboration with the US, there is an **imbalance in the relationship with China**: only 0.4% of China's collaborations involve EU co-applicants while 7% of EU co-applications are with Chinese partners. In the EU, the **digital industrial ecosystem** has the lion's share of innovative activity in the twin transitions. In addition, between 2009 and 2023, **energy-intensive industries** and **electronics sectors** filed for more twin patents in the EU than other industrial ecosystems [542].
One in five patents addressing climate change mitigation has a digital aspect [543]. The EU maintains a **leading position in patent filings** in several areas crucial for the **clean transition**. However, it has not recovered any ground in **smart systems** where it falls behind China, Japan and the US [544]. The EU falls behind in **digital domains** – both overall and when the latter are related to **clean technologies**. For some of the non-digital technologies currently lagging behind, the potential to specialise would come at a lower cost than other (digital) technologies, as the **capabilities needed overlap** with those already present in the Member States [450].

The question of **capabilities** is also highlighted by the fact that there is a **geographical divide within the EU** in terms of SMEs' readiness for the **digital and environmental transitions**, with Nordic and Benelux countries leading the way, while Southern and Eastern Europe face greater challenges [545]. The *European Digital Innovation Hubs network* [546] is a Commission initiative that acts as an **innovation intermediary**, providing services to firms in a multitude of areas, where **digitalisation** is a central part, including **Green Digitalisation** [547]. The network also acts as a **gateway for firms** to receive support in digitalisation. The associated *Digital Maturity Assessment Tool (DMAT)* [548] helps companies to assess how digitalisation contributes to decreasing their environmental impact (**Digital for Green**), and how firms mitigate the environmental impact of using more digital solutions and technologies. According to the DMAT, **Green Digitalisation** is an important aspect of firms' overall **digital maturity** and remains relevant throughout all stages of digitalisation. However, its development varies by sector. For example, **agriculture firms score significantly lower** on this dimension compared to those in other industries [549].

The impact of digital transformation on public governance provides examples of the role of digitalisation in addressing **governance challenges** in the food, energy, work and employment sectors, all of which are of relevance to the **clean transition** [550]. These include insights on platforms that support **sustainable food policies** and **urban-rural linkages**; **energy communities** and the transition to **decentralised energy systems** and **peer-to-peer energy sharing models**; and hybrid- or digitally supported work models and the changes they bring to people's (working) lives. The findings call for further research and action into the best roles that **digital technology** can play, recognising that the **human element is more important than the digital**, but where **public value** can be enhanced by the latter [550]. Careful design (involving relevant stakeholders) should help to use digital solutions meaningfully, intentionally and proportionally, where it adds value and does not **exacerbate inequalities**. Exploring how to combine the distinctive cognitive abilities of workers and the **analytical and processing capabilities of digital technologies** can lead to a more innovative, productive and competitive workforce.

The *Digital Transition Toolkit* was developed by the JRC for policymakers, as an aid to navigate strategic conversations with farmers and rural communities to address the challenges of the **digital transformation in the farming and agri-food sector** [551]. Another important aspect is the potential of **AI**, and particularly **generative AI**, to support the **EU simplification agenda**. By streamlining policy implementation, reducing obligations on companies, and improving **law enforcement efficiency**, AI could accelerate the adoption of **clean transition measures**. For example, generative AI tools could help expedite the processing of **clean transition permits**. Notably, as with any application of the **digital transition**, care should be taken to not simply digitalise existing processes, but to use the occasion to **re-design them** in a way that might simplify existing practices, including data flows that collect required information once-only, and then consider where digital solutions might help to implement and, to the appropriate degree, automate the re-designed procedures.



06

Financing the green transition

Section E
Compass Compass: Horizontal enablers

Key messages (1)

To achieve its climate and environmental objectives, the EU requires a substantial increase in **sustainable investments**.
- To meet the EU's energy transition objectives and ensure secure, clean and affordable energy for all Europeans, the **annual average investment needs** in the **energy sector** are estimated at around **EUR 660 billion** between 2026 and 2030.
- For **climate change adaptation**, the investment needs are estimated at around **EUR 69 billion per year** until 2050**.**
- In addition, the estimated **annual investment gap** to reach the **EU's environmental objectives** – water, circular economy, pollution prevention and control, and biodiversity – is approximately **EUR 177 billion**.

Addressing these investment needs will require **large-scale mobilisation of private finance**. Whilst **public funding** cannot address these needs on its own**,** it **plays a strategic role** by shaping incentives, reducing risk, improving coordination and directing capital towards priority areas aligned with EU objectives.

Mobilising private finance

Mobilising private capital for the clean transition requires a combination of market-based instruments, regulatory frameworks and risk-sharing mechanisms, including: - **Scaling up the use of sustainable debt instruments**, notably through the European Green Bond Standard and the use of voluntary disclosure templates for other green and sustainability-linked bonds.
- **Improving access to private finance for innovative companies**, including measures to support the development of venture capital and growth equity markets
- **Deploying public finance to de-risk and crowd-in investment**, including through EU budgetary guarantees, such as those provided by *InvestEU*.
- **Leveraging the EU sustainable finance framework**, which provides a solid basis for the development of green and transition finance and is undergoing simplification to facilitate implementation and verification by relevant actors.
- **Analysing the data emerging from sustainability-related disclosures** to map and monitor financial investment flows, supporting the assessment of sustainability claims.
- **Tapping into the potential of corporate climate transition plans to act as a common reference point across multiple dimensions of transition**: investment decision-making, financial product design, risk management, supervision and public-private coordination. To fully capitalise on this potential, further research can help clarify what constitutes a credible transition plan. The provision of additional guidance and tools can support the development and use of credible transition plans consistent with EU reporting and supervisory frameworks.

Key messages (2)

Fostering sustainable investments through the next Multiannual Financial Framework (MFF)

The next EU budget is expected to play a key role in supporting sustainable investments:

- The **European Commission's proposal for the 2028-2034 MFF** includes a **35% spending target** for the overall budget aiming at the mobilisation of over EUR 700 billion of EU budget for investments contributing to climate and environmental objectives.

- To track progress towards this target, the Commission proposed establishing **a common budget expenditure tracking and performance framework**, which can help monitor EU efforts in closing investment gaps and identify areas where additional efforts may be required. Furthermore, the granular analysis of the investments on specific areas (e.g. decarbonisation in energy-intensive industries) can be particularly useful to inform key policy developments and priorities (e.g. accelerating the roll-out of clean energy and manufacturing, as reflected in the *Clean Industrial Deal*). Further analytical and methodological work can also facilitate the calculation of the impact of EU-supported activities on EU climate and environmental objectives.

- The Commission's proposal also foresees the development of **a single and simple technical guidance** to streamline the implementation of the **'Do No Significant Harm' (DNSH) principle** across the EU budget. The design of this guidance can be informed by analyses of the benefits and challenges of the current practices and methodologies employed under existing EU instruments, drawing among others on existing assessments and inputs from Member States and stakeholders.

- Beyond EU funding, **Member States' national budgets** will remain central to closing the sustainable investment gap. Against this backdrop, there is an opportunity to further harmonise and simplify the landscape of 'clean transition tools'- including green budgeting frameworks – to better identify, monitor and foster sustainable investments at national level.

Achieving the ambitious EU climate and environmental objectives requires a substantial increase in sustainable investments in the EU.
Since 2020, the European Commission has published multiple estimates of different investment needs for achieving specific strategies (e.g. *REPowerEU*, 2040 climate target). While recognising the existence of several EU-based reports assessing the investment needs and gaps (e.g. I4CE, Rousseau Institute), this section reports on the Commission's official estimates for **public and private investment needs and gaps** required to achieve the **EU's climate and environmental objectives** (referred to hereafter as 'sustainable investments'). These estimates can vary considerably due to changes in the macroeconomic context (e.g. energy crisis, inflation) and technology costs, but also due to different definitions, scope, methodologies and timelines for assessment. Nonetheless, these provide an indicative order of magnitude of the challenge faced by the EU and highlight the need to substantially increase the volume of sustainable investments.
In 2023, the European Commission estimated that additional investment of over EUR 620 billion per year would be needed to meet the objectives of the *EU Green Deal* and *REPowerEU* [555]. More recently, in the context of the *Clean Energy Investment Strategy*, the Commission has estimated that to achieve **EU's energy transition objectives**, as well as secure, affordable, efficient and clean energy for all Europeans, investment levels in the energy sector must reach around **EUR 660 billion annually between 2026 and 2030**, increasing to **EUR 695 billion annually between 2030 and 2040** [556]. This represents a substantial increase compared to the average annual investment of approximately EUR 240 billion observed between 2011 and 2021 [556].

Estimates for investment needs and gaps for **climate change adaptation** are often less clear-cut, considering the uncertainties in climate change projections, as the alignment of adaptation investment needs is strongly dependent on model assumptions and scenarios. Overall, the investment needs for climate adaptation in the EU are estimated to be at around **EUR 69 billion per year until 2050** [557]. Investment needs related to **environmental objectives**, namely pollution prevention & control, circular economy and waste, water protection and management, and biodiversity and ecosystems are estimated to be around **2.4% of EU GDP for the 2021-2027 period** [558], [559]. In 2025, the annual investment gap for biodiversity and ecosystems was estimated at around EUR 37.4 billion, while for pollution prevention and control and for water protection and management objectives was estimated to be at around EUR 35.6 billion and EUR 22.4 billion, respectively [558], [559]. Recently, an annual investment gap of around EUR 82 billion per year between 2025 and 2040 has been estimated for circular economy [560]. Thus, leading to an estimated annual investment gap to reach EU's environmental objectives of around **EUR 177 billion**. At the same time, **significant amounts of public and private investments still flow towards harmful activities.**
In 2023, the total amount of **environmentally harmful energy subsidies**[1] in the EU were estimated at **EUR 136 billion** (38% of total energy subsidies), while around **EUR 93 billion** were linked to **fossil fuel subsidies** [561].

1 Energy subsidies are environmentally harmful if the price or cost reduction that they bring about maintains or increases the availability or the use of energy sources that cause significant negative environmental impacts, as defined in the 2024 Report on Energy subsidies in the EU.

Fossil fuel subsidies represent only a fraction of those which are harmful to the environment (also known as environmentally harmful subsidies). As part of the *8th Environmental Action Programme* (EAP) and to fulfil international commitments [562], the Commission is currently developing a methodology to define and identify other non-energy environmentally harmful subsidies [563]. As a result, there is no comprehensive official estimate of the total public spending in the EU currently harming the environment.

Globally, investments in upstream oil and gas are estimated at around USD 570 billion in 2025 (around EUR 477 billion), which represents a decline of approximately 4% [564]. Within the EU, **investments in fossil fuel power and supply** amount to roughly USD 32 billion in 2025 (around EUR 27 billion) compared to approximately USD 31 billion in 2024 (around EUR 26 billion) [564], [565].

Addressing investment needs will require significant contributions from private finance, while public funding can play a strategic shaping role.

Considering the size of the investment gap, **private financing will be key to reaching EU's clean transition ambitions**, particularly in the current context of constrained public funding. The public share of investments by Member States is estimated to range from 15% to 25% of the additional investment needs [566], [567] [568], [569], [570]. While the Commission has proposed an overall climate and environment spending target of at least 35% of the total amount of the EU budget (around EUR 700 billion) for the 2028-2034 *Multiannual Financial Framework* (MFF) [571], this funding is also expected to play a strategic shaping role, due to its capacity to leverage, de-risk and signal investments priorities.

Through long-term regulatory stability, carbon pricing, environmental incentives such as nature credits, other public incentives and effective policy coordination, **EU policies and funding can help mobilise and crowd in private capital**. In line with this approach, the Commission has adopted a strategy on a *Savings and Investment Union* for private investment for industrial decarbonisation and clean technologies, strengthen the *Innovation Fund* and enhance the effectiveness of State Aid [163]. Furthermore, the Commission has announced as part of the 2028-2034 MFF package that the *European Competitiveness Fund* (ECF) will offer a comprehensive toolkit for crowding in private investment, including ECF's *InvestEU* Instrument, which will continue to leverage private and public investment towards priority areas [571].

Against this background, **this chapter** focuses on two interrelated issues that are central to financing the EU's clean transition: **mobilising private finance** and **fostering sustainable investments through the next MFF**. The aim is not to provide an exhaustive view of potential challenges and opportunities for action, but to **highlight key factors and analytical considerations** that policymakers can take into consideration when designing and implementing policies related to sustainable investments.

6.1 Mobilising private finance

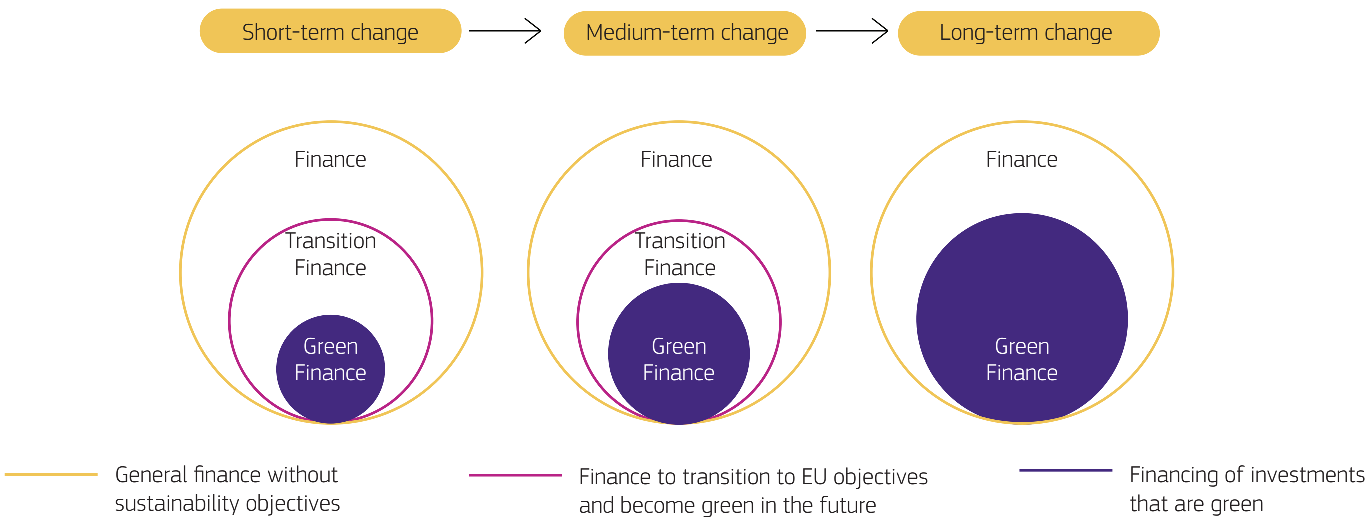
As per the Commission Recommendation (EU) 2023/1425 [572], **sustainable finance includes** what is referred to as **'green finance'**, which supports economic activities already meeting environmental performance targets, and **'transition finance',** which refers to financing the transition towards those environmental performance levels over time. This latter category includes activities or companies which present credible ambition and the ability to transition. What falls within these categories is expected to evolve over time, as environmental performance thresholds and policy objectives become more stringent during the transition to a sustainable economy (Figure 18).

The **EU Sustainable Finance Framework** aims to provide a basis for the development of green and transition finance. As set out in the Communication 'A sustainable finance framework that works on the ground' [573], the sustainable finance agenda promotes financial stability by ensuring that climate and nature-related risks are addressed in a timely manner, thereby preventing disruptive readjustments that could otherwise burden businesses and society. By defining standards for sustainable financial instruments and providing company-level reporting templates like Taxonomy disclosures and climate transition plans, the framework helps the financial sector monitor its exposure to transition risks and better identify the potential for stranded assets[2] [574], ensuring a more orderly transition for the entire economy [572]. Several bottlenecks to accessing green and transition finance may be overcome via financial instruments such as green bonds, sustainability-linked bonds, and venture capital. The opportunities created by EU regulations governing these instruments are explored in Chapter 6.1.1. The effective development of the **EU Sustainable Finance Framework** and the scaling-up of green and transition finance instruments depend on the availability and quality of sustainability-related disclosures. The recently adopted ***'Omnibus'* package** [575], [576], [577] aims to simplify sustainable finance reporting while maintaining sufficient disclosure requirements to support investment decisions. These disclosures create an opportunity to monitor flows of green and transition finance, harmonise impact reporting and enhance the verification of sustainability claims as discussed in Chapter 6.1.2.

Transition plans constitute a strategically important source of disclosures for transition finance. Chapter 6.1.2 examines the opportunities for supporting transition plan preparers, users and supervisors as well as regulators. It also explores how transition plans can facilitate access to finance via financial instruments and informing public policy planning.

2 According to [574], "stranded assets in the context of the low-carbon transition are assets whose profit expectations will be drastically reduced [...] the economy decarbonizes. This phenomenon emerges because of costly reallocation or transaction costs preventing these assets from being easily put to other uses or liquidated."

Figure 18. Relationship between green and transition finance today and over time.



Source: Commission Recommendation (EU) 2023/1425 on facilitating finance for the transition to a sustainable economy [572].

Key Message

Bottlenecks in access to finance to be addressed by leveraging standardised green debt and equity instruments

1

According to the IPCC report [578], "*there is sufficient global capital to close the global investment gaps but there are barriers to redirect capital to climate action*". Bottlenecks to access finance are therefore reported as one of main drivers limiting private green and transition investment. An estimated EUR 33.7 trillion in assets are under private management in Europe[3] [579]. Institutional investors (e.g. insurers and pension funds) control over EUR 12 trillion of assets in Europe [580] and seek the long-term stable returns that energy projects can provide with an appropriate framework in place. According to the 2023 Survey on the Access to Finance of Enterprises (SAFE) of the ECB [581, Ch. 5] more than half of Euro area firms identify high financing cost as a significant obstacle to climate investments. European firms therefore need to attract sustainability-oriented investors and diversify their funding sources, reducing their reliance on bank credit amidst fragmented and undersupplied capital markets.

3 EFAMA's members include national associations from 24 EU Member States, as well as, from Norway, Switzerland, Turkey, UK and Liechtenstein.

***Enabler 1.1**: Leverage the EU Green Bond Standard to mobilise market-based finance for green investments*

Debt capital markets are playing an increasingly important role in scaling up private funding for green investments, also thanks to the development of specific financial instruments. **Green bonds** are debt securities issued to finance investment projects with environmental and climate benefits. To date, green bond proceeds are predominantly used to finance projects for energy efficiency, clean transportation, and green buildings[4] [582], [583]. Since its inception in 2007, the green bond market has grown steadily. Figure 19 illustrates total annual green bond issuances in the EU, broken down by issuer type, and shown as a share of the total bond market. The share of green bonds in the EU27 was negligible in 2015, and has shown strong growth from 2016 onwards, supported by robust market demand and favourable pricing conditions [584]. In 2022, green securities accounted for 4.2% of newly issued bonds in the EU27, while representing a much smaller share (0.7%) of total bond issuance by non-EU entities.

The **European Green Bond Standard (EuGBs)** provides the first regulatory standard for "European Green Bonds" applying on a voluntary basis. Building on market best practice, the standard introduced a robust and harmonised reporting requirements and provides for a system of supervision of external reviewers carrying out pre- and post-issuance reviews at European level. The EuGBs proceeds are to be invested in projects that are Taxonomy-aligned (except for those that could fall in the flexibility pocket). The EUGBs is also closely linked to the *Corporate Sustainability Reporting Directive* (CSRD). Issuers subject to the CSRD, or those that have adopted voluntary transition plan, are required to explain how the use of proceeds from EuGBs-aligned bonds support their transition towards a more sustainable business model. This connection ensures that the proceeds finance activities coherent with the issuer's overall sustainability strategy and objectives.

The synergy between EuGBs, EU Taxonomy, and CSRD strengthens transparency, comparability and credibility for investors, while supporting environmental outcomes. Moreover, EuGBs issuers demonstrate transparency and sustainability, enhancing their reputation and attracting investors. By significantly increasing transparency and certainty, the EuGBs is expected to help foster ambition and standardisation of the EU green bond market. The JRC, who contributed to the development of the EuGBs with scientific and quantitative evidence, could also support the Commission's efforts in helping stakeholders implement the voluntary standard and

4 'Green buildings' refers to one of the use of proceeds categories used by ICMA Green and Social Bond Principles, as described in the 2022 ICMA's Handbook- Harmonised Framework for Impact Reporting

Figure 19. Green bond issuance in the EU, by year and issuer type.

Source: JRC elaboration based on [LSEG](#) data.

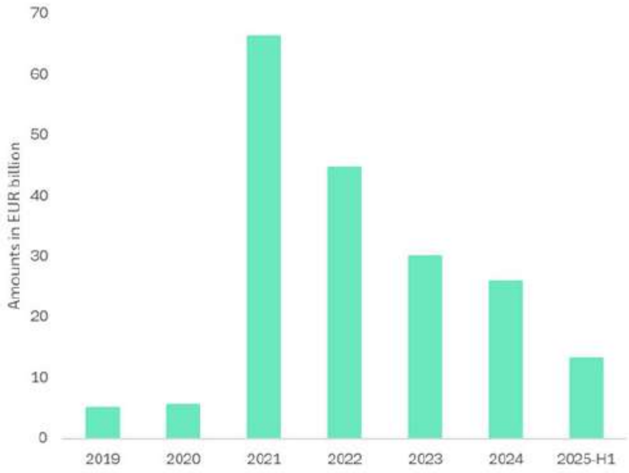
monitor its market uptake. Moreover, green bond issuance by sovereign entities and governments can in fact stimulate corporate issuances, by providing benchmarks for market practice and disclosure [585]. The EuGBs designation can also be used for securitised bonds that meet the requirements set out in the EuGBs Regulation [585]. Overall, as highlighted in the Letta report [3], the market for green and sustainable debt has the potential to act as a catalyst for the development of deeper and more integrated EU capital markets, thereby supporting the financing of the clean transition at scale.

Enabler 1.2: Monitoring sustainability-linked bonds as a transition finance instrument

Unlike green bonds, whose proceeds are tied to specific 'green' projects, **sustainability-linked bonds (SLBs)** raise finance for the pursuit of broader sustainability-related targets. In practice, the financial conditions of the SLBs are explicitly linked to the issuer's sustainability performance, in the form of quantitative targets. While there are open questions on the incentives embedded in the specific security design, SLBs have gained much attention as an innovative and flexible instrument to finance corporate transitions. At EUR 66 billion, the volumes of SLBs issuance peaked in 2021 (Figure 20), under particularly favourable market conditions (i.e. low interest rates) and supported by newly released International Capital Market Association's (ICMA) Sustainability-Linked Bond Principles (SLBP), declining afterwards potentially because of the increased scrutiny from investors. Concerns have mainly focus on the incentive structure embedded in SLBs, whereby issuers that fail to meet declared sustainability targets face higher debt servicing costs. This structure may create incentives for issuers to set less ambitious targets to avoid increases in the cost of debt [586].

To address these concerns and restore confidence in this market segment, there is potential for further guidance and market standards to ensure appropriate incentive design, including the alignment of incentives for issuers and investors and balancing financial and environmental needs. A market-based example in this direction is the 2024 update of ICMA's Sustainability-Linked Bond Principles, which strengthens expectations regarding the selection of key performance indicators (KPIs) and their alignment with the issuer's sustainability strategy. From a science-for-policy perspective, the JRC could monitor this market segment, and provide scientific evidence on the risks and opportunities related to the use of this instrument as they emerge from current market practice and observed outcomes.

Figure 20. Sustainability-linked bond issuance in the EU.

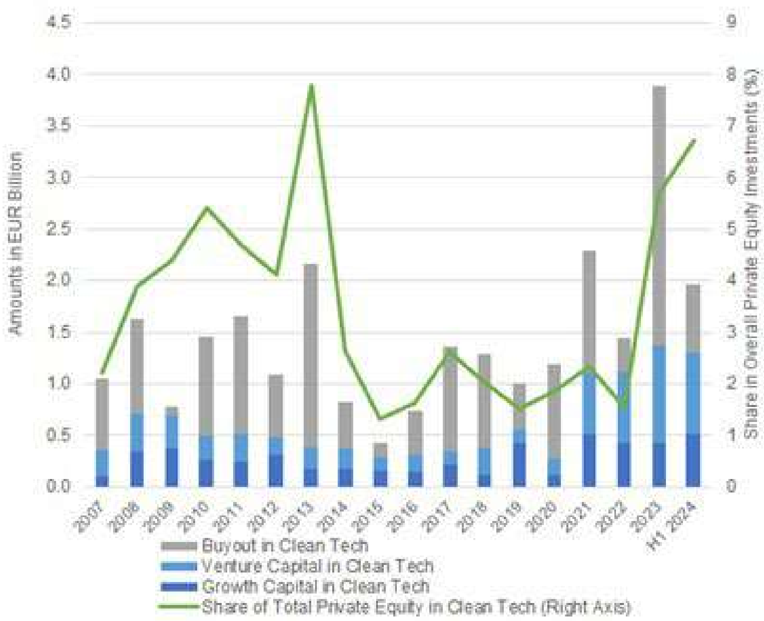


Source: JRC elaboration based on LSEG data.

Enabler 1.3*: Exploit the untapped potential of venture capital to finance green innovation*

Private equity financiers and venture capitalists are particularly well-equipped to finance innovative companies, and they may play an important role in the funding of low-carbon technologies [587]. At roughly EUR 4 billion in 2023, investment in clean tech industries accounted for around 5.7% of the total private equity market in the EU. The peak in 2023 investment levels was driven by a significantly higher volume of buyout capital, i.e. investments in already established companies. In the first half of 2024, venture capital, i.e. investment in new companies, represented the highest share of the total private equity investment in clean tech, at EUR 800 million (Figure 21). Nonetheless, overall, the level of equity investment in clean tech industries remains low, suggesting an untapped potential of venture capital to reach scale and fund more green innovation [588], [589]. Fostering market integration and reducing barriers to cross-border asset allocation can help mobilise private savings and redirect them towards equity investments in innovative firms via venture capital markets. Liquid and deep capital markets are essential to favour the development of innovative startups, allowing them to access a larger set of growth-oriented capital providers. The *EU Startup and Scaleup Strategy* aim precisely at overcoming these shortages by setting out supporting measures to foster start-up activities and scale-up financing across the EU [590]. Box 8 provides an overview of *InvestEU* Fund's role in crowding-in private investments for the clean transition.

Figure 21. Private equity in Clean Technology industries.



Source: JRC elaboration based on Invest Europe data. Data ends in H1 2024.

Box 8. **Crowding-in private investments for the clean transition by de-risking sustainable projects**

Mobilising additional private capital for decarbonising the EU industry, implementing extensive infrastructure projects, and scaling up innovative sustainable companies are essential for supporting the clean transition. In this context, the *InvestEU Fund* as the currently largest EU risk-sharing instrument in place, is playing an important role in addressing financial barriers and crowding-in private finance targeted to key EU policy priorities (e.g. climate action, competitiveness, research and innovation) by providing guarantees to support eligible financing carried out by the implementing partners (i.e. the European Investment Bank, national promotional banks and institutions, and international financial institutions). Between 2022 and 2025, the *InvestEU* Fund mobilised nearly EUR 400 billion in investments, of which 67.1% originating from the private sector. The latest figures5 show that the investments contributing to climate objectives amount to 48.5% of the overall financing volume, corresponding to around EUR 190 billion of investments, which are related to the clean transition.

5 Internal Commission figures, to be published in June 2026. The overall performance, until 2024, of the *InvestEU fund* can be found here. While, key indicators on the implementation of the *InvestEU Fund* can be found here (as of end December 2025).

6.1.2 Private sector sustainability disclosures

Key Message
Leveraging the EU sustainable finance regulatory framework through simplification

2

To address existing data gaps and enable the comprehensive tracking of investments, the Commission is actively driving initiatives to enhance data availability and transparency. In this context, science-for-policy research that maps financing and investment flows and monitors trends across instruments and sectors can provide valuable evidence to support the design of targeted public policies at all governance levels.

The **EU sustainable finance regulatory framework** aims to steer the allocation of capital and facilitate private investments towards green and transition technologies and business models, with the ultimate objective of supporting the greening, the competitiveness and the resilience of the real economy. From a policy perspective, assessing whether and to what extent financial flows are being redirected towards sustainable and transition investments is therefore an important factor. However, persistent data gaps [591] continue to limit the comprehensive tracking of investment flows in the real economy and the identification of their underlying financing sources [592].

Against this background, the Commission is advancing important simplification initiatives to improve transparency and streamline elements of the sustainable finance framework. Measures such as the **'Omnibus' simplification packages** [593] and the **proposed revision of the Sustainable Finance Disclosure Regulation (SFDR)** [594] aim to reduce reporting burdens while supporting greater consistency in sustainability information, and to facilitate its effective use by investors and other stakeholders.

Science-for-policy work can offer analytical support to ongoing policy efforts. Research activities that map financing and investment flows and monitor trends across instruments and sectors can contribute to a more consolidated evidence base. Such analysis can help inform public authorities at different governance levels and support the identification of areas where additional clarity or targeted policy attention may be beneficial.

Future research could also support simplification efforts by analysing sustainability disclosure data and exploring options for harmonised disclosure templates and standardised, sector-specific performance indicators. This could contribute to the development of approaches consistent with a "report once, use many times" principle, with the aim of facilitating the use of sustainability information across multiple policy and market contexts. If pursued, such approaches could help reduce complexity and compliance costs-particularly for smaller entities-while maintaining the robustness and comparability of sustainability-related information and supporting informed investment and investors' decisions.

Enabler 2.1: Mapping financial flows to inform policy and build investor confidence

The full implementation of disclosure requirements for financial and non-financial actors envisaged in the EU sustainable finance legislation is expected to increase the transparency and availability of sustainability-related information for firms within the scope of the regulation. This information will allow to the tracking of financial flows, support investors' decisions, and allows assessment of the extent to which the sustainable finance framework is contributing to support the clean and competitive transition of the real economy, as recommended by the EU Platform on Sustainable Finance [592].

To build on this foundation, the JRC is developing a comprehensive mapping of financing and investment flows, allowing to monitor trends across different instruments and sectors. When fully developed, this mapping could support policymakers in tracking progress over time in both the green and the transition segments of the economy. The resulting science-for-policy applications would be diverse and would involve informing the design of targeted policies for specific market segments, including for those sectors lagging behind, facilitating transparency in reporting and building investment confidence for investors navigating the transition [595].

***Enabler 2.2**: Harmonising impact reporting standards for sustainable finance instruments*

The Commission is actively advancing initiatives to simplify reporting standards, aiming to create a more consistent framework that applies uniform criteria across sustainable finance instruments [576] In addition to simplification, particularly for SMEs, this alignment seeks to ensure that sustainability claims are evaluated against robust, comparable standards to support investors' decisions. Important examples of this direction include the **European Sustainability Reporting Standards (ESRS)** and the **Voluntary Sustainability Reporting Standard for non-listed micro, small and medium-sized enterprises (VSME)** [596] at entity level, and the EuGBs at the product level.

The EuGBs, for example, supports comparability across financial products, issuers and reporting entities by requiring alignment of the bond's use of proceeds with the **EU Taxonomy**, applying standardised disclosure templates, and establishing reporting from pre-issuance (ex ante) through allocation and impact reporting (ex post), in coherence with the issuer's broader sustainability strategy.

Furthermore, harmonisation adds significant value by tapping into the core strengths of the EU single market. By establishing a common set of rules, it helps prevents the market fragmentation, which otherwise acts as a barrier to the cross-border distribution of financial products [597]. Ultimately, a harmonised landscape empowers investors to confidently compare products and efficiently allocate capital across borders into support of Europe's sustainable and competitive prosperity [593].

To build on these efforts, future science-for-policy research could support the development of harmonised disclosure templates. By facilitating cross-country harmonisation, this would aid implementation by relevant stakeholders in the Member States.

***Enabler 2.3**: Enhancing verification of sustainability claims through standardised sector-specific impact metrics*

Enhancing the verification of sustainability claims is an important element in supporting investor confidence and market functioning, and it does not necessarily imply an increase in administrative burden. From an analytical perspective, exploring the use of clear, sector-specific **impact metrics** offers scope to streamline reporting practices while maintaining the credibility and comparability of sustainability information.

By way of illustration, CO_2eq emissions avoided per tonne of cement and CO_2eq emissions avoided per kilowatt-hour of electricity produced represent impact metrics that are inherently material to the cement and electricity sectors, respectively, and less relevant outside these contexts. Focusing on such sector-appropriate indicators can support a more meaningful assessment of outcomes, while avoiding the proliferation of generic or non-material disclosures unfamiliar to the sector concerned.

The European Commission is already advancing initiatives that facilitate greater consistency in sustainability metrics, including the development of **European Climate Law-aligned sectoral decarbonisation pathways** [598]. These pathways for 24 specific sectors provide voluntary, science-based reference points and key performance indicators for high-emitting sectors, with the potential to support convergence in reporting practices, facilitate the design of credible corporate transition plans and reduce duplication of effort.

Building on these developments and drawing on the ex-post reporting principles of the EuGBs, science-for-policy analysis of reported data could help inform reflections on a more harmonised approach to verification. Such analytical work would aim to focus on material impacts, rather than on extensive documentary requirements, thereby supporting proportionality and cost-effectiveness in implementation.

More broadly, quantitative analysis of sustainability-related instruments could contribute to the identification of standardised performance indicators applicable across instruments, where appropriate. This type of evidence-based work aligns with the objectives of the Commission's Omnibus simplification agenda, which seeks to reduce administrative burdens-by at least 25% overall and 25% for small and medium-sized enterprises-by limiting the need for customised or parallel reporting frameworks.

Overall, a science-for-policy approach centred on harmonised metrics and outcome-focused verification could support the practical application of the "report once, use many times" principle. By enabling standardised data to serve multiple regulatory and market uses, such an approach would help minimise duplicate reporting requirements, alleviate administrative burdens, and support informed investment decisions, while remaining fully complementary support informed investment decisions, while remaining fully complementary to the existing regulatory framework. Box 9 explores potential tailored tools and digital platforms that could support EU Taxonomy implementation.

Box 9. **Exploring tailored tools and digital platforms to simplify the EU Taxonomy implementation**

The **EU Taxonomy** is instrumental to the agenda of mobilising private finance, and a cornerstone of the EU's strategy to redirect capital toward activities that advance both climate and environmental ambitions. Capital investments in Taxonomy-aligned activities over the financial period 2022-2024 have reached €742 billion [599] and are expected to be above €1 trillion when considering investments until 2025 (preliminary estimates, with actual figures to be updated and published by the Commission during summer 2026). This figure covers not only green projects, but also the greening of sectors facing steep transition challenges.

At the same time, the European Commission is undertaking a range of initiatives to support the implementation and usability of the EU Taxonomy and unlock its full potential in directing capital to finance the clean transition. These initiatives include the development of supporting tools, such as the EU Taxonomy Compass and the publication of multiple comprehensive frequently asked questions (FAQs). In parallel, the Commission has proposed targeted amendments to existing delegated acts, reflecting implementation experience from the initial reporting periods. The proposed revision aims to streamline criteria and clarify how to demonstrate compliance, as well as better reflect EU legislation and technological advances [600].

To build on this foundation, future science-for-policy could support the development of tailored tools to assist economic operators in assessing and disclosing their eligibility and alignment. These could play a complementary role in supporting simplification, implementation and reducing administrative burden uncertainty for reporting entities. Examples could include: i) Guidance tools informed by implementation experience, for instance on specific technical screening criteria, documentary evidence typically used to demonstrate compliance or on the interpretation of Do No Significant Harm (DNSH) criteria, where users have signalled implementation complexity; and ii) Dedicated digital reporting portals reporting; the establishment or integration of centralised web for sustainability data could streamline the reporting process, improve data quality and consistency and foster transparency. Ultimately, this would aim to lower compliance costs for companies while reducing search costs for investors.

Key Message

Corporate Transition Plans as an anchor point for transition finance

3

The use of **transition finance** is necessary '*to ensure a timely and orderly transition of the real economy towards sustainability while ensuring the competitiveness of the EU economy*' [572]. Transition finance also plays a role in reducing transition risk over time [572]. *This is particularly important for sectors which have a high climate and environmental impact, where financial market players' decisions can play a significant role in shaping transition strategies. In this context,* **corporate transition plans** are receiving increasing attention across jurisdictions and can act as an anchor point to channel transition finance where it is most needed. These plans provide a reference basis for linking financing decisions to forward-looking performance and impact indicators. These can then facilitate the issuance of green and sustainability loans and bonds for green and transition purposes (e.g. use-of-proceeds or general-purpose instruments such as green and sustainability bonds or sustainability-linked bonds).

Highlighting the need for granular, comparable and forward-looking corporate disclosures on their climate transition planning, an OECD survey [601] conducted in 2022 found that, for 79% of financial market respondents, a lack of detailed information from corporates was the main obstacle preventing them from identifying companies they could finance in line with their own net-zero targets.

At EU level, a common regulatory basis for corporate climate transition plans is provided by the **European Sustainability Reporting Standards (ESRS)**[6] adopted under the CSRD. These standards, currently under revision, establish disclosure requirements for companies that develop a transition plan for climate change mitigation (ESRS E1-1). This provides investors and the wider financial market with a common reference for what to look for in a company's transition plan, thereby facilitating the mobilisation of transition finance. Under the current ESRS E1-1, companies for which climate change is identified as a material topic must disclose whether they have a climate transition plan and, if so, report against a defined set of disclosure requirements. When material for the entity, transition plans may also be connected to actions and resources for other environmental objectives (ESRS E2 to E5), as well as a just transition aspect, not only for the entity's own workers, but also for workers in the supply chain, affected communities and consumers (ESRS S1 to S4).

Corporate transition plans are also relevant in the context of prudential transition planning [603]. Under the ***Capital Requirements Directive*** **(CRD VI)**, credit institutions are required to develop prudential transition plans in, with further guidance provided in the EBA 'Guidelines on the management of ESG risks'[7] [604]. Similarly, insurers are expected to address sustainability-related risks in line with the ***Solvency II Directive*** and EOIPA's report on 'Prudential treatment of sustainability risks' [605]. Prudential plans place a strong focus on the credibility of transition plans and require an assessment of whether clients and counterparties can realistically transition. This includes the requirement to link transition planning to financial risk metrics, as well as the alignment of renumeration, lending policies and the risk appetite framework.

Future science-for-policy research could further explore how corporate transition plans can act as a common reference point across multiple dimensions of transition finance: investment decision-making, financial product design, risk management, supervision and public-private coordination.

6 ESRS E1-1 defines transition plans for climate change mitigation as "an aspect of an undertaking's overall strategy that lays out the undertaking's targets, actions and resources for its transition towards a lower-carbon economy, including actions such as reducing its GHG emissions with regard to the objective of limiting global warming to 1.5°C and climate neutrality" [602].

7 The EBA is mandated under Article 87a(5) of CRD6 to issue Guidelines on the identification, measurement, management and monitoring of ESG risks, including by specifying the content of plans to be prepared by institutions in accordance with Article 76(2) of the CRD to monitor and address the financial risks stemming from ESG factors in the short, medium and long term.

***Enabler 3.1**: Providing clarity on credible transition plans to enable efficient transition financing*

To serve investors with valuable information to address climate-related and environmental risks and to inform their progress towards their own sustainability targets [606], counterparties' transition plans need to be credible. **Credible corporate transition plans** can also inform investors' identification of investment opportunities and serve as a basis for engagement with their investees, as reflected in the ECB's 2022 'Good practices for climate-related and environmental risk management' [607]. Many market participants have highlighted the need for further guidance on what constitutes a credible transition plan. Financial institutions, as key users of transition plans, are increasingly expected to analyse transition plans as part of their ESG risk management processes and engage with investees accordingly. However, despite this growing focus, many investors still lack clarity on how to assess credibility [608]. For instance, 62% of financial market participants polled in a 2022 OECD study [601], reported lacking clarity on how to assess transition plan credibility using decarbonisation pathways (responding 'Yes' or 'Somewhat, depending on the region'). The absence of clarity creates legal uncertainty, supervisory inconsistencies and potential greenwashing risks. In response, an increasing number of investors have started to develop their own frameworks for assessing the credibility of transition plans [608]. Leading to a growing fragmentation, where financial institutions independently design their own, often divergent criteria to evaluate transition plans.

At EU level, there is currently no legal definition for credible corporate transition plans. This situation may change in the context of the Commission's **proposed revisions to the *Sustainable Finance Disclosure Regulatio*n** [594]. This proposal includes the introduction of investments in undertakings with credible transition plans as one of the possible criteria for a newly proposed voluntary '**Transition Product Category**' and would empower the Commission, through a delegated act, to specify conditions for investments by categorised products to qualify as contributing to the chosen objective. Subject to ongoing negotiations by co-legislators, this could also involve defining specific conditions for credible transition plans. This would permit the European Commission to further clarify this concept, which could enhance market confidence and support the scaling of transition finance.

In this context, further science-for-policy research could provide analytical support to clarify when corporate transition plans can be considered credible and hence inform ongoing policy developments.

Where appropriate, such clarification could build on existing EU policy references to transition finance, including Commission Recommendation (EU) 2023/1425, as well as on observed market practices and available scientific evidence. Analytical work could support this process by identifying common elements already used by market participants to assess transition plan credibility and by examining their consistency with EU climate and sustainability objectives.

***Enabler 3.2**: Building capacity and providing tools for credible transition planning*

There is a growing demand from corporate transition plan preparers and users for **solid and practical credibility-building tools,** such as the EU sectoral pathways[8] mentioned in the *Clean Industrial Deal* or the recent sectoral decarbonisation pathways for 24 sectors aligned with the *European Climate Law* published by the Commission [609]. Developing capacity building programmes and new toolkits could support corporate transition planning and investment decisions, necessary conditions for the EU to achieve its own policy targets.

Regulators can play a key role in supporting the necessary **upskilling** across the wider ecosystem. For example, transition plan assurers and supervisors will need to develop additional knowledge beyond the usual areas of work to assess the design and adoption of company transition plans and progress in addressing climate-related and environmental risks in prudential transition plans. National competent authorities could benefit from continuous training on the main elements of credible transition plans and the challenges related to their implementation. Future science-for-policy research could provide analytical support to this capacity-building process, leveraging the evidence base developed in this field to help streamline supervisory practices and fostering a level playing field.

In addition, there is an opportunity to aid companies in this journey by providing **guidance on credible transition plan requirements**, building on the draft of the European Financial Reporting Advisory Group (EFRAG) on implementation guidance for climate mitigation [610]. Many different tools are already available for corporates when preparing their transition plans (**Box 10**).

8 Business Europe, Policy priorities on sustainable finance for 2024-2029; IIGCC, Making NDCs investable – the investor perspective; IGCC, Decarbonisation investment solutions for sectors: A discussion paper on Sector Transition Plans and their importance to investors; Climate Bonds Initiative, European Union Chemical Sector Transition Policy Brief

Box 10. **Towards a transition finance data hub?**

To reduce the challenges companies face in finding appropriate and reliable databases and calculations tools to produce their CSRD reports, future research could explore consolidating the substantial set of materials that already exists at EU or Member State level. The creation of an **open-access EU data hub** could enhance the visibility of this material and therefore support the cost-effective implementation of the CSRD.

This free-of-charge centralised access point might include, for example:

- Mapping of emission factors databases to support the calculation of companies' GHG emissions - scope 1, 2 and 3 (examples are in France and the Netherlands).
- Specific supporting tools for SMEs to support their calculation and reporting of GHG emissions (building on EFRAG's recent mapping of digital tools, platforms and initiatives for SME sustainability reporting, as well as from the US Environmental Protection Agency).
- The newly available European sectoral transition pathways, as mentioned in the Clean Industrial Deal, aligned with the *European Climate Law*, which can support the preparation and assessment of credible Climate Transition Plans.
- Examples of good practices and initiatives to help companies draft their own ESRS compatible transition plan or implement concrete GHG emission reduction strategies.

***Enabler 3.3**: Corporate transition plans as a basis on which to build financing instruments, and to monitor the transition*

Financial instruments that connect to **transition plans** can foster access to **transition finance** in **hard-to-abate sectors**, serving as a tool to directly link the planned achievement of sustainability targets (as stated in a company's transition plan) to the necessary financial resources to reach them. The market has historically favoured project-based financing instruments - with green bonds accounting for 47% of sustainable finance instruments in 2022 (based on BNEF data, retrieved in April 2024). This highlights the importance of exploring how existing sustainable finance instruments can also support transition financing when they are explicitly linked to transition plan outcomes. Sustainability-linked bonds and loans, which set targets at the entity level, are in principle particularly fit for financing a whole-of-entity transition, as they allow financing conditions to be linked to the achievement of transition-related performance indicators (Chapter 6.1.1).

From a **monitoring perspective**, corporate transition plans provide a reference point for assessing whether sustainable finance instruments are contributing to the transition of entire business models, rather than financing isolated green activities. By analysing environmental and climate-related outcomes at the company level, public authorities and supervisors can better assess whether these instruments are supporting transition pathways in practice.

To enable such analysis, it is important to track the issuance and characteristics of sustainable finance instruments across companies at different stages of transition, and to examine how the financing conditions evolve as firms progress along their transition pathways. This includes exploring whether companies with more advanced and credible transition plans benefit from differentiated financing conditions, such as lower cost of capital or improved access to finance.

From a **science-for-policy perspective**, analytical work could support this monitoring by combining information from corporate transition plans, sustainable finance instrument disclosures and outcome indicators. Such analysis can provide evidence on how different financing instruments are used across sectors and transition stages and can inform assessments of the effectiveness of the sustainable finance framework in supporting the EU's transition objectives. Ultimately, providing such evidence would support the efficient allocation of capital and empower informed investor decisions across the EU single market.

***Enabler 3.4**: Capitalising on credible transition plans to coordinate policy and private action, ensuring an efficient transition*

Significant **interdependencies** exist between **public policies** and **corporate transition plans.** As detailed in the JRC Science-for-Policy brief on the topic [611], a company's transition plan may have a geographical dependencies[9] on the availability of infrastructure required to decarbonise (e.g. hydrogen pipelines). The availability of this infrastructure can be largely influenced by factors such as public finance support. Conversely, the capacity of the public sector to achieve its climate ambition is closely linked to the scale, credibility and timing of private-sector transition, and the confidence to adopt more ambitious climate policies can increase in line with the private sector's commitments. Inconsistent strategies could slow down the implementation of climate actions and increase the risk of not delivering on commitments. The *Clean Industrial Deal* emphasises the need to accelerate the transition in energy-intensive industries, further underlining the importance of effective coordination between public and private action.

In this context, using data from credible corporate transition plans to inform policymaking can support a more coordinated transition, grounded in an informed dialogue between private and public actors. For example, credible transition plans containing asset-level information may help to identify opportunities (e.g. regional innovation hubs and clusters, expenditure gaps in network infrastructure where private investment can be crowded in) and companies' support needs (e.g. to avoid the stranding of assets that are not able to transition). On the other hand, the preparation and assessment of credible transition plans should consider the relevant information arising from national or regional plans and strategies such as the integrated National Energy and Climate Plans (NECPs), including targets, policies and measures relating to specific decarbonisation levers (e.g. electrification), which can be help guide corporate transition planning and investment decisions.

Therefore, analysing these interdependencies between public decarbonisation strategies and the private sector transition plans can provide insights on transition risk (including geographical dependencies at EU, Member State or regional scale), on areas where prioritisation is needed or where potential for collaboration on infrastructure development exists (e.g. CO_2 pipelines), or on how to manage competition for a scarce resource in the transition (e.g. biomass). Such analysis could support informed and iterative dialogues between policymakers and companies contributing to the design and adjustment of industrial competitiveness and climate policies.

9 A company may depend on several external local factors to meet their emission reduction targets ('geographical dependencies'): physical resource availability at the locations where the company has assets (e.g. decarbonised grids, H_2 availability, CCS infrastructure), and the associated non-physical impediments or opportunities to transition in different regions (e.g. policy support, economic conditions).

6.2 Fostering sustainable investments through the next MFF

On 16 July 2025, the Commission announced its proposal for a **simpler, more flexible and more strategic 2028-2034 MFF**. The Commission proposal puts forward a policy-based budget, where programmes are designed to be complementary by allowing for resources to be combined in support of EU priorities - including for example, competitiveness, decarbonisation, sustainability, and social and territorial cohesion [571].

The Commission proposal includes two keys 'horizontal principles' particularly relevant from a sustainable investment perspective:

1) The climate and environment spending target. The proposal lays down that at least 35% of the total amount of the budget over the entire 2028-2034 MFF must be spent on actions contributing to climate or environmental objectives. This spending target is expected to mobilise over EUR 700 billion of EU budget during the 2028-2034 period.

2) The 'Do No Significant Harm' (DNSH) principle. The 'streamlined application' of this principle to the EU budget aims to prevent the activities supported by the EU budget from causing significant harm to any of the six climate and environmental objectives defined in the *EU Taxonomy Regulation* (Climate change mitigation, climate change adaptation, water, circular economy, pollution prevention and control and biodiversity and ecosystems [612]), except when it is not feasible or appropriate (as in the case of defence and security, according to the Commission's proposal).

Within this common framework, the proposal also lays down specific instruments that will contribute to EU climate and environmental objectives, which notably include [613]:

- The ***European Competitiveness Fund* (ECF)**, which includes a specific 'Clean Transition and Industrial Decarbonisation', as well as a 'Health, Biotech, Agriculture and Bioeconomy' window. Other programmes, such as the *Innovation Fund* will also support the ECF by boosting support to industrial decarbonisation and clean technologies. At least, 43% of the ECF budget must contribute to climate and environmental objectives.
- **Horizon Europe** (future 10th Framework Programme for Research and Innovation) will support the ECF and *Innovation Fund* by providing research application and innovation to support decarbonisation efforts. At least, 40% of its budget must contribute to climate and environmental objectives.
- The **National and Regional Partnership Plans (NRPPs)** will allow a better understanding of the different territorial needs, thus supporting investments across several policy areas, such as agriculture, social innovation, health and clean transition. These plans can improve the links between reforms and sustainable investments, while supporting local communities and businesses in their transition. At least 43% of the budget must contribute to climate and environmental objectives.
- The **Connecting Europe Facility (CEF)** will support key cross-border infrastructure projects in the EU, focusing on energy and transport projects to complete the Energy Union and trans-European networks. At least 70% of the budget must contribute to climate and environmental objectives.

This section builds on this Commission proposal and on the objective of ensuring a more **strategic and impactful EU budget** in the area of 'green mainstreaming', focusing on:

- The potential of granular analyses on the scale and nature of the sustainable investment needs to inform the development of the NRPPs and other national strategies and maximise the impact of EU funds (Key Message 4).
- The role and additional opportunities offered by the methodologies employed to monitor where EU money flows and what is achieved with it (Key Message 5).
- Potential strategies to harmonise and provide upfront clarity on environmental requirements in EU funds. The aim is to foster simplification and increase the predictability of funding decisions without undermining the contribution of the EU budget to achieve EU's climate and environmental objectives (Key Message 6).

Finally, the section points out to the importance that **national budgets** could play towards closing the sustainable investment gap. This is for instance included in the political guidelines for the 2024-2029 Commission, which highlights the important role of public procurement to create lead markets in clean and strategic technologies. As such, this section focuses on the existing opportunity to harmonise and simplify the landscape of 'green-related tools' that Member States can apply to identify, monitor and ultimately foster sustainable investments (Key Message 7).

Key Message **There is no 'one-size-fits-all' green and transition finance strategy: closing the investment gap and fostering EU sustainable competitiveness requires targeted strategies for different environmental objectives and policy sectors** 4

Climate and environmental objectives coexist with other strategic objectives (e.g. competitiveness, social, industrial, economic security) embedded in the EU budget and in the different EU funds into which these targets are mainstreamed. Whilst in some cases synergies exist, climate/environmental objectives and other strategic objectives can compete or lead to trade-offs between them (see Chapter 3 and 4). In this context, a key question to be further explored is how to foster win-win situations and minimise trade-offs between objectives.

Enabler 4.1: Developing more granular analyses at the (sub) objective/sector level to define targeted support to close the investment gap.

There is no clear, single solution on how to maximise the impact of EU funding for the clean transition. Each one of the climate and environmental objectives and sub-objectives have specific characteristics, such as the actors involved (Member States, local authorities, private investors), the market failures that need to be addressed, the profitability of the investments or who bears the cost of inaction, among others.

For example, instruments, such as the **ECF's *InvestEU* instrument** will de-risk specific investments by the private sector and will thus play an important role in the decarbonisation of industry. However, fostering climate resilience can require a more prominent role of public support, which may include setting stronger financial incentives for private actors (**Box 11**).

Following the Commission's proposal, the **National and Regional Partnership Plans (NRPPs)** will be a keystone of the next EU budget. The NRPPs aim to provide a coherent and tailored planning process driven by national and regional authorities. These will focus on the main priorities and challenges identified (for example, through the latest European Semester cycles or drawing from the NECPs), thus providing flexibility to develop national, regional and sectorial actions that are fit-for-purpose and aligned with EU's priorities, such as decarbonisation or environmental priorities [571].

In this context, more **granular analyses of the sustainable investment needs and gaps** for the different climate and environmental (sub) objectives (e.g. water, biodiversity), at national and even regional levels, can play a key role in informing the development of the NRPPs and other national strategies (e.g. the integrated National Energy and Climate Plans). These analyses could focus on key sectors of high relevance for each environmental (sub)objective and would require targeted approaches to collect and analyse the information. As an illustration, Enabler 3.4 describes the possibility of using the information arising from corporate transition plans to help better identify investment needs from a climate change mitigation perspective for high priority sectors, such as energy-intensive industries.

Key Message

Efforts to make the EU budget more impactful also require solid methodologies to monitor where EU money flows and what is achieved with it

5

For the **2021-2027 MFF**, the Commission has set **tracking methodologies** to monitor progress towards the achievement of the climate and environmental mainstreaming targets defined for the EU budget, which currently include: a) the 'climate tracking methodology', monitoring expenditure contributing to climate objectives; b) the 'biodiversity tracking methodology', monitoring expenditures on biodiversity action; and c) the 'clean air tracking methodology', monitoring progress in the Member States' uptake of EU funds for clean air objective[10]. Additionally, certain EU funding programmes (e.g. *Cohesion Policy* funds such as the *European Regional Development Fund*, *InvestEU* and the *Recovery and Resilience Facility*) track also the contribution of the programme to environmental objectives in general.

For the **2028-2034 MFF**, the Commission has put forward a **proposal for a performance framework** to streamline and harmonise the monitoring of EU's spending and performance of the budget [616]. This proposal is based on a single system that includes a harmonised list of intervention fields[11], covering all relevant activities supported by the EU budget, as well as performance indicators (i.e. output and result).

In this context, the next MFF offers a potential to make the most of the information provided by the performance system to further inform EU policymaking.

10 Though the EU has not set any target for the EU budget relating to clean air, tracking these expenditures is a requirement arising from Article this methodology is needed to comply with the reporting requirements laid down in Article 11(1)(c) of the Directive (EU) 2016/2284 of the European Parliament and of the Council.

11 Intervention field means a standardised and predefined category used to classify supported activities (Art. 2 (5),COM Performance Regulation).

Box 11. **The role of public funding to address investment needs on Climate Change Adaptation**

Adaptation is the process of adjustment to actual and expected climate and its effects. In the narrower sense, used here, adaptation refers to a heterogenous set of interventions aimed at reducing the adverse impacts of climate change, including protective infrastructure (e.g. flood barriers and nature-based solutions), and preparedness measures (e.g. adaptation plans and early warning systems). This distinction is important from a financing perspective, as the potential for private financing differs substantially across adaptation categories. Overall, the volume of financial flows towards these projects is significantly lower than those targeting climate change mitigation. Climate Policy Initiative estimates that climate mitigation finance reached a yearly average of USD 1.15 trillion (ca. EUR 1.03 trillion) in 2021/2022, of the USD 1.27 trillion (ca. EUR 1.14 trillion) in global climate finance for the same period [614]. In comparison, finance to climate change adaptation amounted to only USD 63 billion (ca. EUR 56.6 billion), one order of magnitude lower than the volume of finance raised by fossil fuel industries worldwide (ca. EUR 600 billion in 2023).

Furthermore, **adaptation finance** is characterised by the predominance of public flows, which represent 98% of the total adaptation expenditure in 2021/2022 [614]. This can be explained by different factors, such as the fact that the environmental and social benefits provided by adaptation projects are not fully captured in the rates of return for the investment and, hence, generate unfavourable risk-return profiles for investors [615], or that the projects are considered not bankable by the different financiers due to insufficient cash flows to repay the investment.

In this context, greater **financial incentives** for private actors to invest in adaptation, through tax breaks or benefits, risk guarantees, credit enhancement, grants and concessional loans, can help to compensate for the uncaptured externalities. As stated in the European Environmental Agency's European Climate Risk Assessment, Member States could design market incentives to foster private sector investment in climate adaptation, such as specific funding for SMEs or public procurement instruments.

In addition, private investors' and adaptation projects' horizons do not normally match [615]. While private actors operate in the short or medium term, adaptation projects can bring benefits only in the long term, conditional upon uncertain climate outcomes. Furthermore, adaptation investment is context- and location-specific, and so are its benefits.

Long-term planning is also needed to identify and prioritise adaptation needs across sectors in a public-private dialogue ([615] for examples). In this spirit, the new EU Strategy on *Adaptation to Climate Change* advocates for a close cooperation of local authorities between and within Member States in the definition of adaptation strategies and plans.

Enabler 5.1*: Building on the climate and environment tracking methodologies to assess progress to closing the sustainable investment gap.*

The tracking methodology in the Commission's proposal would permit to monitor the stand-alone contributions of the EU budget to climate change mitigation, climate change adaptation and a 'consolidated' environmental objective (bringing together the contributions to water, circular economy, pollution prevention and control and biodiversity). This will be done by assigning each intervention field with a specific contribution (0%, 40% or 100%) to each one of these objectives (Table 3). This tracking methodology would allow to monitor the overall contribution of the EU budget to climate and environmental objectives and assess progress towards the associated 35 % spending target. Furthermore, this methodology would provide for the first time consolidated information for the contribution of the EU budget across multiple policy areas and intervention fields for the climate and environmental objectives (it should be noted that, under the current 2021-2027 system, only certain funds such as the *European Regional Development Fund* or the *Cohesion Fund* track the contribution to environmental objectives). This information, combined with granular investment needs estimations (Enabler 4.1), can be useful for additional purposes, such as monitoring the efforts to close the existing sustainable investment gaps. This work could support the existing monitoring of sustainable investment flows, needs and gaps at Member State level carried out under the *Environmental Implementation Review* (EIR). Finally, the more granular analysis of the investments on specific policy areas (e.g. agriculture, nature restoration and conservation) or even at more granular level (e.g. decarbonisation in energy-intensive industries, recycling of critical raw

Table 3. Illustration of intervention fields, with their contribution coefficients to the objectives of climate change mitigation (CCM), climate change adaptation (CCA) and environment (ENV) and their associated output and results indicators as in the Commission proposal for a performance framework.

#	Intervention field	Contribution to CCM	Contribution to CCA	Contribution to ENV	Output indicators	Results indicators
70	Decarbonisation in energy-intensive industries	100%	0%	0%	• Number of enterprises supported – by micro, small & medium, large	• Number of jobs sustained or created in enterprises supported – by gender • Investment mobilised (EUR) • GHG emission reductions (tCO_2e) • Pollutant reduction (PM2.5 and NO_X) in tonnes
275	Nature-based climate-resilience measures	0%	100%	100%	• Number of adaptation measures supported	• Number of people benefitting from adaptation measure – by gender • Value of assets and / or Population benefitting from climate resilience measures
288	Sustainable afforestation and reforestation	100%	100%	40%	• Hectares of net new afforested and reforested areas	• Annual GHG emissions avoided in tCO_2e

Source: Annex I of [616].

materials) can be particularly useful to inform key policy developments and priorities (e.g. accelerating the roll-out of clean energy and manufacturing, including the support to decarbonise energy-intensive industries, as reflected in the *Clean Industrial Deal*), both in terms of tracking the investments flowing towards these areas and of calculating the results and impacts achieved (Enabler 5.2).

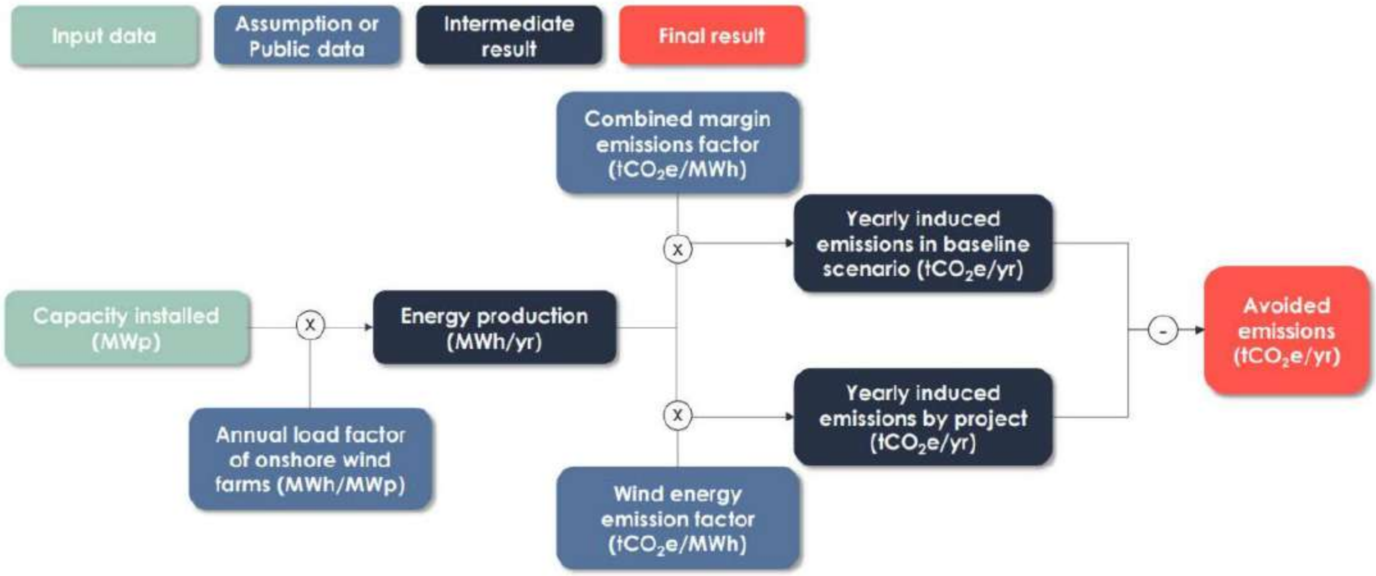
Enabler 5.2: Calculating the impact beyond expenditure: kicking-off methodological work to calculate the impact of the EU budget on objectives beyond climate change mitigation

The European Commission has started to develop a methodology (Figure 22) to calculate the **impact on climate change mitigation** of certain actions funded by the EU budget in the context of its annual reporting exercise for NGEU green bonds. This methodology enables the calculation of the CO_2eq savings achieved and has already been employed to report on the impact of the *NextGenerationEU Green Bonds* [617].

The **performance framework** proposed for the 2028-2034 MFF by the Commission includes a standardised set of performance indicators – output and result indicators – applicable across the whole EU budget and directly linked to the harmonised list of intervention fields [616]. The proposal includes common indicators to measure progress towards different climate and environmental objectives, such as climate change mitigation (e.g. 'GHG emissions avoided'), adaptation (e.g. 'Value of assets and/ or Population benefitting from climate resilience measures'), the circular economy (e.g. 'Tonnes of material recovered'), pollution control and prevention (e.g. 'Pollutant reduction – PM2.5 and Nox – in tonnes') and nature protection and restoration (e.g. 'Hectares of protected or restored areas') [Annex I of [616]]. As part of the Commission's proposal, Member States are expected to assign for each measure in their NRPPs at least one intervention field, as well as corresponding performance indicators. Additionally, Member States are expected to put in place monitoring and reporting systems to transmit relevant information to the Commission on the expenditure tracking and performance framework [616].

This system is key to assess the **results and impacts** achieved by the investments made with the EU budget and could help inform policy decisions to maximise the contribution of EU funds to climate and environmental objectives. In this context, the quality of the results provided by the system will depend on factors such as the quality of the data, the methodological guidance provided to the Member States and other entities implementing EU funds (e.g. *InvestEU* implementing partners), or the quality of the methodologies employed to calculate the results and impacts. With this in mind, further research can help identify, assess and when necessary, develop methodological approaches to calculate the results and impacts indicators, particularly for objectives other than climate change mitigation (i.e. climate change adaptation, water, circular economy, pollution prevention and control, and biodiversity).

Figure 22. Methodology to calculate avoided greenhouse gas emissions from onshore windfarms.



Source: European Commission, DG BUDGET.

Key Message

Further harmonisation of climate and environmental requirements can support a simpler and more impactful EU Budget

6

The 2021-2027 MFF features a diverse landscape of EU funds, each with its own legal basis and specific environmental requirements (e.g. climate proofing, sustainability proofing, the DNSH principle). These requirements often differ between funds and in certain cases do not even cover the same environmental objectives[12].

The diversity of requirements generates questions about overlaps between green requirements (e.g. the application of the DNSH principle and climate proofing for infrastructure in *Cohesion Policy* funds). As detailed in a previous JRC report [619], the divergences between these requirements can also hinder the creation of synergies between funds, making it challenging to optimise their impact. Furthermore, the same type of investment may be eligible for funding under different programmes with varying requirements (e.g. an infrastructure project may require to be climate-proofed under certain programmes but not under others). Finally, the lack of clarity on requirements can also reduce the predictability of funding decisions and hinder the implementation of EU funds[13].

In this context, exploring options for harmonising and streamlining key climate and environmental requirements in the next MFF whilst maintaining a high level of environmental ambition consistent with EU's climate and environmental objectives can support a move towards a more simplified and impactful EU budget.

12 For instance, circular economy is included as a stand-alone environmental objective under the DNSH principle as applied by different programmes (e.g. the RRF, *Cohesion Policy* funds) but not under the sustainability proofing applied by InvestEU.

13 For instance, the European Court of Auditors has identified the uncertainties on the implementing rules for the DNSH principle as one of the reasons causing delays in the implementation of the RRF [618].

***Enabler 6.1**: Streamlining the implementation of the DNSH principle through the development of common tools for its application in the next MFF*

The **DNSH principle** is a key element of the EU's strategy to integrate climate and environmental objectives within the broad EU policy framework. The principle is already applied to approximately 50% of the current EU budget, including the *Recovery and Resilience Facility* or the *Cohesion Policy Funds* (e.g. the *European Regional Development Fund*), as well as to new programmes such as the *Social Climate Fund*. This has led to novel ways of mainstreaming the EU's climate and environmental objectives into EU funding instruments, contributing to integrate environmental requirements beyond legal compliance and 'raising the bar' in terms of climate and environmental performance [619].

Its inclusion in the **recast *Financial Regulation*** [620], which lays down the financial rules applicable to the EU budget, has set a legal basis for its application in the next MFF, '*where feasible and appropriate in accordance with the relevant sector-specific rules*'. Following this, the European Commission has included in its proposal for a *Performance Regulation* for the next MFF the development, by 1 January 2027, of a **'single and simple' DNSH technical guidance** to facilitate the implementation of the principle across the EU budget [616]. Additionally, Article 5 of the *Performance Regulation* deems the application of the DNSH principle not feasible or appropriate under certain circumstances (notably crisis, reasons of overriding public interest and defence and security activities) and requires that DNSH criteria should be developed in a proportionate way.

According to Article 5 of the **proposed *Performance Regulation***, this simple and single DNSH guidance must include general principles and criteria and, where necessary, specific criteria at the level of relevant policy areas. The guidance must particularly distinguish between:

- Policy areas or activities that are always deemed to be in line with the do no significant harm principle, and
- Policy areas or activities that are considered to do significant harm to one or several environmental objectives and can therefore not be financed from the EU budget.

The design of the guidance can significantly benefit from the detailed analysis of the benefits and challenges of the different approaches and methodological bases employed under existing EU instruments (e.g. RRF, *Cohesion Policy*, *InvestEU*, *Social Climate Fund*) and of the guidance documents already available (Table 4).

This analysis can use, among other, existing assessments and inputs already provided by Member States and stakeholders (e.g. in the frame of the Technical Support Instrument project on the implementation of the DNSH principle, within the public consultation carried out prior to the Commission's proposal for the next MFF). The development of this single and simple guidance therefore offers the opportunity to streamline and harmonise the implementation of the DNSH principle across a diverse EU budget and provide clarity for Member States, Implementing Partners and stakeholders.

***Enabler 6.2**: Fostering the alignment of environmental requirements beyond the EU public funding domain: national budgets and private finance*

Beyond direct EU financial support, the EU also lays down environmental requirements for instruments managed by third parties receiving indirect financial support (e.g. under the *InvestEU Fund*) and for specific investments to be supported by Member States national budgets (e.g. EU State Aids rules).

These instruments are increasingly interconnected despite their different legal bases and associated environmental requirements (Box 12) and can act jointly to support the same sustainable investments. For instance, initiatives such as *Important Projects of Common European Interest* (IPCEIs), the *Clean Industrial Deal State Aid Framework* and the *European Competitiveness Fund* are designed to pool public and private finance across borders and governance levels and direct it towards strategic projects.

In this context, further science for policy work can help map the environmental requirements set in these different policy instruments and identify options to foster alignment, when possible and necessary, supporting the efforts to move towards a more consistent and effective investment landscape. This can be particularly relevant to streamline and simplify the implementation of these instruments by Member States, implementing partners and other key actors involved, potentially contributing to the blending of EU, national and private financial support towards sustainable investments.

Table 4. Comparison of key elements in the DNSH-related technical guidance applying to specific EU instruments under the 2021-2027 MFF.

	RRF	Cohesion Policy	InvestEU	Social Climate Fund
Is technical guidance provided for the specific instrument?	Yes, DNSH RRF technical guidance	No. A Commission Explanatory Note recommends using, at the level of the programmes, the same approach taken under the RRF.	Yes. Technical guidance on sustainability proofing for the InvestEU Fund	Yes. DNSH SCF technical guidance
Does the guidance define guiding principles applying to the assessment?	Yes	No. Recommendation to use the same as for the RRF.	Yes	Yes
What tools are provided to guide the DNSH assessment?	Checklists, with two stages: - Screening - Substantive Assessment	Recommendation to use the same as for the RRF.	Checklists, with three stages: Screening Proofing Positive Agenda	Sector-specific annexes defining for 52 activities and assets in the Buildings, Transport and Energy sector: - Detailed criteria - Illustrative sources of evidence Assessment checklist for activities and assets not covered by the information above.
Are there activities considered as 'always compliant' with the DNSH principle?	Activities meeting these conditions are considered DNSH compliant for the specific objective involved: - Activities tracked as 100% supporting one of the climate or environmental objectives. - Activities complying with the substantial contribution criteria of the EU Taxonomy for the objective it contributes to.	Measures assessed as DNSH compliant under the RRF.	No	Yes. The sector-specific annexes contain a list of activities and assets always compliant with the DNSH principle. Activities aligned with the EU Taxonomy substantial contribution and DNSH technical screening criteria are also considered as DNSH compliant.
Do exclusions apply?	Yes. The technical guidance identifies measures that should generally not be supported. Additional exclusions are defined for horizontal products and financial instruments.	Yes. Programme exclusions defined in the legal basis for the specific instruments (European Regional Development Fund, Cohesion Fund, Just Transition Fund...). In the case of the Just Transition Fund, certain additional activities are generally considered as not compatible with the DNSH principle (e.g. unsustainable use of biomass).	Yes. Programme exclusions defined in the InvestEU Regulation	Yes. The sector-specific annexes contain a list of non-DNSH compliant activities and assets.
Are there thresholds defined under which activities do not need to go through an assessment?	No	No	Yes. Generally, €10 million	No general or monetary threshold set. Certain thresholds set under the criteria for specific activities.

Source: Authors' elaboration, building on information provided in the technical guidance for each instrument and in the JRC's DNSH comparative analysis report [619]

Box 12. **Combining EU instruments to leverage private finance**

The current 2021-2027 budget includes examples of instruments aiming to leverage additional private investments, either through budgetary guarantees (i.e. the *InvestEU* Fund) or through financial instruments included under broader programmes (e.g. under the *Recovery and Resilience Facility*). These EU instruments include specific environmental requirements (e.g. sustainability proofing in the case of *InvestEU*, investments excluded from support due to their climate or environmental impact). At the same time, they are implemented by selected implementing partners (e.g. the European Investment Bank, International Financial Institutions, National Promotional Banks and Institutions) who already count with their own internal environmental and climate policies and procedures. For this reason, from a harmonisation perspective, these instruments are also particularly relevant because they are at the intersection between the different environmental requirements of EU public funds and those of sustainable private finance practices.

In this context, the differences in environmental requirements can act as barrier for the generation of synergies across EU funds aiming to leverage private finance. This has been solved until now by implementing mechanisms that warrant equivalence between approaches when certain conditions are met. For instance, those financial products under the Member State compartment of the *InvestEU* Regulation that apply *InvestEU*'s sustainability proofing in combination with the internal policies of certain implementing partners (e.g. the European Investment Bank) are considered as compliant with the DNSH principle for the RRF [621]. A similar approach has also been developed under the *Social Climate Fund* [622].

The preparation of the next MFF, including the development of the single DNSH guidance indicated in the previous enabler, offers the opportunity to map the different methodologies employed and the environmental conditions currently applied across these instruments, and identify in advance options to foster the creation of synergies and prevent the generation of barriers between them.

Key Message 7
Member States' national budgets will be key to closing the sustainable investment gap

The national budgets from EU Member States can play a key role in mobilising public funding to close the sustainable investment gap. As highlighted in '*Draghi report*' [5], 'the EU's annual budget is small, amounting to just over 1% of EU GDP, while Member States' budgets are collectively close to 50%'. Similarly, the *Competitiveness Compass* also highlights the size of the Member States national budgets, indicating that the capacity to finance strategic public investment 'will hinge on prioritisation and coordination of national macroeconomic and fiscal policies towards this goal' [4]. The revised ETS Directive [623], which requires Member States to use all the revenues raised through the auctioning of allowances in the EU ETS to support the clean transition, is an example of EU policy measures aiming to further mobilise national budgets for this purpose (chapter 2.1).

Nevertheless, Member States are also facing tighter budgets and an increase in the number of priorities to be supported. This highlights the importance of ensuring that the national money allocated to green priorities maximises its positive impact and that national budgets identify and phase down those investments harming EU's climate and environmental objectives.

With this in mind, further research can further help Member States to identify, monitor and assess the impact of the sustainable public investments, as well as adequate tax and tax expenditure policy, to move towards the achievement of EU's climate and environmental objectives. This should for example be of interest for the design of the Competitiveness Coordination Tool and for the NRPPs.

***Enabler 7.1**: Identifying options for harmonising and simplifying the landscape of 'green-related tools' that Member States can apply to identify, monitor and -ultimately- foster sustainable investments.*

The current public finance landscape in the EU employs multiple interrelated '**green-related tools**' (e.g. frameworks, methodologies, sustainability criteria). These include the EU Taxonomy for sustainable activities, the DNSH principle, the Green Budgeting Framework and its green and brown budgetary item lists, tracking coefficients and the technical guidance on Environmentally Harmful Subsidies, among others [624].

Many of these tools were designed and developed for highly specific initial purposes. However, their use has spread widely and Member States are aiming to **integrate them into their own green financing strategies and policies**. The EU Taxonomy was for instance developed as a classification system for sustainable activities in the private finance sphere, but it has also been included under the voluntary EuGBs, which also covers sovereign green bonds. Beyond its use in sustainable private finance and EU public funding, different Member States use (or plan to use) the EU Taxonomy and the DNSH principle in national initiatives, including the development of green budgeting methodologies (e.g. tracking methodologies).

In view of the above, further science for policy work can help identify options to move towards a more harmonised and simple landscape, helping to create synergies and prevent and remove barriers for Member States when applying them under elements linked to the financing of the clean transition.

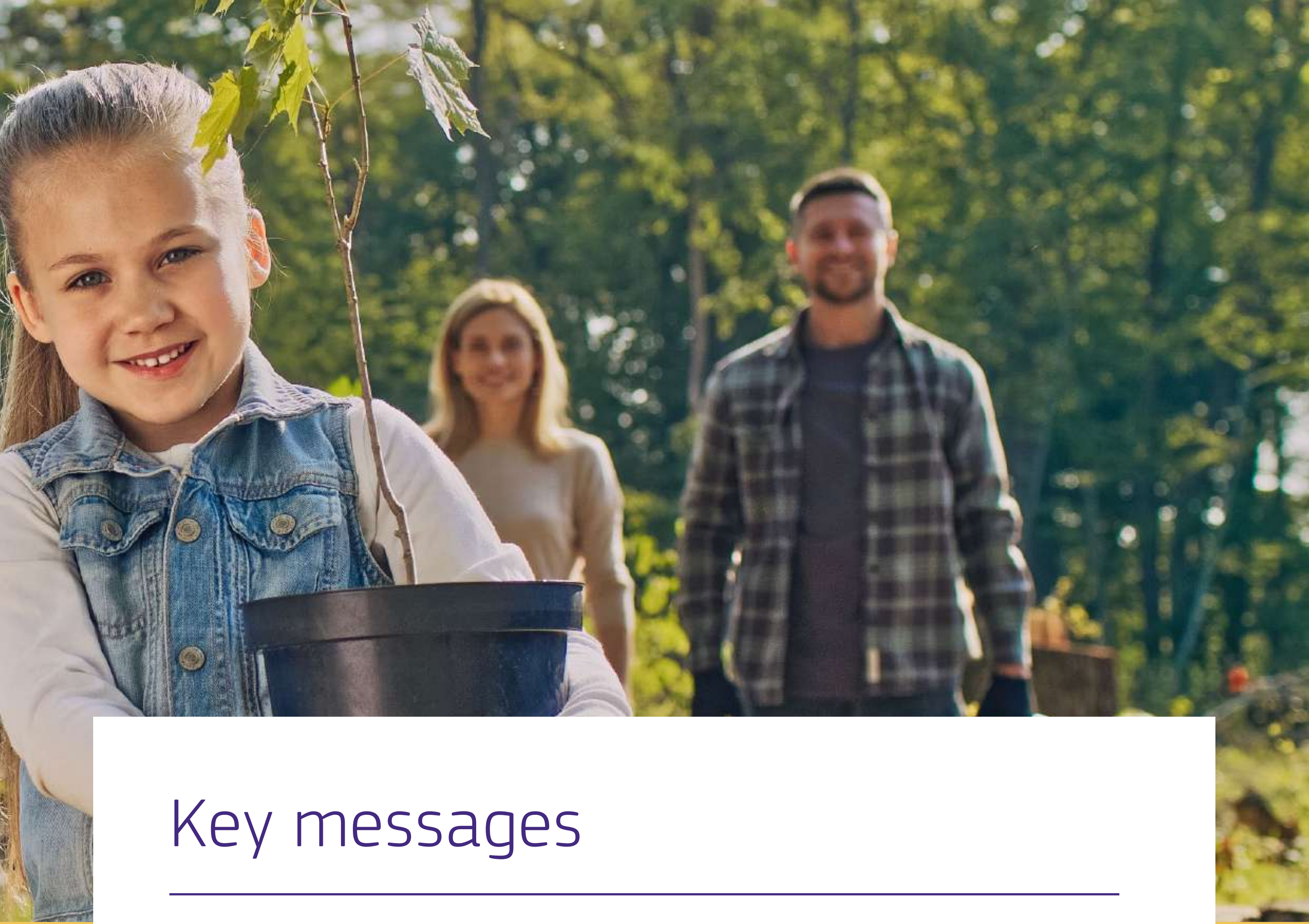
At the same time, Member States have identified the need for methodologies and guidance as one of the main challenges to establish effective green budgeting practices [624]. In this context, there is potential to explore how the different methodologies developed at EU level could serve as a basis for Member States developing their own green budgeting approaches. Further research can help identify additional methodologies and guidance needed to further support Member States (e.g. methodologies to classify the contributions of key budgetary lines, taxes and tax expenditures according to each of the six climate and environmental objectives, or for the calculation of the actual impact of public investments).

These developments could help Member States to move towards the greening of public finance in synchronisation with EU policy efforts to mobilise private finance for the clean transition, seeking maximum impact, while responding to the need for the simplification of tools and reporting frameworks.

07

Ensuring a fair and just transition

Section E
Compass Compass: Horizontal enablers



Key messages

The transition to a green economy must be **fair and inclusive**, requiring deep transformations in production and consumption systems while ensuring that the needs and vulnerabilities of different groups (including low-income households, women, and marginalised communities) are explicitly taken into account.

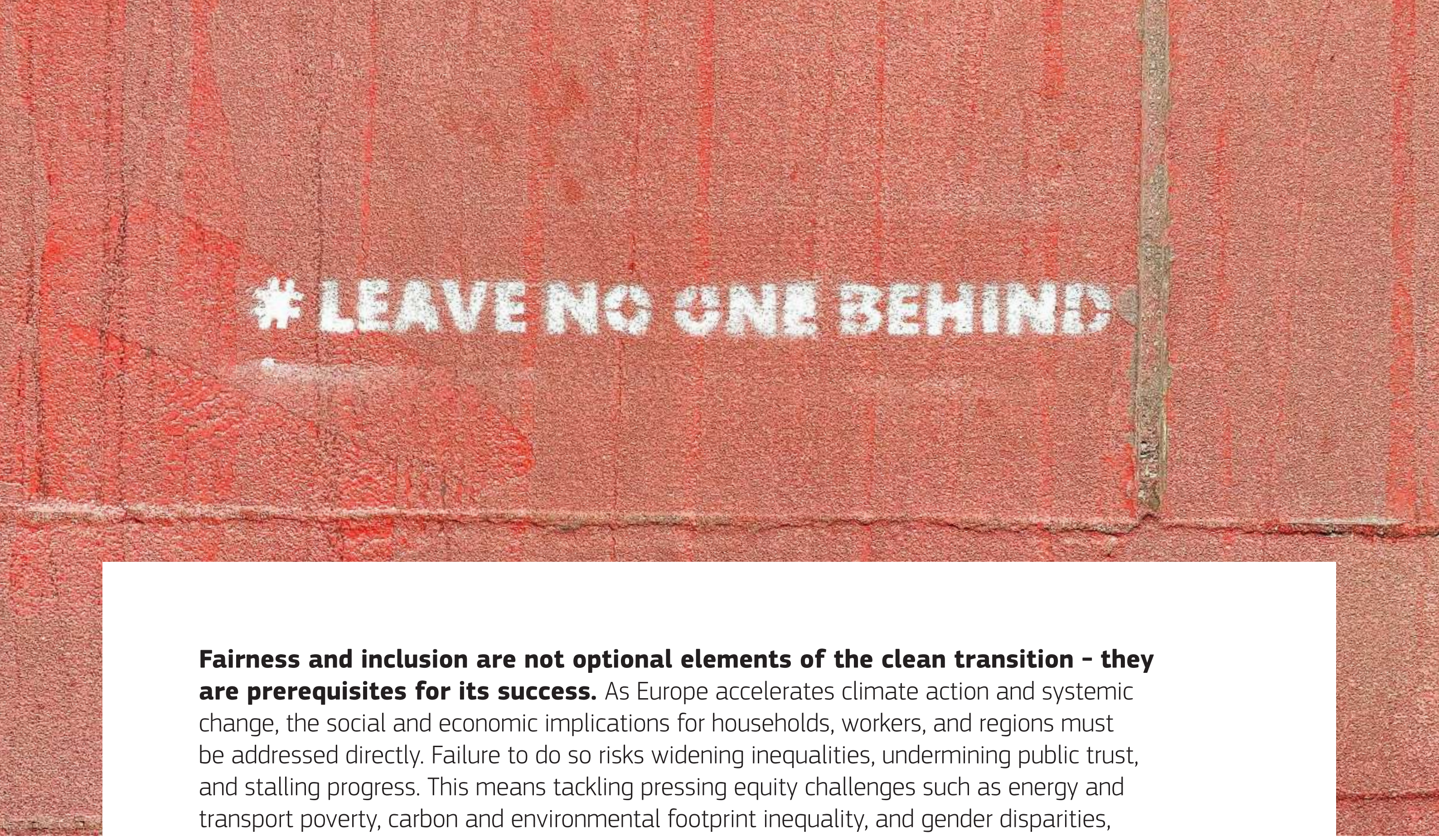
Energy and transport poverty are significant challenges: energy poverty affects 10.6% of the EU population, while transport poverty restricts access to essential services and opportunities for low-income groups.

Carbon and environmental footprint inequality is a further distributional concern: the wealthiest segments of the population have a disproportionate impact on carbon emissions and other environmental indicators, and reducing economic inequality could lead to comparable reductions in environmental footprint disparities.

Carbon pricing policies need to be designed with **distributional** impacts in mind: revenues from these policies can be used to address regressive effects and support a fair and inclusive transition.

Transitioning towards climate-friendly practices may lead to increased **costs for farmers and food producers**, underscoring the need for targeted support measures and a carefully managed transition in the agriculture sector.

Beyond GDP metrics are essential in policymaking. Sustainable and Inclusive Well-being (SIWB) metrics and the Gross Ecosystem Product can provide a more comprehensive picture of well-being and the value of nature, offering a richer evidence base for policy decisions.



Fairness and inclusion are not optional elements of the clean transition – they are prerequisites for its success. As Europe accelerates climate action and systemic change, the social and economic implications for households, workers, and regions must be addressed directly. Failure to do so risks widening inequalities, undermining public trust, and stalling progress. This means tackling pressing equity challenges such as energy and transport poverty, carbon and environmental footprint inequality, and gender disparities, while also advancing a fair and ethical food system that supports access to healthy diets and sustainable livelihoods. Building on the principle of "leaving no one behind," embedded in the 2030 Agenda and underpinning Europe's clean transition, this chapter examines these challenges and highlights key policy levers and enabling conditions for a socially just and inclusive transition across regions and sectors.

7.1 Socio-economic risks and opportunities

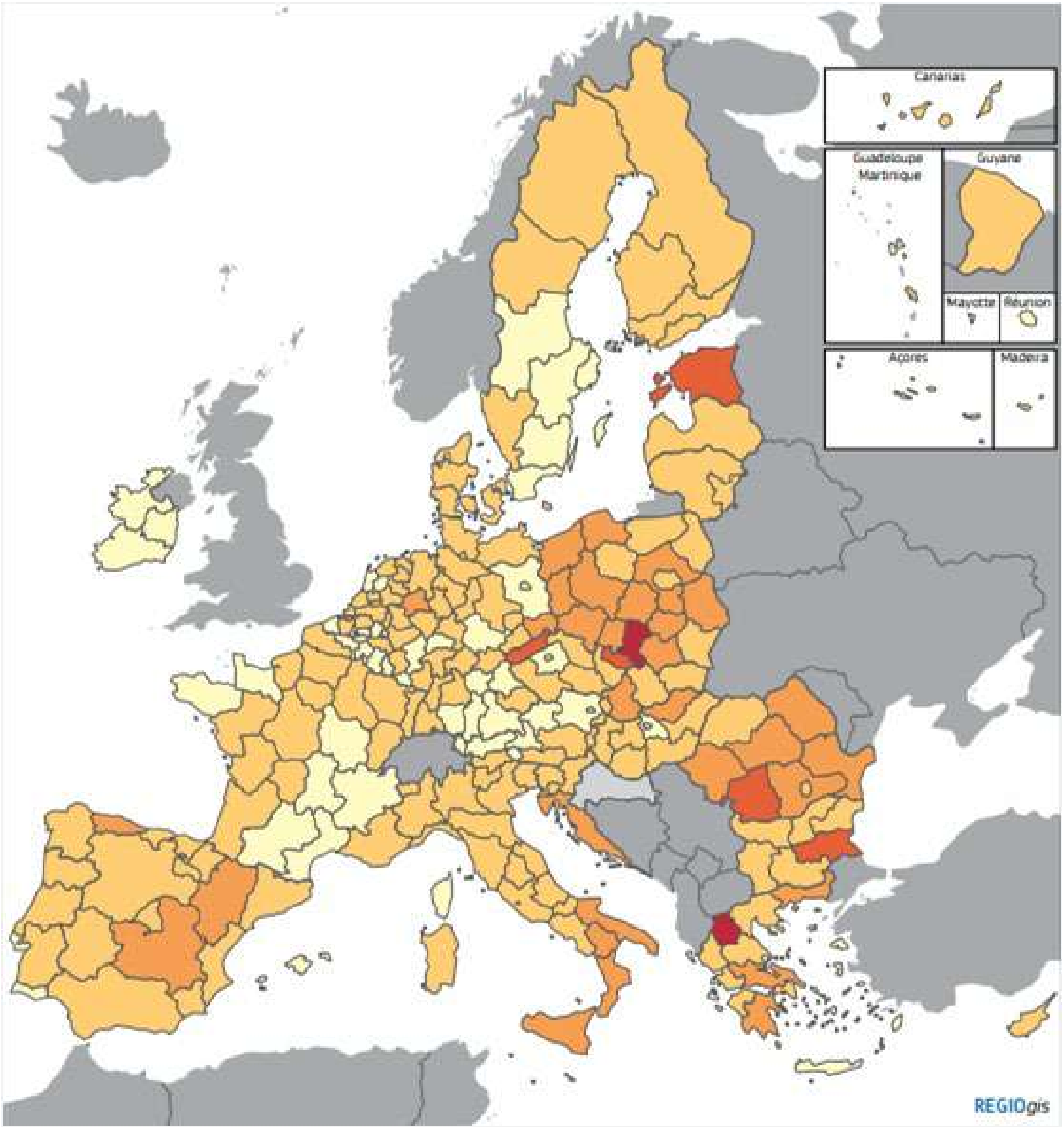
Delivering the clean transition requires profound structural changes across energy, mobility, food systems and industry, with impacts that vary by sector, region and social group. **Addressing these distributional effects is essential to ensure fairness and inclusiveness throughout the transition**. Vulnerable demographic groups are extremely exposed to fossil fuels dependency and shocks, which stresses the importance and value of a fair and just transition.

The *Clean Industrial Deal* commits to a "just transition that delivers quality jobs and empowers people, building on their skills, while promoting social cohesion and equity across all regions" [625]. Moreover, as recently stated in the *Competitiveness Compass*, social fairness and effective social policies are crucial for competitiveness, prosperity and security [4]. A stronger Europe with a higher level of productivity can ensure that the European social model remains affordable in the long term.

Achieving these goals requires deep transformations in the production and consumption systems. A key challenge is to ensure that the benefits of the transition are broadly shared and that its costs are distributed fairly. The EU has put in place robust policies and targeted funding instruments. Key initiatives include the Just Transition Mechanism and its three pillars - the *Just Transition Fund*, the *InvestEU Just Transition* scheme, and the *Public Sector Loan Facility* - which provide support to carbon-intensive regions and industries facing the greatest socioeconomic risks. The *Social Climate Fund*, established under the *Fit for 55* package, addresses the distributional impacts of carbon pricing, particularly for households at risk of energy or transport poverty.

Additional instruments such as the ***European Social Fund Plus***, ***Cohesion Policy*** funds, and the ***European Pillar of Social Rights Action Plan*** reinforce measures for reskilling, social protection, and inclusion, ensuring that the transition fosters opportunities while protecting those most exposed to its costs [626]. The consequences of climate change, pollution and environmental degradation may disproportionately affect vulnerable and disadvantaged communities, groups that often bear the least responsibility for causing these environmental problems, underscoring systemic inequities in environmental justice [627], [628], [629], [630]. This includes notably low- and lower-middle income households, who spend a high share of their income on essential services such as energy, transport and housing, as well as micro, small and medium-sized enterprises [631], [632]. Therefore, maintaining high clean transition ambitions while fostering greater solidarity and justice in the pursuit of its objectives is essential to ensure that actions taken to mitigate and adapt to climate change are socially fair.

Figure 23. Socioeconomic risks associated with the clean transition by NUTS 2 region.



Source: [23]. Map elaborated by DG REGIO based on results of the CINTRAN project [633]. Note: The 'Socioeconomic risk' index measures the overall risk with respect to the socioeconomic situation in a region, considering vulnerability, hazard and exposure The indicator rests on the definition of the IPCC, which treats risk as the combination of Hazard, Exposure and Vulnerability. In the Socio-economic risk index, Hazard is described as the drop in production of fossil fuel-related sectors due to the transition risk, Exposure is the respective employment share, while Vulnerability is a composite index of socioeconomic sub-indicators that further describe Sensitivity and Adaptive Capacity of the regions. For further details on the methodology, see [633].

Implementing the clean transition makes a significant impact on business and employment, these will vary by sector, occupation, region and country, and bring job changes within sectors. For example, regions with strong economies, more innovation and knowledge-intensive services are better equipped for a clean transition; economically diversified regions tend to have lower socio-economic risk, while those reliant on fossil fuels face higher risks [23]. Results of the CINTRAN project, which examined the risks of territorial imbalances that could result from the clean transition, identified the 15 EU regions likely to be affected most by the transition (Figure 23) [633]. According to a study from the JRC [634], the potential social consequences of increasing energy and consumer prices in the EU vary significantly **between and within Member States**, based on the structure of household expenditures. Low-income households spend considerably more on food and energy in relative terms and are therefore particularly exposed and vulnerable to the effects on price changes. The social situation is especially problematic in Central and Eastern European countries, where large segments of the population devote the majority of their budget to essential items.

The **gender perspective** in the clean transition should also be further strengthened, as several studies highlighting the different impacts and vulnerabilities to climate change, energy and transport poverty between men and women, due to their different social roles, status, and resources [635], [636]. For instance, women are more often caretakers and spend more time at home and are thus more exposed to indoor cold due to energy poverty, with the consequential adverse physical health impacts [637]. Transport poverty, often linked to fuel poverty, is also a significant issue that affects women differently than men. For example, women tend to adjust their travel patterns due to safety concerns and they often engage in trip chaining, combining paid and unpaid activities with family responsibilities, resulting in longer, more frequent, and complex travel patterns [636].
Thus far, this aspect has only been partially addressed [638], [639]. A further JRC study analysed the effects of the energy transition on women, shedding light on the often-overlooked impact of gender disparities in access to clean and affordable energy, highlighting the need for immediate action to bridge the gap and foster social resilience [640]. It emphasises the importance of inclusive policies to guarantee women's active engagement and representation in the energy industry, not just as customers, but also as decision-makers and innovators, with increased political and managerial engagement.

As highlighted also by the European Social Observatory [638], the EU framework for the just transition needs to be significantly broadened and made more effective, strengthening the link between the clean transition and welfare policies, and also reinforcing the involvement of citizens and stakeholders. Justice must also become a central pillar for climate adaptation measures, to ensure social fairness and build a truly resilient and inclusive Europe [630].
The new competitiveness strategy reinforces the urgency of promoting skills and quality jobs while safeguarding social fairness. The success of the transition to a green and competitive Europe hinges on the ability to address the concerns of those most vulnerable to change. Achieving a fair and just transition requires a clear understanding of the challenges, distributional impacts, and inequality risks such as energy and transport poverty, carbon footprint disparities, and gender gaps.

7.1.1 Energy poverty

Energy poverty is defined, in the 2023 *Social Climate Fund Regulation* and the revised *Energy Efficiency Directive* [123], [124], as 'a household's lack of access to essential energy services that provide basic levels and decent standards of living and health, including adequate heating, hot water, cooling, lighting, and energy to power appliances, in the relevant national context'. Energy poverty is becoming a pressing issue for a socially inclusive clean energy transition in the EU, due to its impact on vulnerable populations [634], [641], [642]. After a decade of decline, energy poverty is on the rise again, particularly since energy prices significantly increased in 2021 in the wake of Russia's war of aggression against Ukraine [643]. More than 10% of the EU population struggled with inadequate home heating in 2023. Variations across regions and demographic groups illustrate the complexity of the issue. Low-income households were disproportionately affected, with some regions reporting that up to 55% of individuals were unable to meet their energy costs [644]. This underscores the urgency for comprehensive policy measures that address both the symptoms and the root causes of energy poverty.

Tackling energy poverty has become a specific policy priority in the legislative package *Clean Energy for All Europeans*, which was strengthened with the *Recommendation on Energy Poverty* [645], issued as part of the *Renovation Wave* package and recently strengthened by a *Second Recommendation on Energy Poverty* [646]. Supporting the *Clean*

Industrial Deal, the *Action Plan for Affordable Energy* will focus on decreasing energy costs for citizens, businesses, industry and communities across the EU, considering the needs of all people, including vulnerable groups. The European Affordable Housing Plan further supports these objectives, working across all levels of national authorities and bringing stakeholders together to deliver affordable housing to all Europeans [647]. **The energy efficiency of residential buildings** is a key determinant of energy poverty. The *Energy Performance of Buildings Directive* [122] includes provisions to tackle energy poverty and mandates Member States to design and implement financing schemes that not only incentivise building renovations but also include robust monitoring of social impacts to prevent any adverse effects on vulnerable populations.
A close analysis of recent EU climate and energy policy proposals reveals **four main layers of action** that relate to energy poverty: initiatives directly related to energy poverty and broader social aspects; the energy performance of buildings; energy efficiency measures; and related climate and energy policies [49].

Energy poverty is primarily caused by high energy prices, low income and energy-inefficient housing. Therefore, energy efficiency measures, funding mechanisms and targeted protection and support measures are frequently recognised as a way to mitigate energy poverty [648]. However, with the introduction of consensus-based indicators of energy poverty, individual behaviour has been considered as a fourth driver of energy poverty: behaviour change strategies are therefore an additional means not only to address energy poverty, but also to empower individuals to take an active role in the energy transition as *energy citizens* [649].
The concept of ***energy citizenship***, which emphasises the role of **citizens as active social and political participants in the energy transition**, is closely linked to addressing energy poverty, as its promotion helps to combat the energy injustices underlying energy poverty [85]. To help policymakers elevate citizens from passive policy recipients to active and knowledgeable participants, behavioural insights are key. As an example, to involve citizens in policy development **"thinks" and "nudges plus"** can be used. *Thinks* are deliberative interventions where citizens engage in reflecting on issues and proposing solutions, such as through citizens' juries, assemblies, and participatory budgeting. *Nudges plus* combine the reflective aspect of thinks with nudges, resulting from a co-design process involving both citizens and local policymakers [49].
The energy poor can also be empowered to become energy citizens by engaging in **energy communities** (bottom-up initiatives of citizens who come together to produce, share, and manage their own renewable energy). This involvement allows them not only to take ownership of the energy they produce, thus promoting ***energy democracy***, but also to alleviate energy poverty, making energy bills more affordable [650].

While numerous measures to combat energy poverty exist, their effectiveness relies on accurately identifying the target group, i.e. the energy poor. The latest data from Eurostat show that approximately 40 million Europeans across all Member States, representing 10.6% of the Union population, were unable to keep their home adequately warm in 2023. This represents a sharp increase since 2021, when 6.9% of the population were in the same situation [646]. However, keeping one's home adequately heated or cooled represents only one of the multiple dimensions underlying energy poverty. Energy poverty is, in fact, driven not only by energy affordability and access, and housing quality, but also, by geographical factors, path dependencies, existing inequalities (e.g. gender inequality, marginalisation) and health factors [651].

Because of this multidimensionality, measuring energy poverty remains challenging, and many EC initiatives and collaborations – such as the ISG on Energy Poverty and Vulnerable Consumers, the Covenant of Mayors, and the European Advisory Energy Poverty Hub (EPAH) - are in place to improve the identification of, and ways to address and support the energy-poor. These initiatives underscore the **key role that local and urban actors play** not only in addressing energy poverty, but also in local climate action that promotes **climate justice** [652]. Given the strong relationship between energy poverty and income, **income-support policies are essential** to tackle energy poverty situations in terms of crises, especially for households under the poverty line [643]. However, other types of policy may support the energy poor within middle-income groups. This is the case for price caps, which reduce the burden of expenditures on energy goods [648], or structural interventions that step up energy efficiency by reducing the need for energy consumption. Finally, behavioural levers such as assisting consumers in setting goals for reducing energy consumption through apps and the implementation of educational campaigns to make investment choices that improve energy efficiency may also be effective in reducing energy poverty, especially in the long-term.
Access to affordable energy is a cornerstone of the *Clean Industrial Deal*, and the *Action Plan for*

Affordable Energy reaffirms the EU's commitment to an inclusive energy transition where no individual or community is left behind. A key component of the strategy to ensure affordable energy is adopting a preventive approach to energy poverty by identifying households at risk. High rental expenditures are a significant risk factor for energy vulnerability [653]. This approach allows for targeted measures, such as rental interventions, and helps mitigate the risk of summer energy poverty, which is more prevalent in urban areas with higher rental rates [128].

7.1.2 Transport poverty

Transport poverty refers to the lack of affordable, accessible and reliable transport options, limiting people's ability to meet essential needs and participate fully in society [654]. Recent resources to support policymakers in addressing this issue include recommendations for Member States by DG MOVE [655] and the Transport Poverty Hub, an online platform providing insights into the state of development of regional transport networks [654].

The European Social Policy network (ESPN) report observes that the **irregular distribution of public transport networks** in EU Member States restricts accessibility to essential daily activities (e.g. travelling for work, education, healthcare, groceries and other similar vital trips) for low-income groups, with negative consequences [656]. This lack of accessibility can lead to reduced mobility, forcing individuals to forgo essential activities and limiting opportunities for work and education. Over time, this may contribute to social exclusion with possible negative consequences for health and well-being.

Dwelling and transport costs are also interconnected. Poorer households often move to suburban areas to lower housing expenses, but this can lead to higher travel costs and greater reliance on private cars. This car dependency exacerbates negative externalities in their communities and increases both transport and energy poverty.

Lower-income individuals, women, people with disabilities, older people, and various marginalised groups are most affected by transport poverty. These groups often face limited mobility options, higher relative transport costs, longer travel times, and safety concerns, leading to greater social and economic disadvantages. Furthermore, as discussed in Chapter 2, zero-emission vehicles (ZEV) are often not affordable for vulnerable households.

The consequences of transport poverty are extensive, including social exclusion, immobility, time poverty, community segregation, reduced educational opportunities, health inequalities, pollution, housing issues, discrimination, car dependency, and energy poverty due to local fuel prices.

A JRC study [636] has also identified some of the measures taken to address transport poverty, which include social justice policies, gender mainstreaming, housing and sustainable mobility strategies, active mobility solutions, polycentricity and the concept of 15-minute cities, and fighting isolation in remote areas as well as the digital divide. Many living areas across Europe, both urban and rural, are now being planned in a way that reduces the negative consequences of transport as much as possible. In this respect, the spatial arrangement of the built environment is vital to carrying out daily activities and accessing goods and services.

The new *Clean Industrial Deal* has announced a Sustainable Transport Investment Plan, to support specific renewable and low-carbon fuels for aviation and waterborne transport, and new rules facilitating the shift towards sustainable land transport modes.

7.1.3 Environmental footprint inequalities

Carbon inequality refers to the unequal distribution of carbon emissions (or carbon footprint) and relative impacts across regions and different socio-economic groups [657]. Chancel [658] estimated the global inequality of individual GHG emissions in 2019 and found that the bottom 50% of the world population emitted 12% of global emissions, whereas the top 10% emitted 48% of the total. Inequalities in carbon footprints remain large both between and within world regions. Inequality of carbon footprints between income groups is expanding across all regions, with a declining trend in the carbon footprint for developed economies, and an increasing trend for developing countries across all income groups [659].

However, focusing solely on carbon inequality is not enough without addressing underlying economic disparities. **Reducing income inequality**, for example, could lead to comparable reductions in carbon footprint gaps [660]. In addition, considering carbon as the only measure for assessment of environmental impact may hinder possible trade-offs with other environmental dimensions such as particulate matter or resource use among others [661].

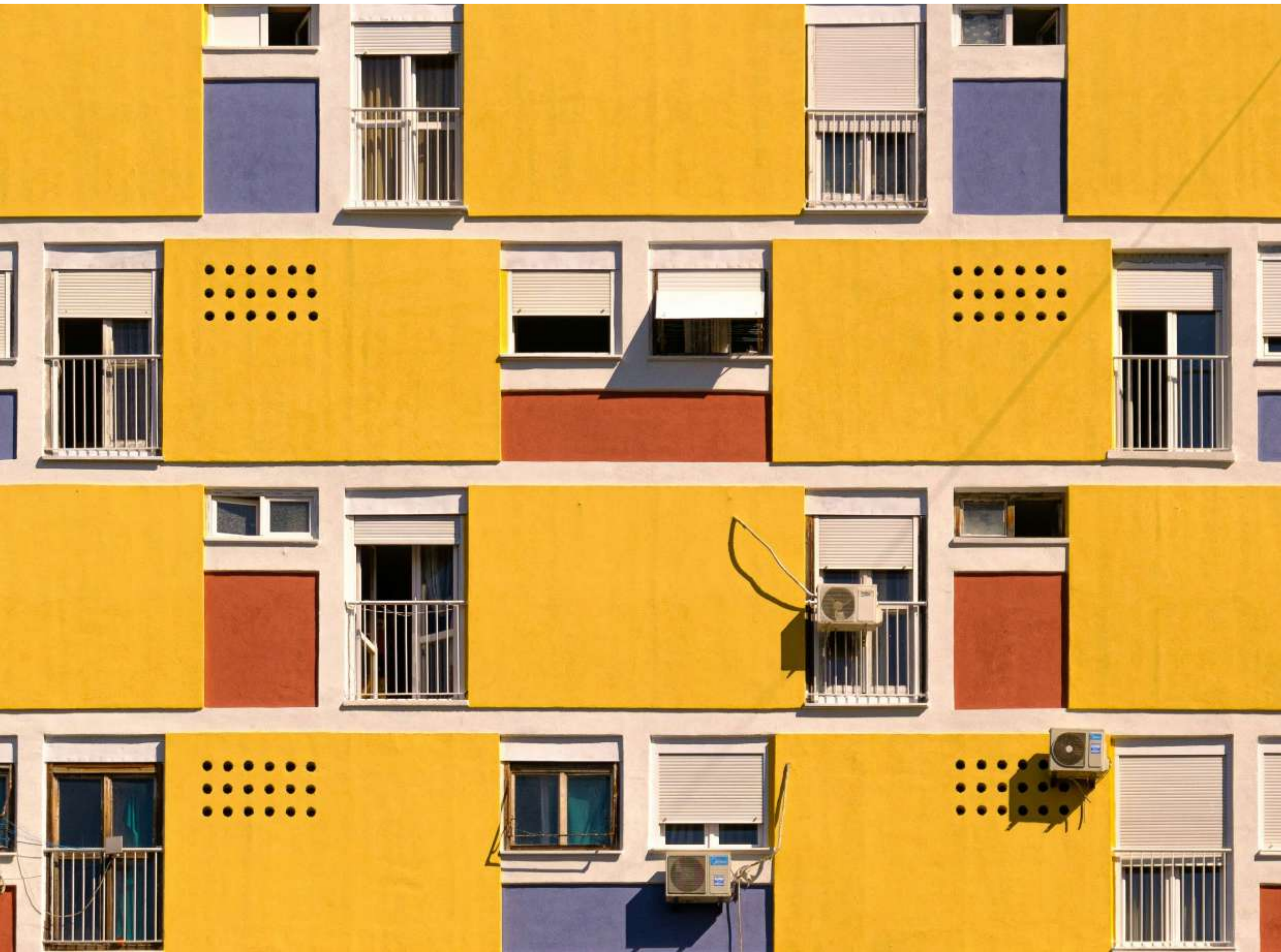
For the European Union, an ongoing JRC research project on the **distributional aspects of the carbon and other (15) environmental footprint indicators of households' consumption**[1] confirms the large inequality in consumption footprints across different segments of the population [661]. This study estimated that **the 20% of EU households with the highest income have a footprint 179% of the size of the poorest 20%**. However, a **remarkable variation** exists across EU countries, reflecting differences in how consumption levels and compositions relate to environmental impact.

The relationship between income and footprint stems from unequal consumption levels by different income groups and, potentially, from differences in consumption patterns between lower- and higher-income households. Data suggests that as income increases, there is a trend towards a higher consumption footprint in mobility, household goods, and appliances, whereas the relative footprint for food and housing decreases.

Beyond the average picture presented above, research within the framework of the DISCO(H) project provides evidence on the possible impacts on the environment and planetary boundaries. The research highlights that the environmental impact of consumption from the lowest-income household group in the EU lies above the planetary boundaries for five out of 16 impact categories [337]. Estimates of income-based inequality in the impact of consumption show that the richest considerably distinguish themselves for their contribution to the **depletion of non-renewable finite resources as minerals and metals** [661]. The footprint contribution of the top 20% income earners is 264% that of the bottom earners.

These data are pivotal to ensure a fair transition towards a modern, fair, efficient and sustainable economy. **Identifying the socio-economic and demographic groups** that are **contributing the most** to climate change and environmental

1 DISCO(H) Project, "Distributional assessment of the consumption footprint of households in the EU: addressing carbon and other environmental footprints", financed through an administrative agreement between DG Employment and Social Affairs and the Joint Research Centre [661]. The project builds on a novel dataset of households' consumption footprint, combining household expenditure data and the JRC Consumption Footprint suite of indicators [337], [662].



degradation is key to ensure that the burden of the policies needed for achieving climate neutrality is **distributed proportionally** in the population, so that those already contributing the least are not overcharged.

The decarbonisation of the energy supply can have another important role in reducing carbon inequalities [663]. **Changes in consumption patterns are** also **crucial** to move towards more sustainable consumption and a lower impact on carbon emissions, even if behavioural changes are particularly critical for the richest segment of the population, which has the largest impact [664]. This might include both a reduction in the consumption level of more privileged groups and a change in the type of goods consumed [660].

7.1.4 The impact of carbon prices

Policy instruments such as carbon pricing can play a key role in steering consumption patterns toward lower use of imported fossil fuels, which triggered the recent energy crisis in 2022, leading to lower emissions. However, these measures can also have distributional implications. Introducing a price on carbon, especially for fuels purchased by households for heating and private transport, is shown to have regressive effects without compensating measures [49], [665], [666] [667], [668], which have the potential to undermine support for climate policy [669].

The JRC leveraged its modelling capacities to analyse and identify different policy designs to address the distributional effect of carbon pricing to fuels used by households, [49], [665], [666]. Revenues from carbon pricing policies could be used to compensate the most affected vulnerable groups, such as households in energy or transport poverty, so they are not left behind during the clean transition [665], [667], [670]. The *Social Climate Fund* (SCF), created alongside the new *Emissions Trading System* (ETS2), was designed to use revenues from emissions through appropriate policies and support schemes [665], [667], [670], e.g. to improve energy efficiency or to provide support to low-income households for replacing their heating systems.

Moreover, the JRC analysed distributional impacts of the proposed revision of the *Energy Taxation Directive* (ETD) and *Carbon Border Adjustment Mechanism* (CBAM) reforms [671], [672] [665], [667], combining its general equilibrium macroeconomic model for energy, climate and environment (JRC-GEM-E3) and its microsimulation model for tax and social benefits (EUROMOD) [671], [672]. Results confirm that **higher energy taxes lead to a shift towards greener energy use and investments in energy efficiency.** In line with their intended purpose, the proposed ETD reform will reduce emissions associated with the use of energy, and fossil fuels in particular. These changes are unlikely to have uniform impact across sectors and countries: simulated price and wage changes are more pronounced in the transport sector, where fuel inputs represent an important component in overall production costs, especially in Central and Eastern European countries, Luxembourg, Malta, and Greece. The same analysis indicates that the ETD will have, in the short-term, negative but small welfare effects on households. These effects are, however, rather uneven between and within countries. In particular, households at the bottom and the top of the income distribution are generally found to be most affected [673]. This is the result of a regressive "price effect" driven by the expected increase in consumer prices, that disproportionately affects low-income households; and a progressive "income effect" driven by the expected decrease in labour and capital income, which mostly affects middle- and high-income households. The overall effect is to increase inequality in some countries.

The recent energy crisis was largely driven by spikes in the price of imported fossil fuels - particularly natural gas - exposing the EU's vulnerability to external supply shocks. This demonstrated the need to carefully design compensatory measures to reduce the impact of higher energy prices. In this context, EU carbon pricing instruments aim not only to reduce emissions but also to structurally decrease reliance on fossil fuel imports, thereby mitigating exposure to such price volatility over time.

The efficacy of such measures to reduce the effects of higher energy prices can differ significantly. Amores et al. [674] compared the (untargeted) price caps introduced in 2023 in Germany, the Netherlands and Austria with alternative hypothetical policies (targeted price caps and targeted and untargeted lump-sum benefits) with respect to their efficiency in attenuating the inequality and poverty increasing effects of surging energy prices. Their estimates show that price cap policies partly absorbed the negative distributional consequences of the inflationary shock and counteracted the increase in energy poverty. However, even after the implementation of price caps, the poorest households were still the most severely affected. In other words, price caps were not sufficient to offset their welfare losses. The authors find that simpler measures, such as targeted lump-sum cash transfers, would be more efficient in cushioning the inequality-increasing effects of inflation. Price caps, on

the other hand, are more efficient in reducing energy poverty, given the non-negligible incidence of energy poverty in middle-income groups. In general, more targeted measures provide a better support to the vulnerable households; however, they may be more difficult to implement, especially on short notice as was the case in the recent energy crisis.

7.1.5 A fair, inclusive and ethical food system

A sustainable food system, that allows everyone access to a nutritious and healthy diet is a significant challenge [675]. The **need for a paradigm shift towards sustainable food systems** is gaining recognition, as demonstrated by the growing number of initiatives implemented across the EU and worldwide [216].

There is an urgent need to **make the food system** not only **economically viable, but also fair, inclusive, ethical, healthy and environmentally-friendly** both within the EU and globally [676], [677]. This ambition is reflected in key EU frameworks, including the *European Pillar of Social Rights*, as well as strategic initiatives such as the *Vision for Agriculture and Food*, and the *European Ocean Pact*. It is further reinforced in complementary policies, including the *Biodiversity Strategy*, the *Bioeconomy Strategy*, the *Circular Economy Action Plan* and the new *European Industrial strategy*. The health dimension of sustainable food systems is further supported by initiatives such as *Europe's Beating Cancer Plan* and the *EU4Health Programme*, which emphasise the role of diet in disease prevention and public health.

The *Vision for Agriculture and Food* published in February 2025 [68] encourages the agri-food system to be attractive, competitive, sustainable and fair for current and future generations. It reinforces the need for social sustainability, to foster fair living conditions in rural areas, protect the rights of workers, develop skills and attract more women and young people to agricultural professions. It also highlights the importance of reestablishing the link between farming, food and territories to enhance the affordability and availability of healthy, high-quality food, including by providing the right incentives to promote the consumption of local, seasonal products, and food produced with high environmental and social standards, including organic products and food originating from shorter supply chains. The *European Ocean Pact* highlights generational renewal, female participation, upskilling and appropriate working conditions as essential ingredients for a prosperous and attractive blue economy.

Existing challenges relating to various environmental, social and economic developments taking place in the EU and globally, threaten the long-term viability and resilience of the food system in reducing its future capacity to face, respond and adapt to disturbances and shocks [678], [679]. Social challenges in the food sector include poor working conditions, inadequate occupational health and safety, unfair remuneration, exploitation of migrant and seasonal workers, gender inequality and discrimination [680]. The globalised nature of agri-food value chains requires consumption-based methodological approaches, which take into account the potential adverse impacts of EU consumption on third countries. The social footprint methodology applied to EU food consumption, for instance, reveals social hotspots in terms of child labour, forced labour and fair salary, for vegetables, fruits, and rice, which are key for healthy and environmentally sustainable diets [681].

Climate change will intensify pressures on the ecosystem services that underpin food systems, degrading air, soil, and water quality and affecting primary production. These changes will have significant consequences for food security and, in particular, the nutrition of vulnerable groups [682]. A cascade of impacts from climate change outside Europe may affect the price, quantity and quality of products, and consequently trade patterns. Increased prices for inputs, such as fertilisers and fossil energy, can cause production challenges and supply uncertainties, thus affecting food availability. On the other hand, transitioning towards climate-friendly practices may lead to **increased costs for farmers and food producers**, which could impact food prices and, in turn, **food security** [683], [627], [629]. Low-income households, that usually purchase less expensive food products, face particular constraints in accessing and affording sustainable food [684]. Balancing environmental goals with economic viability and social equity is an ongoing challenge, which requires a multi-faceted approach, addressing the complex interplay of social, economic, and environmental factors.

Research and innovation play a key role in developing solutions that can facilitate food system transformation: Food 2030 is the EU's **research and innovation policy framework** supporting the transition towards sustainable, healthy and inclusive food systems that respect planetary boundaries. It sets out 11 **pathways for action** where research and innovation can concretely deliver co-benefits related to nutrition, climate, circularity and communities, at multiple levels: from local to international [685]. Furthermore, an EU monitoring system has recently been set up to provide information on **progress** towards a fair, healthy and environmentally friendly food system in the EU. It is built on a set of key indicators, encompassing all the dimensions of sustainability - environmental, economic and social (including health) [336].
A fair, inclusive, and ethical food system in the EU requires a comprehensive approach that addresses policy, stakeholder engagement, innovative business models, and sustainable practices. In this way the EU can promote a more equitable, environmentally sustainable, and socially responsible food system. The ongoing Food Dialogues with the food system's actors, including consumers, primary producers, industry, retailers, public authorities and civil society, provide an important input for consensus building and implementation of the social dimension of food systems.

7.2 Accounting for well-being and ecosystem services

Delivering a fair and just clean transition depends not only on the right policies and investments but also on how progress is measured. Traditional metrics such as GDP fail to capture social equity, environmental integrity, non-monetary aspects of the quality of life, and intergenerational well-being, which are central to fairness. Without complementary indicators, risks such as rising inequalities or deteriorating health prospects, loss of natural capital, and regional disparities may remain hidden, undermining trust and accountability. The integration of socio-ecological and well-being indicators in EU policymaking is key to monitoring and foster a fair and just clean transition [638] and to align with the SDG framework, which emphasises the need "to develop **measurements of progress** on sustainable development **that complement GDP**" (SDG target 17.19) [686].

GDP is one of the top-level indicators of the System of National Accounts, which serves to compile market-based measures of economic activity. It is, however, often used as a single indicator to measure economic and even societal progress. In such a role, this metric has important shortcomings: it neglects social, political, geopolitical and environmental values and in particular does not address the well-being of people in a comprehensive way. Moreover, it takes into account increased production without considering its full range of costs. Therefore, while GDP remains the single most important economic indicator to measure the overall state of an economy, there is a need for measures that supplement GDP and can evaluate countries' long-term sustainability by taking into account the interplay between natural, social, and human capital [687], [688]. This strategic shift is further underscored by the UN Secretary-General, who identifies "complementary measures to GDP" as a crucial step for accelerating the achievement of the SDGs and leaving no one behind [689]. This was pursued further in the recently adopted *Pact for the Future*, in which Action 53 commits to developing 'a framework on measures of progress on sustainable development to complement and go beyond gross domestic product'. With the nomination of the High-Level Export Group in May 2025, this work has already begun.

7.2.1 Beyond GDP: Sustainable and inclusive well-being

The disruption of established lifestyles by the Covid-19 pandemic has reignited the long-standing 'beyond GDP' debate on the kind of economic growth that is desirable, and on what matters for human well-being in a world of finite resources. The triple planetary crisis (climate change, biodiversity loss and pollution), financial crises, persisting poverty, social exclusion and increasing inequality and societal polarisation all call for political objectives beyond GDP alone.

In this context, people's **well-being** is gaining political traction as an explicit political objective in the EU. It is enshrined in the Treaty on European Union (Article 3(1) TEU: "The Union's aim is to promote peace, its values and the well-being of its people"), and there is a wide range of related activities across the Commission, reflecting the political attention given to well-being. For example, the UN's Sustainable Development Goals and the European Pillar of Social Rights are now reflected in the European Semester's competitive sustainability framework [690] (addressing **inclusiveness** and environmental sustainability aspects in social and economic policy coordination, recognising that an economy must work for the people and the planet). The *8th Environment Action Programme* [691] aims to ensure well-being for all within the planetary boundaries, adding a **sustainability dimension to well-being**. This is further extended by the recently launched work on the EU's Intergenerational Fairness Strategy, looking at the balance between the well-being of current and future generations.

Grounded in the "first Stiglitz Report" [692], the OECD is leading efforts to develop indicators that measure the well-being of individuals, families, society, future generations and the planet, to help monitor societal progress and inform policy decisions across multiple dimensions. The 7th OECD World Forum held in November 2024 stressed the need for well-being approaches to jointly address the social, economic, and environmental challenges, and to help ensure that the green and digital transitions are fair, just, and inclusive. Well-being indicators, grounded in multidimensional, people-focused frameworks, can help monitor the effects of specific policies and clarify trade-offs and positive synergies across different policy areas and different sectors of society [693]. This is important not only for strengthening evidence-based policy making but also for supporting public acceptance of necessary reforms and building more cohesive and resilient societies. Their emphasis on future well-being establishes a link with the emerging strategy on intergenerational fairness - a priority also strongly advocated by the beyond GDP research community, including in a joint paper co-issued by five well-being-related Horizon research consortia [694]. Several initiatives are adopting the beyond GDP concept, aiming to develop a more comprehensive approach to measure prosperity and well-being, encompassing the effects of global challenges and policies on the quality of life, health, living and working environments, inequalities, environmental sustainability, and intergenerational fairness [687], [695], [696]. To complement the GDP metric, a range of alternative indices and indicator sets has been developed and integrated into policy making, providing a more nuanced and multidimensional understanding of societal progress. Examples of these measures include the OECD's Framework for Measuring Well-being and Progress, the Human Development Index [697], the Social Progress Index [698], the SDG index [699], and the ZOE's compass [700], among others. Further examples include: the Eurostat collection on the 'Quality of Life', the World Bank's Changing Wealth of Nations report series, the Doughnut framework, ETUC's Decent Work & Sustainable Growth Index, GSI's Recoupling Dashboard.

This plurality, however, represents a major practical hurdle for beyond GDP initiatives: without a common language and methodology, it is difficult to compete with the highly standardised and polished framework of the System of National Accounts [701] that underpins GDP. The notion of **sustainable and inclusive well-being** is increasingly seen **as a new consensus term for beyond GDP** – as advocated by the Horizon research consortia WISE Horizons and MERGE, for example. Similarly, the UN Network of Economic Statisticians is working on an overarching framework for inclusive and sustainable well-being [702].

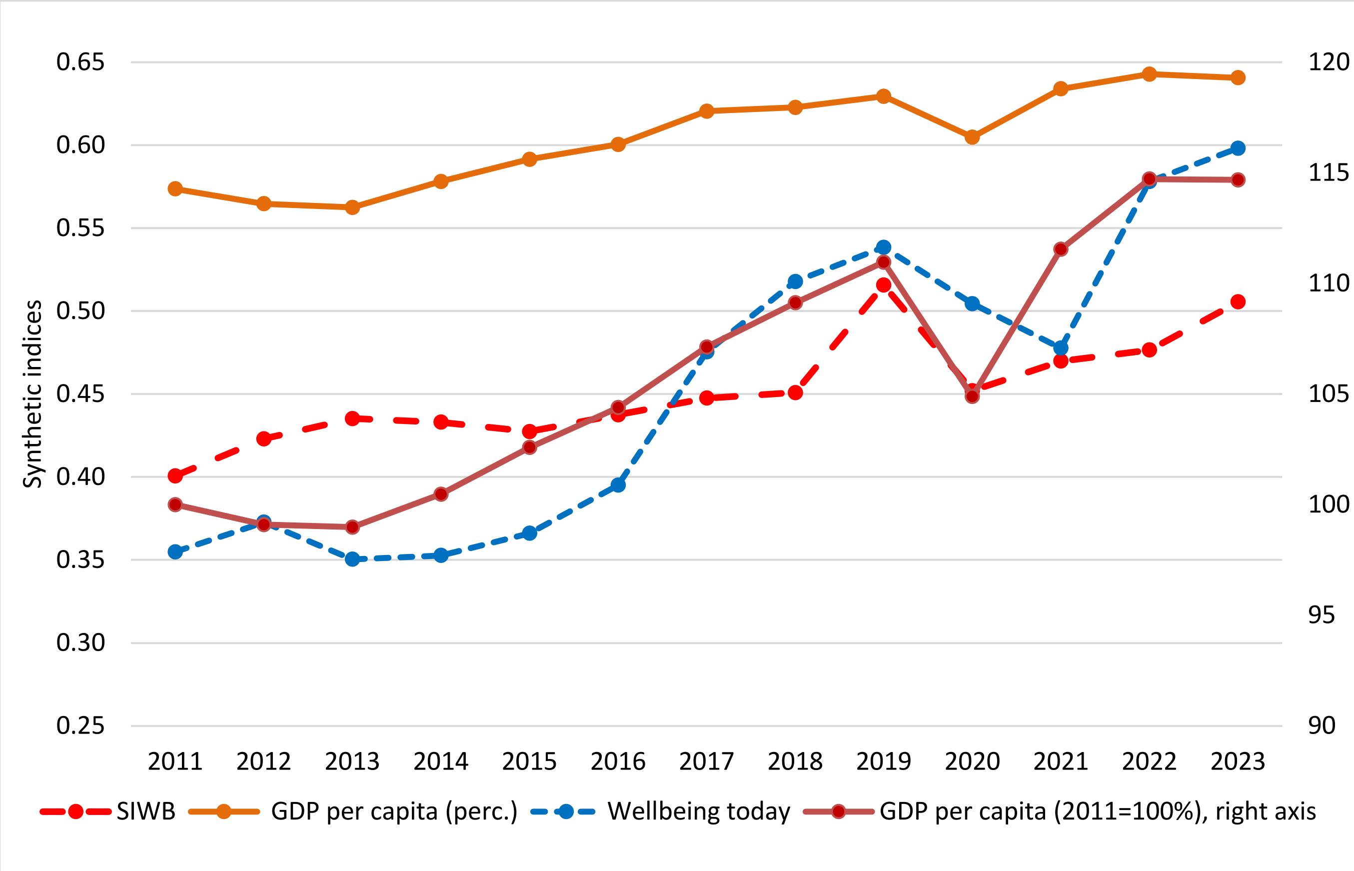
The European Union has been supporting these initiatives and has been playing a key role in promoting the development and use of such indicators, presenting a **roadmap for transitioning beyond GDP in EU**, in the Communication adopted in 2009 and its follow up [703], [704]. This commitment is further reinforced by the 8th EAP [691], which emphasises the need for a more holistic approach in EU policymaking to ensure a just transition, incorporating a summary dashboard that measures economic, social, and environmental progress beyond GDP.

Building on this momentum, the 2023 Strategic Foresight Report [538] has announced the Commission's plan to develop sustainable and inclusive well-being metrics [705], to **progressively complement the use of GDP with well-being indicators in EU policymaking**. Such metrics help monitor progress towards the well-being of current and future generations, facilitating the communication of policy challenges. By adopting a people and planet-centred approach, the SIWB metrics represent a significant step towards a more balanced and inclusive understanding of societal progress in the EU. This has led to the development of a multidimensional SIWB framework and indicator dashboard [706], together with experimental augmented-GDP type metrics [707], [707], [708]. Equally importantly, the initiative has shaped and supported the new SIWB consensus term (with SIWB referring to **the well-being of all people of the current and future generations, and of the planet**), and the corresponding dashboard is its first complete European implementation.

The analysis based on the dashboard of 50 indicators reveals that the key drivers of well-being are not solely economic factors. Other factors, such as social relationships, environmental conditions, and access to social and healthcare systems, also play a significant role. This underlines the need for targeted policy actions to address existing inequalities, balancing economic objectives, social inclusivity, environmental sustainability, and long-term prosperity. Well-being in the EU has increased over the past decade [709], but it varies across Member States, with some countries succeeding in certain areas while struggling in others. The trend of well-being aligns with that of GDP per capita (blue line), though current well-being improved more in percentage terms [706] (Figure 24).

In times of renewed discussions around the need to boost the competitiveness of the EU, the framework adds an important directionality to competitiveness: to use resources efficiently to deliver wellbeing to people in a sustainable and inclusive way. In particular, some of the outputs of every country's "broad economic system" are not measured directly in economic accounts (like domestic production, health outcomes, inequalities, or the state of the environment and climate). If a country devotes more of its resources to such unmeasured elements of societal wellbeing than another country, then a purely GDP-based comparison (of progress, prosperity, or well-being) can be misleading.

Figure 24. Evolution of GDP per capita, current well-being and SIWB index (and its components) over time, EU 27, 2011-2022.



Source: [706]

7.2.2 Nature counts: Gross Ecosystem Product

The "beyond GDP" metrics may also include nature in the economic policy assessment. As noted above, GDP does not fully capture nature's contribution to the economy and wellbeing, and does not factor-in environmental impacts [710], [711]. This is particularly important in view of the present and future state of the environment, given that the global stock of ecosystems, for example wetlands, grasslands, and forests, is under increasing pressure from an expanding world population with rapidly changing consumption patterns [712]. The benefits provided by ecosystem services, such as crop pollination, carbon sequestration, and water purification, are of great importance to any economy, both directly and indirectly (Figure 25). With reference to the above considerations, Ouyang and colleagues [713] have proposed and further developed [714] the concept of the **Gross Ecosystem Product** (GEP), which summarises the **value that ecosystem services provide to the economy in monetary terms.**

The concept of GEP is receiving increasing attention worldwide. In March 2021, the UN Statistical Committee approved a global standard on Ecosystem Accounting (EA) under the System of Environmental Economic Accounting (SEEA), which reflects the contribution of nature in measuring economic prosperity and human well-being. Since then, several countries have started moving towards its adoption and policy implementation [716]. For instance, the Netherlands and Iceland have decided to reflect the value of ecosystem services in national accounts [717], [718]. China is the first country to implement the GEP and integrate the value of ecosystem services into decision-making processes alongside conventional macroeconomic indicators such as GDP [714], [719].

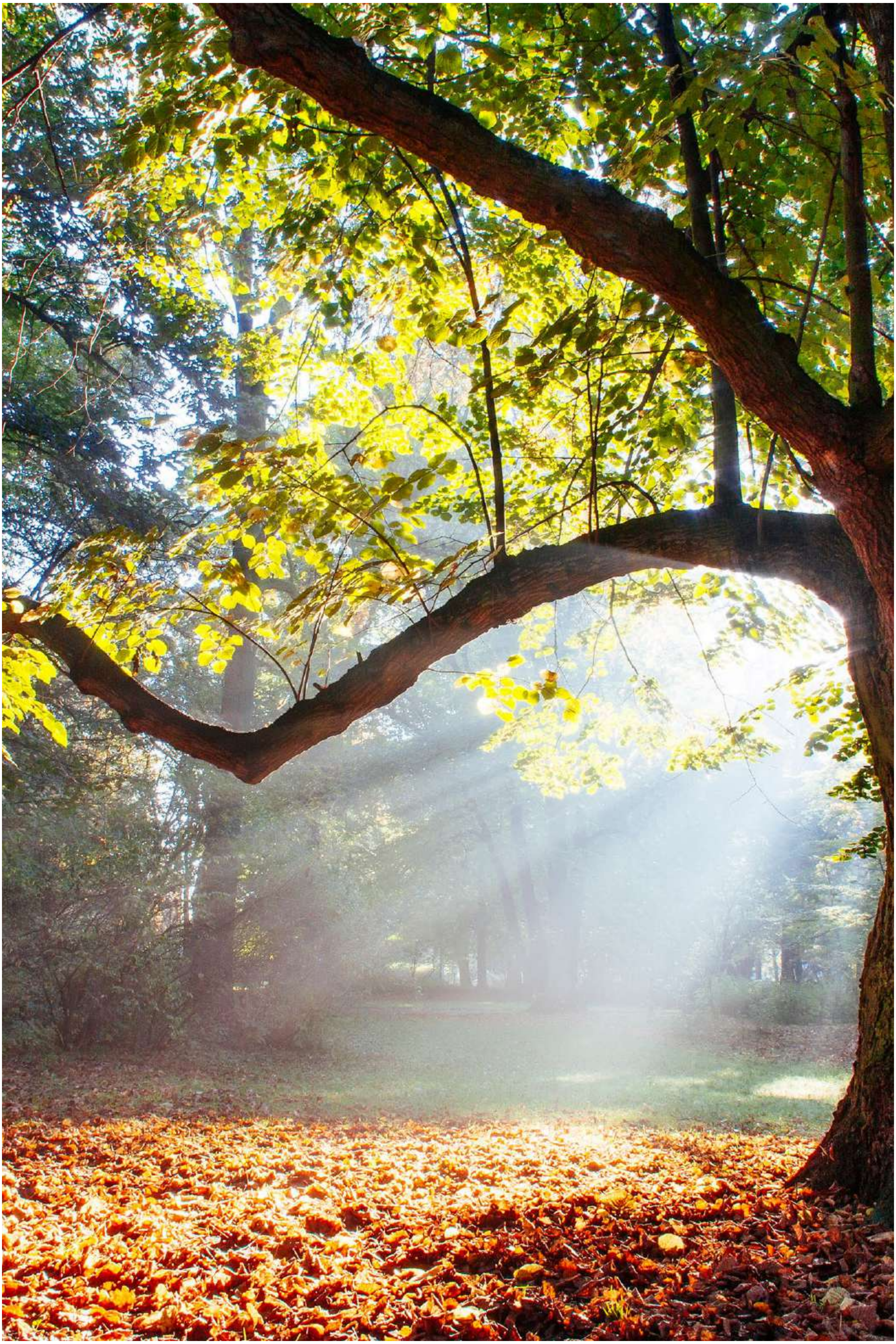
The strength of GEP lies largely in its ability to serve as a **complement to GDP measures.** By using the national accounts approach, it provides policymakers with a clear and intuitive indicator of the value of nature. The use of GEP alongside other macroeconomic indicators provides a more accurate picture of the impact of policies on the economy and on nature, to be included in the decision-making process. Analogous to GDP, GEP can be assessed not only as a single metric; an evaluation of the different components and related indicators is also useful. Trade-offs (and synergies) among different categories of ecosystem services, such as provisioning services, regulating services, and cultural services, represent one of the most important current sustainability issues and should be considered in decision-making [720], [721].

Although the GEP has been present in environmental analyses for some time, it has not yet been applied in macroeconomic modelling to assess the impacts of different policies. The JRC, together with Wageningen Economic Research, have recently developed a model that links ecosystem flows and their values to known macroeconomic indicators for nature inclusive decision-making [722]. This enables forward-looking economic scenario studies on the relationship between macroeconomic indicators and GEP. Building upon the Integrated Natural Capital Accounting (INCA) database on monetary value of ecosystem services, the new model enables the comparison of the impact of different policies on both GDP and GEP in the European Union. For example, in a scenario that assumes a significant change in consumption patterns (where global consumption gradually shifts towards plant protein), the results of preliminary simulations show that such an impact can differ significantly both between GDP and GEP and across particular ecosystem services. According to the simulation results, the altered consumption pattern has a marginal positive impact on GDP (+0.01%) in the EU in 2030 compared to the reference scenario. In contrast, the GEP index increases by 1.5%, or EUR 2.3 billion compared to the reference scenario.

Ensuring a fair and just transition requires more than sectoral interventions; it calls for an integrated approach that addresses socioeconomic disparities, territorial imbalances, and environmental justice while safeguarding the well-being of current and future generations. This involves targeted policies such as the *Just Transition Mechanism* and *Social Climate Fund* to mitigate distributional impacts, encourage the active participation of citizens in shaping transition pathways, and develop monitoring frameworks that go beyond GDP to truly reflect social and environmental progress. By combining fairness in process with fairness in outcomes, the EU can foster a clean transition that not only achieves climate neutrality but also strengthens social cohesion and resilience across regions and generations.

Figure 25. Natural Capital Stock, Ecosystem services, Benefits and Value.

Source: [715]



08

Horizontal enablers

Section E
Compass Compass: Horizontal enablers

Key messages

Equipping Europe's **workforce with green skills** (technical and cross-sectoral) is essential for a fair, inclusive, and competitive clean transition, supporting millions of new jobs and socioeconomic resilience.

Education systems need to embed sustainability into curricula and strengthen vocational training, supported by EU frameworks such as GreenComp and Erasmus+, sustained financial investment, and better coordination to align skills with evolving labour market needs.

Education and training programmes must address **skill shortages**, particularly in the **energy sector**, ensuring workers have the technical and cross-sectoral competencies the transition demands.

Better coordination and **inclusive governance** models are essential for transformative change: the clean transition requires integrated, multi-level policy coherence and stakeholder collaboration across sectors, as well as anticipatory, adaptive, and evidence-based governance.

Behavioural insights can improve policy effectiveness and public support. Integrating them into policymaking can help overcome resistance to change and low awareness, guiding both individual-focused nudges and broader policy mixes toward systemic change.

Cities and regions play a crucial role in the clean transition, accounting for a large share of emissions and serving on the front line of implementing clean transition policy targets.

Structural challenges continue to hamper transformative change at the EU city level, including the rigidity of built environments, short-term mindsets, siloed policymaking, limited social acceptance, inadequate implementation capacity, insufficient trust and knowledge-sharing among stakeholders, competition over land use, and financial constraints.

Advancing clean transition policies at the **urban level** requires: strengthened community and citizen engagement; upgraded urban infrastructure and nature-based solutions; innovative governance and policymaking; sustainability education and skills; twin green and digital transitions; adequate financial resources and public–private cooperation; and transparent communication and information sharing.

Inclusive governance (integrating multi-level coordination, stakeholder collaboration, and participatory processes) is as important as technological innovation in enabling transformative and resilient change.

Beyond the three major pillars and their flagship actions, the EU *Competitiveness Compass* identifies five **horizontal enablers** to strengthen competitiveness across all sectors. **Three** of these are addressed in Chapter 6 (*Financing the clean transition*) and in the present chapter. In particular, *Skills and quality jobs* (Chapter 8.1) and *Better Coordination* (Chapters 8.2, 8.3, 8.4) are framed here as key cross-cutting enablers, supported by the *Behavioural insights for Policy making*. With regard to skills and jobs, the chapter emphasises the need to develop adequate **green skills** aligned with the EU's climate and industrial ambitions, with particular attention to the **energy** sector, where employment in clean energy technologies is expected to grow faster than in the rest of the economy.

On **better coordination**, a paradigm **shift in governance** approaches is required: embedding orchestration, uncertainty management, and policy-mix design as core elements. Governance for the clean transition requires enhanced vertical coordination across EU levels, combined with greater and systematic **integration of behavioural insights** into policymaking. In fact, delivering on the clean transition ambitions demands a shared understanding that most implementation challenges and opportunities have strong local and behavioural dimensions, with **cities and regions (Chapter 8.4) at the forefront** of the transition, being the spatial scale where governance, skills, and behavioural change converge in practice. This calls for more experimental governance arrangements capable of navigating transition complexity in a context of shifting geopolitical priorities and an evolving policy framework.

8.1 Education and skills for the clean transition

Ensuring the effective implementation of the clean transition and strengthening Europe's socioeconomic resilience requires education and training systems to adapt to meet evolving labour market needs. A profound transformation of Europe's economy and workforce, underpinned by a fair, inclusive, and competitive transition, is a necessary condition to achieve the goals of the clean transition and the *Clean Industrial Deal* [625]. This shift spans all policy domains involved in the EU clean transition, requiring the development of **green skills** and the creation of jobs aligned with EGD ambitionsthe EU's climate and industrial ambitions. The workforce must be equipped with knowledge, competencies, and adaptability to support this systemic change, from primary sectors to emerging industries. To increase competitiveness, the EU will focus on adult and lifelong learning, and up- and re-skilling, to ensure alignment with labour market demands.

The **transition to sustainability** offers unparalleled opportunities to simultaneously address socioeconomic and environmental challenges. Green skills encompass both technical abilities and cross-sectoral competencies, such as systems thinking and collaboration, which enable the workforce to meet the demands of rapidly evolving markets. As highlighted by recent assessments [723], this transformation is expected to generate millions of jobs across all sectors of the green economy, particularly in roles requiring mid-level and high-level skills. Promoting skills and quality jobs while ensuring social fairness is one of the horizontal enablers of the *Competitiveness Compass* [4], a reminder that the clean transition has to be fair and competitive for the economy and society.
The success of this transition hinges on addressing structural gaps in education and training. Existing EU frameworks, such as **GreenComp** (the European sustainability competence framework, offering common reference points for developing and assessing knowledge, skills, and attitudes on climate change and sustainable development), provide a shared reference for integrating sustainability competences [724], while financial instruments such as the **European Social Fund+**, **Youth Guarantee**, and **Erasmus+**, support re-skilling and up-skilling. Additionally, investments including the **EUR 3 billion for sustainable school infrastructure** demonstrate the EU's commitment to preparing future generations for the green economy. This commitment is reinforced by the *Clean Industrial Deal*, which prioritises access to the skills needed by industry and worker support during the transition. As part of this effort, the Commission will establish a *Union of Skills*, investing up to EUR 90 million from Erasmus+ in workforce training and quality job creation in strategic industries. The Union of Skills will include a *STEM Education Strategic Plan*, a *Basic Skills Action Plan* focused on school education, and a *European Strategy for Vocational Education and Training* while strengthening the European Universities Alliances. Additionally, mobility across the EU will improve with better recognition of skills and training, extending to skilled professionals from third countries. NZIA also proposes setting up Net-Zero Industry Academies that will provide training and education on net-zero technologies, and lead to the creation of quality jobs.

8.1.1 The energy sector as a catalyst for the clean transition

The transition from brown to green jobs in the EU, driven by the clean transition, is expected to bring significant changes to the Member States' labour markets. The energy transition, and the related scale-up of EU net-zero technology manufacturing, will accelerate demand for workers with green skills. Skilled technical workers, already in persistent shortage, are in high demand and such shortages may hinder the energy transition, if not addressed [462]. **Jobs in clean energy technologies are growing faster** than in the rest of the economy [725]. This sector employs more than 2 million people in the EU[1]. Most of these jobs are in the renewable energy sector [726] (mainly heat pump, solar and wind) and the manufacturing segment. To deliver on the clean transition ambitions, this workforce needs to expand further in the coming years [727]. However, this sector is marked by a high job vacancy rate, with 15% of companies in manufacturing electric equipment reporting **labour shortages as the main factor limiting their production**[2].

1 Eurostat, Environmental goods and services sector accounts [env_ac_egss1]. Clean energy sector contains CEPA1, CREMA13A and CREMA13B. See the Methodological note in Box 4 of [462].

2 DG ECFIN Business and consumer survey database, subsector data for 2024.

As the energy transition unfolds, structural mismatches [725] can lead to persistent shortages in some technical skills and occupations, such as installers and repairers of electrical equipment and machinery mechanics [723]. The energy industry faces the double challenge of an aging workforce and changing skills needs resulting from digitalisation [728]. In addition, the electricity sector is among the most affected by the demographic shift, due to the ageing population [723] and the persistent underrepresentation of women. Gender disparities in scientific publications, particularly in STEM fields, also persist [450]. **Demand for trained and skilled technicians will remain high**, since 75% of the jobs created by the energy transition will be in these roles [729].

The European Commission [730] has recently concluded that most Member States have not set specific objectives or allocated funding to address the skills gaps necessary for implementing the *Net-Zero Industry Act* (NZIA) [98]. **Increasing the production of clean technologies will require further investment in skills**, estimated to range from EUR 1.7 billion to EUR 4 billion [5]. The raised climate ambition and accelerated deployment envisaged in the *REPowerEU Plan* could create up to 1 million additional jobs by 2030 [732].
Some of the technical profiles needed are transferrable from the fossil fuel industry and other related sectors. The development of job-specific training programmes, including **EU-wide certification and mutual recognition of skills**, is crucial to facilitating sufficient labour supply. Nevertheless, the shortage in high-skilled occupations may create a bigger bottleneck as it takes longer to obtain the required educational credentials [723]. The clean energy and green economic transitions are taking place in parallel to and in the context of digitalisation. These simultaneously occurring global trends require education and skills responses from policymakers, companies and education institutions alike [728].

As **employment declines in high-pollution sectors and grows in low-pollution sectors**, economic disparities and poverty risks may rise, particularly for workers in fading industries. However, Member States' tax-benefit systems can help mitigate these effects by **supporting those most affected by the transition**, redistributing income, and offering social protection. These systems play a crucial role in ensuring the green job transition results in a more equitable distribution of economic outcomes across the EU, protecting vulnerable populations from the worst impacts (evidence developed under the AMEDI project - Assessing and Monitoring Employment and Distributional Impacts of the Green Deal - a joint cooperation between DG EMPL and the JRC; explore also chapter 7 on a *Fair and just transition*). The clean energy sector has the potential to bring back some of the industrial jobs that have been disappearing from Europe. Importantly, these jobs have an opportunity to fill the void in medium-skilled jobs as nearly 60% of job creation could fall into this category [733]. Renewing societal trust in a labour market that creates life-long opportunities and security can turn the labour force from a bottleneck to a positive force in the transition to climate neutrality.

8.1.2 Learning for the clean transition

Environmental sustainability demands a wide range of knowledge, skills, attitudes and values. The **GreenComp framework** defines four main areas of competence: *embodying sustainability values*, *embracing complexity in sustainability*, *envisioning sustainable futures* and *acting for sustainability*. Promoting education for the clean transition therefore requires **coordination** and **political willingness** at national and sub-national levels to design **portfolios of initiatives**, and act and implement measures **at multiple levels.**

The **European Council** invited Member States to establish learning for the clean transition as one of the **priority areas** in national education and training policies [734]. This would also demand **alignment**, in close cooperation with relevant stakeholders, of education strategies and plans with the EU clean transition objectives, including formal and non-formal education support from early childhood to foster a **culture of sustainability**. Infrastructure and investment should move towards **sustainable equipment** for learning, socialising and recreation, including the tools and resources required to support the **digital competences** of **learners** and **educators**. Learners, in particular, can be motivated with an understanding of how climate change and environment protection are actionable through **local examples**, problems and responses. Furthermore, feeling of fear and **disempowerment** in the face of the planetary crisis can be reduced by engaging learners directly in **local decision-making** ensuring **gender-balanced** participation and **co-creation approaches**. In particular, collaborative and experiential approaches relevant to local contexts should be encouraged, stimulating and fully recognising **civic engagement** actions. From the **educators'** perspective, they should be enabled to raise learners' awareness on **SDGs** and explore **innovative** and **transdisciplinary** teaching approaches, including **STEAM** (i.e. connecting STEM education with the arts, humanities, and social science), hackathons, gamification, and service learning. Integration of the clean transition and sustainable development into initial teacher and trainer education programmes would be a key asset. Finally, investment is needed in **monitoring** and **reflecting** on the impact of such initiatives on policymaking.

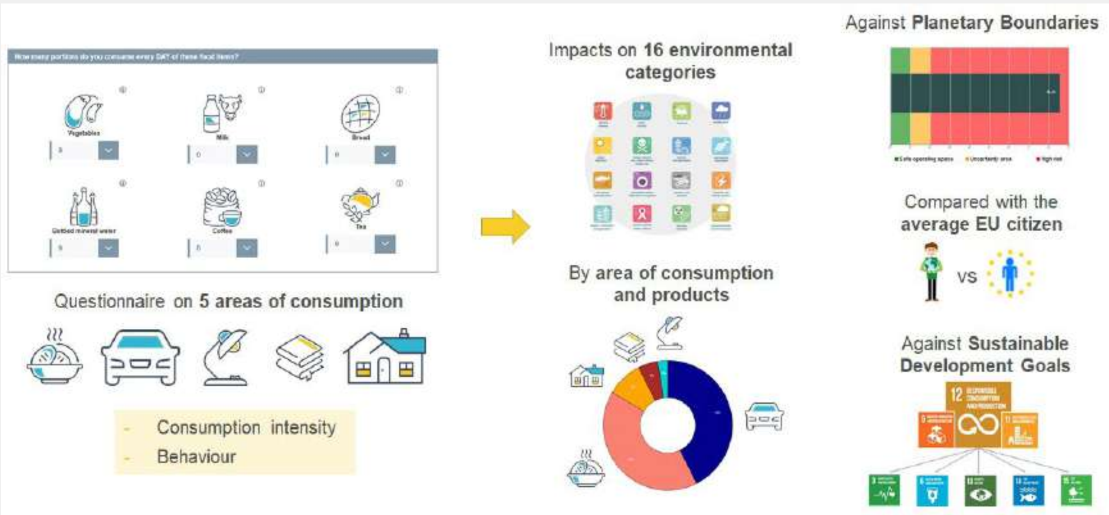
The Eurydice assessment also provides insights into how education systems in the Member States can effectively support the clean transition's implementation [735]. While sustainability features prominently in all Member States' curricula, the assessment identifies areas where targeted improvement could accelerate progress. **Teacher preparation**, for instance, emerges as a key area of focus, with many educators expressing strong interest in sustainability topics but seeking additional support to teach them effectively. **Investing in professional development for sustainability education** presents a significant opportunity for system-wide improvements. EU-level collaboration on certification standards could facilitate consistency in quality while supporting professional mobility across Member States [735]. Additionally, aligning education outcomes with evolving labour market needs, particularly in technical fields, could help expand the workforce, especially in light of demographic shifts and gender imbalances. In fact, as noted above, the clean transition has profound economic implications for the skill balance of the labour market. [733],

Box 13. **The Consumer Footprint calculator**

The Consumer Footprint Calculator is a tool for the quantification of the environmental impacts of the consumers' choices in terms of food, housing, mobility, appliances and housing goods. It is an adapted version of the Consumption Footprint model (Chapter 3) and is available online in the 24 official languages of the EU, to enable citizens to calculate the environmental impacts of their consumption patterns and assess how changes in their lifestyle may affect their personal footprint [736].

The Consumer Footprint Calculator not only calculates the CO_2 production for consumers but also assesses impacts through the 16 environmental impact categories (Chapter 3.1.1) of the Environmental Footprint method). The consumer footprint of each individual is calculated in absolute sustainability terms and also in comparison with the planetary boundaries and the Sustainable Development Goals, providing links to sustainability "good practices", to increase awareness and encourage more sustainable lifestyles.

Figure 26. The Consumer Footprint calculator.



Source: [736].

Box 14. **Art and Science for education**

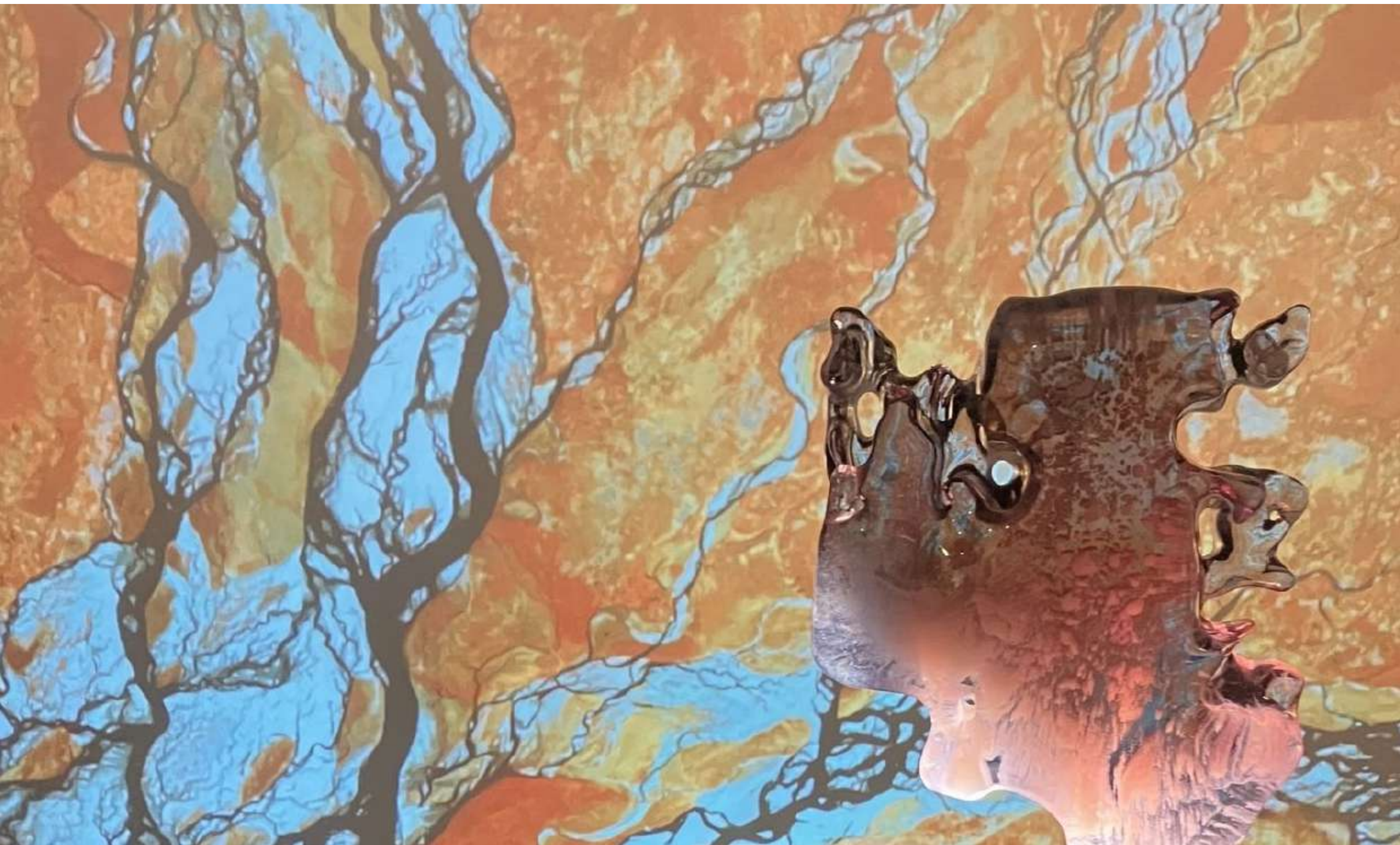
The SciArt (Science and Art) field has expanded vastly in recent years, developing a variety of dynamics to link science and society through art and aesthetic experiences. Using artistic exploration as a new medium to explore and transfer scientific knowledge offers new ways of connecting people with scientific and artistic inquiry. This allows complex issues and global challenges such as climate change to be addressed in a way that makes science easier to understand and connect to emotionally.

The JRC SciArt programme brings together scientists with artists and policymakers to discuss matters of concern, not only to the JRC and the European Commission but also more widely to society. These result in exhibitions to engage with the public, provoke conversations with citizens and create cultural products of contemporary relevance.

In some cases, art has much more potential to convey messages to the public than science and can be more effective in changing people's minds and engaging in their feelings. This is particularly important for the profound societal shift required by the clean transition in the coming years.

Artivism is a growing constituent of environmental activism, articulated around three major topics. The first one is the education of audiences through performative expressions of today's global environmental crises, especially climate change. The second one involves ecocritical reflections of environmental controversies and conflicts towards creative emancipatory practices. The third one positions art practice as an avenue for environmental improvement across different sectors (e.g. water, mining, urban) with involvement of citizens, governments, and corporate actors.

The JRC has explored the role of Science and Art for transdisciplinary education, collecting insights, experiences, and recommendations on how culture sectors and industries can drive the clean transition and engage civil society [737]. Combining science with artistic research has the potential to enrich science with new insights involving ethics and aesthetics and make it more approachable and credible at a time when populism and mistrust towards the institutions are on the rise.



highlighting the need for a strategic approach to technical and vocational training. Ensuring the effective implementation of these programs will support workforce transitions while maintaining high quality standards. Additionally, the development of common certification approaches will strengthen workforce mobility across Member States while ensuring consistent quality standards.

The 'New Skills Agenda' was introduced to foster sustainable competitiveness, social fairness, and resilience. The agenda set ambitious objectives for upskilling and reskilling workers to navigate the clean transition. It also includes **training for circular economy** activities, such as design, materials sourcing, maintenance, repair, refurbishment, repurposing, and recycling. For example, new benchmarks under the *Critical Raw Materials Act* have created demand for skills related to circularity and sustainability across various value chains. At the same time, there is a general lack of technical expertise, both in the public and private sectors, to develop and implement innovative circular solutions. Investing in the development of skills is equally critical in other areas such as the food chain workforce. Fostering a skilled and adaptable workforce, along with promoting research and innovation in areas like **sustainable agriculture and food technology**, will be key to long-term success. These efforts will drive increased efficiency and productivity, benefiting all stakeholders.
On the education side, bridging the knowledge gap between consumers and the resources used to produce their food is essential. By fostering transparency and **educating consumers on sustainable practices**, informed choices can be made that support the overall health of the food system. By implementing these measures, the EU can create a food supply chain that is both economically viable and environmentally responsible, ensuring a secure and sustainable food future for all. For this purpose and spanning food as well as other households' consumption products (including housing, mobility, appliances, and household goods), the JRC has developed the Consumer Footprint Calculator, an online tool to raise EU citizens awareness about their personal consumption footprint (Box 13) [736].

Similarly, it is vital to ensure that **land ecosystem restoration** is properly resourced with skilled professionals who can address the socio-ecological complexities of restoration projects. These professionals must be equipped with the knowledge, tools, and expertise to **implement science-based restoration techniques**, and to monitor and evaluate progress effectively [249].

To maximise the impact of these frameworks and instruments, strategic coordination is essential. Effective deployment of EU funding mechanisms, combined with systemic changes in educational institutions - from infrastructure improvements to curriculum development - can significantly amplify the impact of these investments. Member States that have successfully integrated sustainable education practices into their teaching, infrastructure, and assessment systems provide valuable evidence that this coordinated approach accelerates the development of green skills and competences.
The ongoing implementation of the clean transition will benefit from continued attention to educational strategies. While robust frameworks exist through various EU initiatives, enhanced coordination could further support the evolving needs of the green economy. Aligning educational outcomes with green economy requirements strengthens both the implementation of the clean transition and the goals of a just transition. By building the long-term capacity of the education sector, the EU can ensure that the transition to a sustainable future creates opportunities that are accessible across all regions [725].

8.2 Better Coordination: Governance for Transformative Change

Effective governance is the backbone of the EU's clean transition. Ambitious targets alone cannot deliver climate neutrality, resource efficiency, and social fairness unless institutions at all levels can coordinate policy mixes, mobilise resources, and learn from evidence. Governance must therefore integrate long-term vision with day-to-day implementation, balance EU-wide coherence with local diversity, and remain adaptable to rapid technological, economic, and social change. Against this backdrop, the following section examines the drivers that shape governance needs, the mechanisms for orchestrating action across multiple levels and sectors, and the data and monitoring systems required to steer transformative change.

8.2.1 Megatrends in the clean transition

The success of the clean transition is impacted by overarching global megatrends, long-term driving forces that will have significant influence on the future of the EU and globally. To mention a few, climate change and environmental degradation, aggravating resource scarcity, continuing urbanisation, accelerating technological change, growing consumption, widening inequalities, increasing demographic imbalances, and geopolitical shifts; these megatrends affect the different components of the green and digital transitions. They are highly interconnected, and successful outcomes require a nuanced understanding of how these megatrends influence policy areas and the society. To anticipate and prepare for those changes and support the transitions to a green, digital and fairer future, strategic foresight must be used to build effective evidence-based anticipatory policymaking [738]. Strategic **intervention areas** - ranging from governance reform to economic and educational shifts - play a crucial role in guiding the EU's approach to navigating these challenges, supporting transformative change:

Climate ambition: Policies to drive decarbonisation and adaptation address both local and global megatrends of climate change.-Addressing climate megatrends requires coordinated interventions across energy and industrial sectors to ensure a comprehensive approach to emissions reduction, as well as a mix of solutions to cope with mitigation and climate resilience. Through coherent policy mixes, this area emphasises regulatory alignment and economic incentives to drive decarbonisation.

Clean, affordable, and secure energy: Here,

adaptability is key. Policies prioritise flexible, resilient energy systems that respond to fluctuations in demand and supply. This approach supports the EU's goal of energy independence while ensuring affordability, especially in the context of rising resource scarcity.

Circular economy: interventions in this area foster innovation in green technologies and encourage sustainable consumption. They aim to reduce Europe's dependence on high-emission industries and third countries promoting circular practices, resource use, and eco-design principles.-This area focuses on reshaping production-consumption patterns through targeted policies that foster sustainable economic models. Innovations in green technologies and circular practices are facilitating a transition towards low-waste, high-efficiency systems.

Sustainable and smart mobility: Growing urbanisation pressures drive interventions in this area, focusing on adaptive frameworks for sustainable transportation. Policy mixes emphasise green infrastructure and incentives for low-emission vehicles, helping to manage urban expansion and reduce pollution.

Sustainable food systems: To address food security and achieve a resilient food system, this area focuses on the interplay of various actors and orchestrating policy measures all over the food supply chain, from primary production to food consumption, including food processing and distribution. The overall objective of sustainable food system governance is to make healthy and sustainable dietary choices accessible, while providing fair income distribution in the value chain and guaranteeing food at affordable prices even to the most vulnerable groups of population. Ideally, local initiatives and sectorial interventions are guided by sustainable food system strategies that are aligned with broader sustainability goals.

Preserving and protecting biodiversity: Resource scarcity and shifting geopolitical influences drive policy in these areas, where multi-level governance structures are needed. This includes interventions for ecological conservation that prioritize adaptive, place-based strategies to address uncertainties tied to climate and biodiversity loss. The EU emphasises collaborative frameworks to manage biodiversity, responding dynamically to environmental changes while maintaining ecosystem health.

Zero Pollution Ambition: Tackling pollution demands robust regulatory frameworks. This area benefits from cross-sector policy coherence that aligns environmental, industrial, and public health policies to achieve broad anti-pollution outcomes.

Meeting the EU's transformative sustainability goals means **addressing gaps in governance coherence, adaptive policy frameworks, and multi-actor collaboration**. Opportunities exist in developing a flexible governance structure that can adjust to the evolving **impacts of megatrends** while fostering an inclusive, collaborative approach across sectors and levels of government. By emphasising **integrated policy mixes, adaptive capacity, and collaborative orchestration**, the EU can harness agency (Chapter 8.2.2) to drive sustainable transitions across all thematic areas, setting a global standard for sustainable development.

The transformation required by the clean transition demands sophisticated governance models that effectively combine policy mixes with enhanced agency – i.e. the capacity to act – for sustainability transitions [739], [740]. Success depends not only on developing collaborative capabilities but also on strategically deploying policy mixes that can address multiple megatrends simultaneously while enabling transformative change [739].

Three key aspects of agency emerge as critical for success. First, the ability to shape through policy mixes must integrate regulations, incentives, and cross-sectoral policies effectively. Second, navigating uncertainty requires the development of adaptive governance frameworks that can respond to rapidly changing conditions. Third, orchestrating processes and relationships becomes essential for enabling collective action and stakeholder alignment [739].

While governance challenges are substantial, they can be addressed through strategic interventions that combine policy coherence, adaptive frameworks, and collaborative approaches [739].

Success will increasingly depend on:

- Developing **integrated policy mixes** that can address multiple sustainability challenges simultaneously
- Building **adaptive capacity** across governance levels to respond to emerging challenges
- Strengthening multi-stakeholder platforms for collective action
- Creating **learning systems** that enable continuous improvement and innovation [740], [741].

The future of Europe's sustainability transitions relies not just on technological innovation but on the capacity to innovate in governance and policy deployment while fostering agency among all actors involved in the transition process [8], [739].

8.2.2 Orchestrating the implementation of the clean transition

The clean transition represents an unprecedented socioeconomic transformation strategy that demands coordinated action across multiple governance levels [739]. The EU is often regarded as a paradigm of multilevel governance, further solidified by the enactment of its first *Climate Law* in 2021. In fact, the Commission must enable an inclusive process, involving all societal actors, to facilitate the achievement of climate ambitions, considering **Local and Regional Authorities** (**LRAs**) as often best positioned to implement tailored climate solutions reflecting community needs.

Current governance structures, while evolving, face significant challenges in enabling the systemic changes needed for sustainability transitions. The implementation of the clean transition reveals several persistent implementation challenges in current governance structures [8]. A fundamental misalignment exists between EU-level ambitions and local/regional implementation capacity, often resulting in fragmented decision-making and limited coordination between national and local authorities [740]. This is compounded by insufficient cross-sector collaboration mechanisms and resource constraints at regional and local levels, which hamper effective implementation.

Multi-level governance adds an additional layer of complexity, as local, national, and international actors must coordinate efforts and ambitions to deliver changes [742]. The clean transition ambitions demand a national coherent and effective policy implementation first. Yet, **differences in national approaches, administrative limitations, and varying levels of commitment to EU goals slow progress** and complicate the path to achieving sustainability targets across the region. At EU level, **the complexity of the EU administration can hinder or slow the reforms and innovations,** needed to achieve climate neutrality in 2050 [5], [743].

The challenges in question are being met with emerging opportunities for transformation [741], [744]. Networks for knowledge sharing between cities and regions are growing, while new participatory and co-creation approaches are gaining traction [745]. The rising importance of regional and city-level initiatives, coupled with innovative public-private partnership models, presents new pathways for implementation [739], [741]. A successful example of this can be found in the innovative mission-oriented approach, with specific reference to the *100 Climate Neutral and Smart Cities* programme, which establishes direct contact between the Commission and citizens and supports cities to orchestrate the design of **Climate City Contracts** under the *NetZero Cities* initiative. Similar approaches in other missions and in the New European Bauhaus have also delivered impact.

The development of agency in sustainability transitions requires attention to three interconnected approaches [740].

1) Shaping through Policy Mixes. These integrate regulations, incentives, and cross-sectoral policies while aligning objectives between governance levels [741]. This approach creates synergies between initiatives and supports experimentation and learning. For example, the EU's Climate Ambition is advanced by regulatory frameworks that incentivize carbon reduction and clean technology investments. These policy mixes provide cohesion across levels of governance, allowing for targeted efforts to phase out unsustainable practices, particularly in high-emission sectors. The *Fit for 55* package uses an integrated approach, combining carbon pricing, renewable energy mandates, and support for green technology. This helps actors navigate the climate megatrend by promoting a unified, EU-wide approach to emissions reduction.

2) Navigating Uncertainty. Adapting to uncertainty is essential for the EU to respond dynamically to shifting economic and environmental factors. It requires adaptive management approaches and flexibility in governance arrangements, enabling continuous learning and adjustment through risk-sharing mechanisms [739], [740]. Strategic interventions foster resilience by building flexibility into policies and encouraging adaptive governance. This is especially relevant for sectors like energy and mobility, where rapid technological changes and fluctuating resource availability necessitate adaptive frameworks. The strategic use of scenario planning in the *EU Sustainable and Smart Mobility Strategy* allows it to account for varied future developments, such as shifts in fuel types or transportation demand, which are crucial in the context of rapid urbanisation and resource challenges.

3) Orchestrating Processes and Relationships. Orchestrating collaboration across sectors and levels of government fosters an environment for collective action. It involves building trust and legitimacy while creating shared visions and goals, establishing clear roles and responsibilities, and developing effective coordination mechanisms [741]. By strengthening multi-stakeholder platforms, the EU enables alignment across actors, enhancing the effectiveness of sustainability transitions. This approach is evident in Greening the Common Agricultural Policy, where relationships between local governments, farmers, and environmental bodies are coordinated to create synergies that support sustainable agriculture practices. The *EU Biodiversity Strategy* leverages local and international partnerships to orchestrate conservation efforts across ecosystems, showing how cross-actor collaboration can amplify impact and address global biodiversity concerns.

8.2.3 Supporting adaptive governance through data and monitoring

Advancing the clean transition requires governance systems that can go beyond goal setting to steering implementation in dynamic and complex environments. This calls for stronger capabilities to measure progress, evaluate the effectiveness of interventions, and adapt policies in response to changing conditions. Embedding robust monitoring frameworks and interoperable data systems into the governance architecture is essential for linking system-wide objectives to local-level actions and enabling feedback across scales. By grounding decision-making in timely, spatially explicit, and policy-relevant evidence, governance can become more adaptive, responding to territorial diversity, evolving conditions, and context-specific interplay between multiple sustainability goals.
To operationalise adaptive governance, policy interventions must be guided by a structured, evidence-based process that links system-wide objectives to real-world change and shifting priorities. This involves three key steps building on lessons learnt from the JRC assessment exercise on the EU Green Deal's progress [8]:

Define how to measure progress toward targets using indicators that can be aggregated from local to EU level, supported by appropriate monitoring systems. In some cases, relevant data are already available and accessible. In others, it may be necessary to define proxy indicators to approximate improvements. Even when measurement is challenging, it is essential to establish a clear metric of success for each target and ensure continuous monitoring. Otherwise, progress will only be assessed through ex-post evaluation in 2030 or 2050, which would prevent timely adjustments and limit the effectiveness of policy interventions.

Measure what works, when, and for whom, based on evidence from policies already in place or tested through pilot projects. Although targets are defined at aggregate level, the actions needed to achieve them are carried out by a wide range of actors at local level. These include, for example, individuals, businesses, public authorities, and land managers, whose decisions are shaped by specific spatial and temporal contexts. As a result, the effectiveness of different policy combinations will vary. Integrating existing data sources (e.g. satellite imagery and national registries) through interoperable systems would help monitor local trends more effectively and support EU efforts to steer policies toward greater impact.

Adapt and scale interventions based on evidence, applying the "what works" approach, in which policy interventions are designed using elements that have worked in the past and are evaluated quantitatively to measure their impact, to refine policies in an iterative way as real-world conditions evolve [746]. Local contexts vary widely, so strategies that are effective in one setting may not be transferable to others (EU Competence Centre on Microeconomic Evaluation). Monitoring systems must therefore support continuous learning by capturing how different measures perform over time and in combination. This evidence can inform adjustments to EU-level guidance, funding priorities, or regulatory frameworks, helping ensure that interventions remain relevant, effective, and aligned with overarching goals. Achieving this requires strong **institutional commitment** to measuring progress, analysing results, and adjusting policies as part of an integrated governance cycle. Embedding **monitoring and learning into implementation** processes will strengthen the EU's ability to guide the clean transition in a responsive and context-sensitive way.

8.2.4 Cross-cutting data gaps for the clean transition

Despite ongoing improvements, persistent data gaps and fragmented monitoring systems continue to undermine the EU's ability to steer the clean transition effectively, both across key policy areas and governance levels. Notably, this was also highlighted in the JRC assessment [8] of progress towards the EU Green Deal policy targets, which showed that data are not available or insufficient for 28% of the targets assessed.

Land and soil data

Carbon baselines required by the land use, land use change and forestry (LULUCF) proposal face technical and administrative challenges, limiting carbon farming and emissions tracking [747]. Persistent data uncertainties, especially in tracking biomass changes over short time periods and in recent years, can result in overlapping greenhouse gas estimates for the same area. Broader gaps affect soil knowledge, knowledge sharing, and the application of research in practice [748]. Communication barriers in nitrate pollution management and limited emphasis on long-term behavioural change in agricultural education further constrain effective soil stewardship [749].

Climate action and emissions data

The monitoring of climate action plans is hindered by inconsistent data collection, uneven data quality, and unaccounted emissions [92], [750], [751], e.g. emissions from wildfires, supply chain gaps, or international bunker fuels that are measurable but often excluded from official inventories. In addition, technical difficulties in comparing EGD targets with mitigation pathways may lead to underestimation of emissions when using integrated assessment models [752]. A further limitation is the lack of ground-based data for carbon sinks and the challenges of integrating such data with satellite observations, which complicates accurate monitoring and modelling.

Sustainable food systems

Significant data gaps persist in monitoring sustainable food systems across environmental, economic, and social dimensions. Environmentally, there is limited data on GHG emissions by product type, pesticide use, water consumption and reuse, land allocation among food, feed, and biofuels, crop rotation, and aquaculture sustainability. Economic gaps include insufficient information on profit margins along the value chain, concentration of land and markets in food processing industry and that of inputs (such as fertilisers and seeds), and the uptake of emerging technologies (like precision farming, intelligent labelling, or the use of blockchain technology for product traceability). Social data are lacking on employment conditions - particularly in small-scale and informal work - animal welfare, food environments, and accessibility of sustainable diets.

Biodiversity

Biodiversity has the highest number of policy targets for which progress cannot be assessed due to insufficient data [8]. Monitoring remains in an early phase, with a pressing need for improved indicators, methods, and knowledge. The *Nature Restoration Regulation* is expected to accelerate indicator development and data collection. Persistent data gaps also limit the ability to assess biodiversity baselines and impacts, creating space for misinformation and resistance to change. In addition, the multidimensional nature of biodiversity makes it difficult to define relevant parameters, and the high cost of collecting ground-based data further constrains progress, as remote sensing alone is often insufficient.

Circular economy and waste monitoring

Data on material and waste flows (e.g. construction and demolition waste) remain limited or incomplete, particularly regarding waste generation [753] and the quality of collected and treated outputs [169]. In many cases, Member States have reported recycling rates based on collection or sorting stages, often overstating actual recycling outcomes [169]. The **Circular Economy Monitoring Framework** has been updated to address product-related gaps and better reflect consumption, material footprints, and contributions to the EU's strategic autonomy. However, key challenges persist, including missing or partial data for areas like product design, and the absence of harmonised indicators and targets to evaluate circular practices comprehensively [169].

Critical Raw Materials and supply risks

The implementation of the *Critical Raw Materials Act* will require improved knowledge and modelling on supply security risks and impacts beyond current screening-level assessments, especially concerning impact reduction. The current limited knowledge and modelling on the sustainability and impacts associated with increased extraction and processing driven by the CRMA could hinder the achievement of clean transition objectives.

Zero pollution

In the area of zero pollution, limitations in data availability, data sharing, and monitoring - particularly regarding air and water quality - remain a significant challenge, as highlighted in the Environmental Implementation Review [754]. In the case of air quality, the lack of detailed and mandatory rules for locating monitoring stations gives too much discretion to national authorities [318]. This can undermine Member States' obligations to report on areas with the highest pollution levels as well as those representative of general population exposure. The review [754] also identifies challenges such as insufficient training and knowledge sharing on environmental crime, along with weak coordination, especially within decentralised administrations. Improving the temporal frequency, spatial coverage, and interoperability of datasets remains critical for monitoring progress across all sectors - particularly in land use, air, soil, water, and pollution. Better coordination within and among Member States is essential to resolve persistent reporting challenges. Advances in data collection and analysis technologies, including Earth observation, automated ground-level measurement, and AI-supported optimisation, offer promising avenues for more cost-effective and granular monitoring [23].

Data governance will play a key role in enabling a more responsive and integrated policy cycle. Legislation such as the *Data Governance Act*, the *Data Act*, the *INSPIRE* Directive, and the *Public Access to Environmental Information Directive* provides a framework for improved data sharing, though significant gaps remain.

A recent JRC report emphasises the need for systemic **data justice**, clearer incentives, and stronger links between data supply and demand to build a more sustainable and equitable data ecosystem for the clean transition and beyond [755]. Realising the full potential of data for steering the clean transition will require the principles of public interest data, quality assurance, and interoperable infrastructure to be embedded into governance systems.
A balanced approach - combining common governance rules with decentralised data management tailored to specific use cases - can help bridge these gaps. Ultimately, strengthening the EU's capacity to **generate, integrate, and use data** is essential for more adaptive, transparent, and effective governance of the clean transition.

8.2.5 The path forward

Implementation across key policy areas involved in the EU clean transition reveals distinct governance challenges and opportunities that require tailored yet integrated approaches [8]. Each area demonstrates distinct governance needs while sharing common threads of multi-level coordination and stakeholder engagement. The successful implementation of clean transition policies requires the integration of the three interconnected approaches to agency across different thematic areas [740]. Policy mixes, uncertainty navigation, and process orchestration must work in concert to enable transformative change. To cope with the complexity of implementation processes, an innovation portfolio approach can enable territorial actors to bundle different policies into a unified effort [756]. This is crucial to address the cross-cutting challenges that such transitions bring with them while contributing to the transformative capacity of the regional system to become more competitive and resilient [744].

Climate action implementation demands stronger vertical integration between EU, national, and local levels. Member States often differ in their commitment to climate targets, with some relying only on binding EU policies, while others establish national climate laws. This variability, coupled with inadequate support for monitoring and evaluation at the municipal and sub-national levels, impedes the efficient tracking of progress toward the EU climate goals [757]. Local authorities often struggle with limited resources and technical and anticipatory capacity to implement ambitious climate targets [8]. However, emerging city networks and regional partnerships are creating new opportunities for knowledge-sharing and collective action. The success

of climate initiatives increasingly depends on the ability to mobilise local stakeholders while ensuring policy coherence across governance levels [739]. Cities have emerged as particularly important actors, being responsible for the implementation of most climate mitigation and adaptation policy targets and with their capacity to integrate climate considerations into urban planning, building regulations, and local transport policies [739].
Policy mixes need to combine emissions reduction targets with adaptation measures, while building flexibility to navigate uncertain climate impacts. Process orchestration becomes crucial in engaging stakeholders across sectors and governance levels to implement these policies effectively [8]. Dialogue and cooperation among advisory bodies could allow for the exchange of experience and good practice and may help national governments coordinate cross-boundary solutions for the transition to a climate-neutral Europe [11]. To this end, efforts should continue to ensure the coherence and consistency of energy and climate policy by revising regulation towards a single framework that brings together the multiple planning, reporting and monitoring obligations that were previously scattered across several pieces of EU legislation [758]. Often, this is a continuous process involving learning by doing, especially given the complex nature of the policy frameworks underpinning the EU clean transition. Iterative planning and reporting regimes, such as the one in the *Regulation on the Governance of the Energy Union and Climate Action*, lend themselves to incremental learning and improvements to alleviate inconsistencies and administrative burden [759].

In the **clean energy** domain, governance challenges lie in coordinating multiple policy domains and mobilising innovative financing mechanisms [8]. The transition requires the orchestration of changes across energy infrastructure, building standards, and consumer behaviour. Public-private partnerships have proven essential, particularly in developing smart grids and renewable energy projects. Local energy communities are emerging as crucial innovation spaces, demonstrating how new governance arrangements can enable citizen participation in energy transitions [741]. Policy mixes must integrate technology innovation support with market creation mechanisms. Uncertainty navigation is particularly important given the rapid evolution of energy technologies and changing geopolitical dynamics. The orchestration of processes between energy producers, infrastructure operators, and consumers becomes essential for system transformation [739].

The **circular economy** presents governance challenges related to value chain coordination and ecosystem development [8]. Implementing circular strategies can be complex, since it requires action across multiple sectors (e.g. construction, manufacturing, waste treatment) and engagement with multiple stakeholders (e.g. industry, local and regional authorities). Therefore, the lack of coordination and collaboration can lead to delays in implementing circular policies, as well as to the development of siloed approaches[9]. Success requires unprecedented collaboration between producers, consumers, and waste management operators. The lack of guidance can contribute to delays and uncoordinated approaches. For instance, in the case of textile waste management, the transposition of the directive by Member States leaves flexibility on the exact rules for implementation and level of ambition. Cross-border coordination becomes particularly important given the international nature of material (and waste) flows and supply chains [739]. Policy mixes need to address both production and consumption patterns. Navigating uncertainty requires experimental approaches to new business models and value chains while ensuring environmental protection. Process orchestration must focus on building new relationships between traditionally separate sectors and stakeholders.

Sustainable mobility exemplifies the need for integrated governance approaches [8]. The sector requires coordination between transport planning, urban development, and environmental policy. Behavioural change initiatives must be combined with infrastructure development and new mobility services. Cities are increasingly experimenting with innovative governance arrangements, such as mobility-as-a-service platforms that integrate public and private transport options [741]. As such, the sector demonstrates how these governance approaches intersect in practice. Policy mixes combining infrastructure investment with behaviour change initiatives must be adaptable to uncertain technological developments. Successfully orchestrating the transition requires coordinating across urban planners, transport providers, and citizens.

Sustainable food systems demonstrate the importance of territorial approaches and stakeholder engagement [8]. Effective governance must balance productivity goals with environmental protection supported by a future-oriented perspective, while ensuring fair transitions for farming and fishing communities. Knowledge networks play a crucial role in disseminating sustainable practices, while value

chain coordination is essential for developing more efficient and more sustainable food systems. The success of transitions depends heavily on building trust and cooperation between farmers, researchers, policymakers, and consumers [739], [741]. The food system involves agriculture, fisheries, food processing, and distribution, each regulated differently; therefore, making comprehensive and cohesive policy actions is challenging. The fragmentation of governance of food systems may lead to incoherent and sometimes controversial measures, where the absence of dialogues and trade-offs compromise the endeavours in several policy fields, as well as the overall goal of transforming food systems towards sustainability. Food system actors (from producers to consumers) act on their own interests which may lead to failures in addressing the food system as a whole and result in poor or even unexpected outcomes. All food system actors are interconnected, and it is important to design policies in a holistic way, taking into account how food choices are linked to production practices, health and environmental impacts. Involving different levels of governance, in particular national and local is also key. Local authorities are often well placed to lead engagement on how to shape favourable food environments through community-led initiatives, including food councils that foster dialogue on how to enhance the affordability and availability of healthy, high-quality food
For example, the national food-based dietary guidelines should integrate recent scientific evidence and sustainability goals balancing environmental, economic and social interests. In this context, the role of local (sub-national) authorities is also critical as they manage, for instance, public procurement, school food policies, and public awareness initiatives. The sector particularly highlights the need for territorial approaches that combine elements of official programs with social innovation and bottom-up initiatives. This is especially relevant to address the needs of underrepresented and marginalised groups and connect the actors across the food system. Policy mixes must address uncertainty, which requires adaptive management approaches. Process orchestration becomes critical in engaging farmers, food processors, retailers, and consumers in transformation efforts [739].

Preserving biodiversity requires distinctive governance approaches that acknowledge the complex interconnections between ecosystems, economic activities, and human well-being [8]. The governance challenge is multifaceted, requiring coordination across protected areas, urban spaces, and productive landscapes. Traditional conservation approaches are being supplemented by new governance models that recognise the role of indigenous and local communities in biodiversity management. Success requires innovative funding mechanisms, stronger scientific-policy interfaces, and new forms of stakeholder engagement that can effectively represent both human and ecological interests [8], [739]. Policies related to biodiversity are often fragmented across different sectors, leading to inconsistencies and inefficiencies in conservation [760], [761]. There is often a disconnect between biodiversity conservation policies and those aimed at other environmental or economic goals. This can lead to conflicting priorities and ineffective outcomes [251]. In particular, the JRC has noted the 2020 *Biodiversity strategy* conservation outcomes felt short due to limited integration with other dimensions and sectors [8]. Biodiversity restoration is another field facing hurdles related to coordination and motivation among local decision-makers, the lack of skilled professionals, and insufficient standards to measure progress [23]. Additionally, the lack of coherence in EU, national and sectoral regulations governing sustainability objectives and the fragmentation of policy may be impeding the comprehensive consideration and addressing of food system impacts on biodiversity [762], [763]. The establishment of a unified policy framework for the food system would not only enhance the system's sustainability but also facilitate a more integrated comprehension and assessment of these impacts.

The **zero-pollution** ambition for a toxic-free environment presents distinct governance challenges related to the complexity of chemical regulations, monitoring systems, and enforcement mechanisms [8]. Effective governance in this area requires unprecedented coordination between environmental, health, and industrial policies. Implementation demands new approaches to chemical assessment and management, including improved coordination between regulatory bodies at different governance levels. Despite a general improvement in the target related to health impacts of air pollution, there are continuous breaches in air quality standards due to weak enforcement, excessive flexibility, and delays in national response measures. This raises questions about the role of national administrations as "watchers" within the current enforcement framework [318]. Improving compliance will require stronger tools, as well as a revision of national enforcement frameworks. This involves strengthening the science-policy interface, developing anticipation capacity and more integrated monitoring systems, and creating new platforms for stakeholder dialogue about acceptable risk levels and mitigation strategies [741]. Policy coherence and alignment are particularly important for the reduction of marine plastic pollution, which originates from a plurality of land-based sources (and multiple human activities at seas, making its governance difficult). Moreover, marine litter can be transported long distances from the pollution source, and the negative impact of marine plastic pollution goes beyond national and EU borders. The transboundary nature of this problem calls for international solutions. The analysis reveals that while the challenges are substantial, they are not insurmountable. Success will depend on leveraging emerging opportunities while systematically addressing structural barriers through reforms and capacity-building at all governance levels [740], [741]. The future of European sustainability transitions relies on the ability to innovate in governance as much as in technology and policy [8], [92].

Across all areas, governance innovation is essential for enabling transformative change. This includes developing new coordination mechanisms, experimenting with different stakeholder engagement models, and creating learning systems that enable continuous adaptation and improvement [740]. The experience across these areas suggests that successful governance arrangements must be both robust enough to provide clear direction and flexible enough to adapt to local contexts and changing circumstances.

A concrete example is the commitment already undertaken to tackle the administrative burden related to the *Energy Governance Regulation* and the National Energy and Climate Plans. Reducing the planning, reporting and monitoring obligations under EU law, without undermining the main policy objectives, is essential to enable more effective coordination, implementation and also experimentation [758].

This integrated approach to agency across thematic areas requires **new governance capabilities and institutional arrangements** [740]. These include joint public-private efforts for the implementation of diverse portfolios of actions. These can act as vehicles for transformative innovation policy by coordinating multiple interventions across system levels while maintaining adaptability to different institutional contexts [744].

The transformation required by the clean transition demands governance models that combine top-down direction with bottom-up innovation while ensuring coordination across multiple levels and sectors [739], [740]. **Success depends on building capacity for policy integration, adaptive management, and stakeholder engagement at all governance levels. Furthermore, these approaches must be supported by robust monitoring and evaluation systems that enable learning and adjustment over time [741].**

8.3 The potential of behavioural insights for policy making

8.3.1 Behavioural challenges in the green transition

A number of the challenges identified for implementing the clean transition have a behavioural dimension. Behavioural barriers can stem from **capability, motivation, and opportunity-related factors**, and are often reinforced by social norms and cultural contexts. Behavioural challenges include:

- **Lack of awareness and knowledge**: Some individuals remain unaware of the urgency or effectiveness of climate-related actions or hold misperceptions about which behaviours matter most. For example, people may not realise the environmental impact of fast fashion or how to correctly sort waste. Similarly, local communities may lack information about the biodiversity impacts of land use changes, which can hinder conservation efforts.
- **Resistance to change and status quo bias**: Even when aware of risks, people often default to existing habits. Inertia and aversion to perceived risks or unfamiliar behaviours can be powerful obstacles, especially in the absence of trusted examples or community support. Landowners and farmers, for instance, may resist adopting new practices, despite incentives, due to risk aversion or a lack of relatable role models [764].
- **Motivational gaps and low perceived efficacy**: Some people feel individual action is ineffective, leading to apathy or indifference. Others may lack intrinsic motivation or fail to identify with the goals of climate and environmental policy. For example, a lack of sense of identity or emotional attachment to the landscape can reduce willingness to engage in biodiversity restoration [249].
- **Short-termism and uncertain outcomes**: Behavioural tendencies such as risk aversion, loss aversion, or underestimating long-term benefits can hinder change. For instance, even when the risks of inaction are understood (Chapter 1.2), individuals may prefer immediate convenience or financial savings over long-term sustainability gains.
- **Social and cultural resistance**: In some cases, behaviour change faces opposition not only at the individual level but also at the collective level. For example, hydrogen technologies [90] and hydrogen mobility [89] have suffered from low social acceptance. Some local communities may also oppose biodiversity conservation projects due to socioeconomic concerns, such as displacement or restrictions on land uses [255].

Behavioural sciences study human behaviour, focusing on cognitive processes, beliefs, habits, social norms, emotions, culture, and values. **Behavioural insights** apply behavioural science to policymaking, analysing the behavioural dimension of the policy problem at hand, to identify the type of policy intervention to be adopted (behavioural, traditional or a mix of both). This involves considering how both individual factors and the broader system impact behaviour. Behavioural insights for (environmental) policymaking, when integrated early in the policy process, have the potential to improve policy effectiveness and acceptability [765].

8.3.2 Why behavioural insights should be integrated early in the policymaking process

The use of behavioural insights in EU policymaking is enshrined in the *Better Regulation* Toolbox [766] (tool #69), which provides valuable guidance on their incorporation into policy development. Incorporating behavioural insights in policy from the outset has several advantages:

- **Improved policy effectiveness**: Early integration helps identify behavioural barriers that could hinder the implementation of policy options and behavioural levers that could augment the efficacy of policy options. This allows for the development of strategies to address hard-to-change behaviours and deeply anchored habits, guiding them towards desired outcomes.
- **Containment of policy resistance**: By investigating prior policy support and developing communication strategies that accurately convey the policy's effects and benefits, it is possible to counteract incorrect beliefs and build broader support, leveraging positive behavioural factors.
- **Identification of policy conflicts**: Early integration can reveal conflicting signals across policy domains. For example, a vibrant tourism economy currently involves high long-distance travelling patterns while a climate neutral economy can only be achieved by reduced travel and shifting to net-zero travel modes such as rail, which conflicts with insular and peripheral tourist destinations.
- **Prevention of negative spillovers**: Implementing a policy to reward pro-environmental behaviour, such as biking to work, risks diminishing the intrinsic motivation of existing participants. To mitigate this,

combining the reward with a campaign that reinforces personal norms, and the environmental benefits of biking can maintain and even boost motivation.
- **Promotion of positive spillovers**: Subsidies encouraging investments in energy efficiency can have their impact magnified by behavioural strategies. For instance, a public campaign that highlights the popularity of energy-efficient technologies in local communities can leverage social norms, encourage wider adoption and create positive spillovers.

8.3.3 How behavioural insights can contribute to systemic environmental change

There are five different ways of integrating behavioural insights into the policy landscape (Figure 27):

1) Behavioural interventions, such as nudges, target specific individual behaviours to encourage desired actions or decisions. They are often used as a *plug-in* to the policy process once the policy options have already been decided upon. One way to use behavioural interventions is as a follow-up to already existing regulations. This is, for example, the case when a label is mandated in a regulation, and behavioural scientists are called in to design the label *ex post*, making sure it is effective (e.g. *Directive on Energy Labelling*, *Eco-design Regulation for Smartphones*). Another way to use behavioural interventions is to support the communication of traditional interventions that may be already in place, with the objective of making them more transparent and acceptable (e.g. Eurobarometer survey *Fairness perceptions of the green transition, Perceptions of distributional impacts of Fit for 55 Package* [49]). Behavioural interventions are usually low cost and easy to implement. While it is possible that cascading effects result in system-wide impact, the effects are often found to be marginal [767].

2) Traditional Interventions: when a behavioural element is found relevant in a policy context, behavioural insights can also recommend or inform traditional instruments or policies such as regulations, taxes, and subsidies upstream. In this case, traditional interventions can be designed by modifying the fundamental aspects or mechanisms of a system or environment rather than following or fixing pre-existing policy mechanisms already in place. For example, the 2011 *EU Consumer Rights Directive* included a number of measures informed by behavioural insights, such as banning pre-ticked boxes for additional services when shopping online, which relied on inattention and the tendency of consumers to follow the default option.
Examples include the *Revision of the Energy Efficiency Directive* and the *Energy Efficiency Financing Recommendation*, which both benefited from an understanding of energy efficiency (investment) decision drivers and the identification of additional solutions through the behavioural economic lens [768], [769], [770]. The *Energy Poverty Recommendation* relied on insights on consumer empowerment and energy poverty drivers through the behavioural economic lens [85], [771].

3) Policy Mix: behavioural insights can have two different roles: (1) a ***complementary*** role, enhancing the effectiveness of behavioural interventions within a broader policy mix without directly influencing the design of traditional interventions in the mix; or (2) a ***cross-cutting*** role, informing the development and implementation of both behavioural and traditional interventions within the mix, ensuring coherence and synergy across all policy tools to achieve the intended policy goal. For example, combinations involving nudges and monetary incentives are more effective in promoting pro-environmental behaviour than monetary interventions alone [772].

4) Policy interconnections: behavioural insights can also analyse how various policies from different policy domains interact and impact the behaviour of specific stakeholders collectively, identifying synergies and conflicts between policy signals. In such analyses, the traditional approach of first identifying behavioural aspects and then designing interventions to achieve specific goals is insufficient [773]. Instead, it is crucial to consider how interventions in one domain might impact another.
An example of how behavioural insights could contribute comes from the intersection between tourism and climate policies. For the EU to achieve climate neutrality by 2050, there is a need to reduce long-distance travelling. At the same time tourism is seen as a key sector in the EU, so there is a need to reconcile how a vibrant tourism economy can be achieved with lower travel intensity or zero-emission transport. In such cases, applying a behavioural lens enables an assessment of potential conflicting goals across policy domains and helps promote coherence across different policy areas by taking the individual's perspective.

5) System: Systemic change is ultimately driven by human behaviour. While structural and technological conditions matter, it is individuals' decisions and actions that shape outcomes. Behavioural insights can help identify key behaviours, influencing factors, and stakeholder interactions through behavioural systems mapping. This approach reveals leverage points where behavioural barriers hinder change, allowing the design and testing of targeted policy tools.

A JRC project [774] on EU green policy implementation applies this approach to understand how behavioural factors contribute to common obstacles - including financial, political, and governance challenges. It traces the journey of EU law from adoption to enforcement, mapping key stakeholders and their influence [765]. The project began with a workshop where public officials reflected on behavioural drivers of implementation gaps, leading to hypotheses further explored and tested through interviews, workshops, journey maps, computational modelling and experiments.

Behavioural insights fully embrace the principle of evidence-based policymaking by making the case that - whenever a behavioural element is identified that may help determine the potential success of a given policy intervention – it is necessary to collect and take stock of behavioural evidence. For example, although it may make sense in theory, a new label is not necessarily the solution, unless consumers can access it, trust it, understand it, and use it to make decisions.
In this sense, **behavioural insights ask further questions that can help generate more precise answers** and a more effective policy response to unlock the positive potential of human decisions to tackle collective challenges.

Figure 27. The five ways behavioural insights integrate the policy landscape.

	Behavioural intervention	Single policy	Policy mix	Policy interconnection	System
What	BI can target individual actions	BI can support the development of individual policy tools, whether traditional or behavioural	BI can align policy tools to work together towards a shared objective	BI can examine the interactions between policies from a behavioural standpoint	BI can pinpoint leverage points where behavioural analysis helps to develop targeted policy tools
How	By using behavioural interventions like nudges and boosts	By understanding and analysing behavioural factors relevant to the policy context	By relying on relevant behavioural factors for the overall design of the policy mix	By bringing a human perspective into the policy landscape and identifying behavioural issues leading to policy fragmentation	By mapping stakeholders and their behaviours, influential factors and key relationships (behavioural systems mapping)
Why	*To influence individual behaviour and improve communication of existing policies*	*To ground policy choice and guide policy design*	*To leverage synergies between traditional and behavioural policy tools within a policy area*	*To enhance policy coherence across different policy areas*	*To unlock key behavioural barriers and achieve a more cohesive, well-functioning system.*

Source: Authors' elaboration [765].

8.4 Cities and regions at the forefront of the EU clean transition

As the governance level closest to citizens - and among the most trusted [775] - Local and Regional Authorities (LRAs) are the pioneers of the EU's clean transition and long-term competitiveness. Furthermore, growing urbanisation is a megatrend [538] in expansion: cities occupy approximately only 4% of EU land today, but are home to 75% of EU citizens and responsible for over 70% of global GHG emissions and waste production. While urban centres are widely recognized as hubs of technological and broader societal innovation [776], in the face of climate crisis the governance of local transition towards more sustainable production and consumption patterns has become a task defined by both **urgency** and **uncertainty** [777], [778].
The *EU Climate Law* emphasised the necessity of accessible, inclusive processes to engage all governance levels and societal stakeholders in achieving climate goals. The active involvement of urban and regional areas is central to implementing 70% of climate mitigation [779] and 90% of adaptation policies [780]. Furthermore, cities alone are urged to implement 50% of EGD targets in all thematic policy areas [781] and 65% of the 169 SDG targets [782].
Key consultative bodies of the EU, such as the Committee of the Regions [780], [783] and the Economic and Social Committee [784], have raised concerns about the insufficient involvement of social partners and subnational authorities in the policymaking process for the clean transition. The lack of effective mechanisms for multilevel governance is seen as a significant obstacle to EGD implementation [780]. In turn, stakeholders have indicated that the local and regional execution of the EGD has been inadequate to date [364]. The clean transition and EGD policy implementation are further hampered in EU cities by the unprecedented high number of policy targets, a rapidly evolving policy framework, the changing geopolitical context [785], and shortages in resources and skills [786].

8.4.1 What are urban clean transitions?

As explored by recent research [787], the urban clean transition for EU cities refers to a process of profound, systemic, and multidimensional transformation within urban socio-technical and ecological systems to support the implementation of clean transition policies while delivering on the 2030 Agenda for Sustainable Development. This transition is inherently collaborative and iterative, requiring the integration of a strong multi-level governance framework, place-based solutions, and inclusive approaches to co-create transition pathways with local actors.

The urban clean transition process emphasises the **interdependence of local innovations**, such as urban living labs and experimentation, with broader systemic changes at EU level, aiming to bridge urban niches with national and EU-level regimes to co-create new shared values and understanding.
A critical component of the urban clean transition should be the incorporation of learning and self-reflexivity into experimentation processes. This includes adaptive monitoring and iterative evaluations that not only assess the outcomes of innovative solutions against indicators but also promote the capacity to refine strategies dynamically. Furthermore, place-based innovation is needed to address the distinct challenges and opportunities of specific urban contexts and related priorities. This involves mobilising territorial assets, aligning local capabilities with broader goals, and fostering inclusive stakeholder engagement to co-create actionable pathways and roadmaps, ensuring that territorial diversity becomes a source of resilience and innovation for enhanced EU competitiveness.

8.4.2 Structural challenges hampering transformative change

(Clean) transitions imply radical transformations of current socio-technical systems towards low- or zero-emission status (for example, energy, housing, transport, agri-food systems) [742]. These systems, at the urban scale, co-exist and interact [788] but are often resistant to radical transformation due to entrenched structures, behaviours, and vested interests, which can create inertia and pushback against efforts to shift towards more sustainable practices [789]. Many intertwined challenges (institutional, economic, technological, cultural, and behavioural) [790] impede the transformative changes required by clean transitions.
Research at the JRC [791] explored possible

relationships and causalities among these challenges. The analysis has led to the identification of **structural hampering conditions**, i.e. systemic, self-reinforcing mechanisms embedded within current socio-technical and institutional systems that perpetuate the status quo of urban development and hinder transformative change [792]. These conditions are characterised by their interconnectedness and influence over multiple domains, creating feedback loops that amplify effects and make them resistant to change. They regard insufficient policy implementation, challenging upgrade of the consolidated built environment layout, short-termism and no perceived urgency or need to change, a lack of knowledge, data sharing, and trust among stakeholders, silos in policymaking, budget, and development processes, competition among stakeholders over urban space use, limited social acceptance, and limited financial resources.
These conditions are deeply **interconnected**, forming lock-ins that reinforce systemic inertia [742]. For instance, insufficient policy implementation, which was found to be the structural condition with the most negative impact, might be intricately tied to nearly every other condition (Box 15).

The challenging **upgrade of the consolidated built environments**, due to sedimentation of buildings and infrastructures over centuries, might feed directly into insufficient implementation, as outdated infrastructures create logistical and financial barriers to policy execution. This condition is also linked to limited financial resources, which constrain investments in the technological and operational capacities required for upgrading urban systems. Silos in policymaking might further exacerbate implementation challenges by fragmenting efforts across departments and budgets, limiting coordination and integrated approaches necessary for effective urban transitions.
Short-termism and no perceived urgency or need to change play a pivotal role in sustaining the inertia of other structural conditions. This condition is directly connected to limited social acceptance, as the absence of long-term vision often undermines efforts to build public trust and support for transformative initiatives. The resulting lack of social acceptance, in turn, might diminish stakeholder engagement, reinforcing competition over urban space use, where immediate economic interests might be prioritised over long-term environmental objectives.
The interplay between limited **knowledge, data sharing, and trust** among stakeholders and other structural conditions further highlights their mutual reinforcement. Poor knowledge-sharing mechanisms reduce the ability to build consensus and align efforts across diverse actors, which is essential for overcoming silos in policymaking and improving policy implementation. This lack of trust also contributes to competition among stakeholders, as fragmented efforts create inefficiencies and tensions over limited resources and conflicting priorities.
These conditions are highly context-dependent and are not always valid or of the same magnitude. There cannot be one-size-fits-all solutions. However, ongoing research has found some promising leverage points that can be used to dismantle them [787], [791], [793].
The **lack of adequate technical expertise** in urban departments is seen as one of the most impactful challenges, serving as a foundational impediment and influencing a wide range of issues such as insufficient policy implementation, fragmented knowledge-sharing, and limited capacity for innovation in urban sustainability. For example, without adequate expertise, urban departments might struggle to implement advanced energy-efficient technologies, decarbonisation strategies, or nature-based solutions, which in turn might reinforce other constraints such as limited financial resources and competition over urban space use. This highlights the cascading effects of addressing – or failing to address – technical expertise within local administrations.
Limited leadership emerges as another critical challenge by perpetuating fragmented decision-making, a lack of strategic vision, and insufficient prioritisation of sustainability transitions. Weak leadership might exacerbate issues such as short-termism and the underestimation of participatory governance methods, as decision-makers fail to champion innovative, inclusive, and long-term approaches. The **prevailing economic efficiency and GDP-oriented paradigms** similarly hold a pivotal role in shaping systemic resistance. This tendency prioritises short-term economic gains over long-term sustainability goals, influencing a wide array of challenges such as limited social acceptance, insufficient policy implementation, and competition among stakeholders. For example, the continued emphasis on economic growth metrics might discourage investments in green infrastructure or circular economy practices, reinforcing structural inertia and undermining the transformative potential of urban clean transitions (Chapter 7.2 on beyond GDP initiatives). Different and **conflicting visions on what sustainability means** represent another highly influential factor, leading to fragmented efforts and preventing the development of cohesive strategies, feeding into challenges such as competition over urban space use and a lack of trust among stakeholders, in turn challenging policy coherence at all governance levels.

Box 15. **The local policymakers' consultation on the EGD: target priorities and challenges**

Beyond considerations on structural hampering conditions, the JRC launched a consultation with local policymakers on "The future of the Green Deal (with)in cities. Priorities for and barriers to Urban Green Transitions". The aim was to understand the policy priorities in the EGD implementation at sub-national level. The first step consisted of isolating the EGD targets involving cities in the implementation [781]. As a second step, this subset of targets was submitted to academic experts to identify the most promising targets in driving the clean transition at EU urban level.

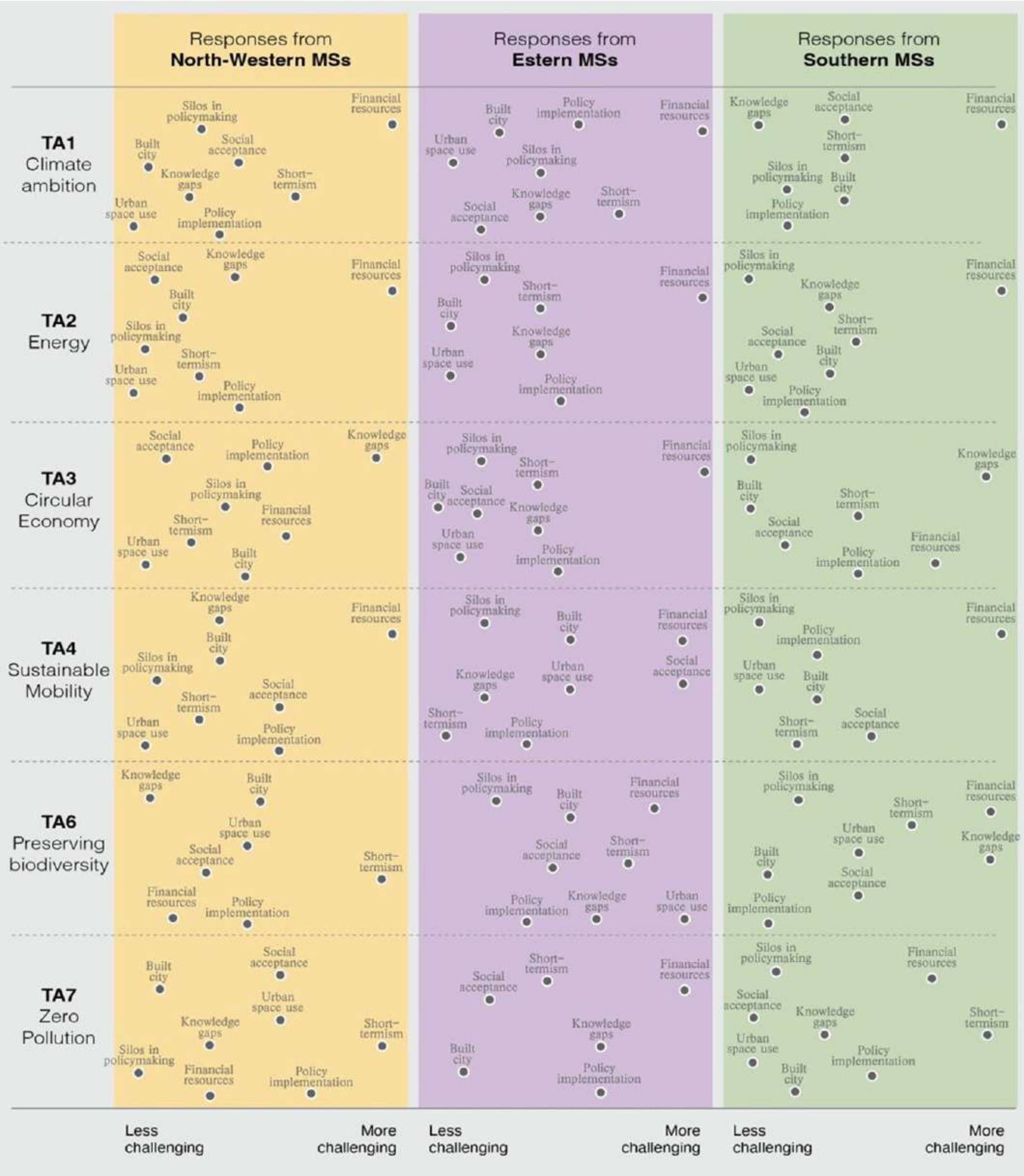
Overall, respondents prioritised the targets on zero pollution as the most urgent to implement in their local context (8.3/10 average score), followed by biodiversity preservation (8.1/10), climate ambition and circular economy (8.0/10), sustainable and smart mobility (7.4/10) and finally clean energy (7.2/10). Some geographical differences emerged, with respondents from north-western Member States tending to prioritise the climate targets while eastern and southern European Member States saw zero pollution targets as the most urgent to implement. Respondents from eastern Europe perceived the mobility targets as the least urgent, with specific reference to fleet electrification and hydrogen-related targets, while respondents from north-west and south ranked the energy targets at the bottom.
Looking at more granular insights, the top three ranked targets belong to the zero-pollution domain: improving water quality by 2030, reducing microplastics by 30%, reducing waste/plastic litter at sea by 50%, and reducing premature deaths caused by air pollution by 55%. Those are closely followed by reducing GHG emissions by 55% by 2030 (TA1), planting 3 billion trees by 2030 (TA6), eliminating the use of pesticides in sensitive areas such as urban areas (TA7), recycling or preparing for reuse of 70% of packaging waste by 2030 (TA3), reversing the decline of pollinators (TA6), zero emissions in urban logistics and cutting transport sector emissions by 90% by 2050 (TA4). Respondents from eastern European Member States specifically ranked the air quality target first, north-western respondents ranked the GHG emission target first, and southern respondents ranked the microplastic target first.

8.4.3 A stakeholder consultation with EU cities

To further explore how these structural conditions act in local contexts, the JRC launched an open consultation which collected the views of **170 local-level policymakers**, coming from 105 LRAs which represent 20% of EU populations from all Member States (with the exception of Cyprus and Malta) and the most important EU urban networks (URBACT, ICLEI, EUROCITIES) (Box 15).
Limited financial resources were ranked first, followed by short-termism and no perceived urgency to change, difficulty upgrading consolidated built environment, and a lack of knowledge, data sharing, and trust among stakeholders.

Many differences emerged among Member States (clustered following the grouping used in previous research, such as the *2024 Social Progress Research 2.0* [794]) and policy domains. Responses from eastern European (EE) policymakers (Bulgaria, Czechia, Estonia, Croatia, Latvia, Lithuania, Hungary, Poland, Romania, Slovenia, Slovakia) confirmed the lack of adequate financial resources as the most challenging issue in all the areas but biodiversity, where competition among stakeholders over land use seems to be the most challenging question.
According to North-Western (NW) countries' respondents (Belgium, Denmark, Germany, Ireland, France, Luxembourg, Netherlands, Austria, Finland, Sweden), inadequate funding affects the area of climate ambition, energy, and mobility, while lack of knowledge sharing and trust among stakeholders is the most challenging issue for the circular economy, and a short-term mentality hampers biodiversity and zero pollution ambition. The same applies for southern Europe (SE) countries (Greece, Spain, Italy, Cyprus, Malta, Portugal), even if they also consider inadequate financial resources as the most

Figure 28. Ranking of structural challenges for the urban clean transitions by thematic area and cluster of Member States.



Source: Authors' elaboration

challenging issue for biodiversity as well. There is a strong recognition that the political will for policy implementation has a strong influence on achieving the clean transition, especially for energy and mobility (Figure 28).

8.4.4 Enabling conditions for achieving urban green transitions

Funding is necessary – but not in itself sufficient alone – to achieve the clean transition [795]. Capacity building and budget management are also needed to make good use of existing financing tools (e.g. Cohesion Funds) and remove market barriers which hamper the labour market and business environment at national scale.

An international expert workshop was organised in October 2024 to explore the enablers which can be used to address structural hampering conditions and specific policy domains at urban level. Experts participated from academia and research bodies, major urban networks, climate activists and NGOs, LRAs, the Committee of the Regions (the ENVE Commission), and international urban/landscape firms. They worked collectively to identify enabling conditions for the clean transition and imagine the city of tomorrow in response to the desirable climate neutrality 2050 scenario [793]. Several advanced techniques, including a novel serious game designed to identify enablers for implementing the EGD locally and foresight exercises, were employed to co-create urban transition scenarios.

Overall, the working groups identified more than 100 enablers to achieve the EGD policy ambitions and overcome the structural challenges. Recurrent topics emerged as key **enabling conditions** to foster the clean transition at the urban level: community and citizen engagement, upgrading of urban infrastructure and NBS uptake, innovative governance and policymaking, streamlined communication and information sharing, adequate education and skills, sufficient financial resources and public-private cooperation, and the twin green and digital transitions.

Granular enablers were proposed that could support the implementation of several policies involving EU cities. Figure 29 links the list of enablers to the main EGD policies. The **transversal enablers** identified during the workshop, mostly belonging to comprehensive, systemic planning and strengthened citizen and community engagement, might serve as essential building blocks for achieving urban policy public adoption and implementation. Actions such as engaging local content creators, leveraging digital tools like digital twins, and organising public meetings allow urban governments to demystify complex policy objectives, making them accessible to citizens and stakeholders. Furthermore, interdisciplinary skill-building and systemic partnerships with academia and research bodies might ensure that urban policies remain informed by cutting-edge research and reflect diverse societal perspectives. Critically, adequate financial resources and public-private partnerships are needed in all areas.

In the context of **climate ambitions** (TA1), urban enablers such as "3-30-300 based policies" (requiring that every citizen can see at least three trees from their home, have 30% tree canopy cover in their neighbourhood, and live no more than 300m from the nearest green space [796]), the promotion of wildlife corridors, and the establishment of minimum greenery thresholds contribute to the broader goals of emissions reduction and land-use optimisation. These enablers might support TA1 policies (e.g. the EU Emissions Trading System) and directly contribute to TA6-TA7 ambitions as well. Particularly impactful might also be initiatives like converting roads to cycling lanes and clustering urban functions through revised zoning plans, advancing the implementation of the "**15-minute city"** concept (a model designed to ensure residents can meet their daily needs within a 15-minute walk or bike ride, reducing car dependency and fossil fuel consumption [797]). These actions can reduce urban sprawl, enhance carbon sequestration, and promote sustainable mobility. Intermodal hubs, e-mobility incentives, and the development of public transport infrastructure are considered pivotal for achieving the *Sustainable and Smart Mobility Strategy* and *Alternative Fuels Infrastructure Regulation* (AFIR) targets, often linked to air pollution and GHG emissions. These enablers have been thought to be key in reducing urban reliance on private vehicles while promoting cleaner, multimodal transport options and people's health. Strong emphasis is also put on social acceptance, seen as one of the most hampering challenges in this area.

The **zero-pollution** ambitions might benefit from higher data quality and granularity via monitoring systems spread in the urban built environment. Promoting the adoption of nature-based solutions and implementing green standards directly into building design might contribute to *Zero Pollution Action Plan*, the *Ambient Air Quality Directive* and some energy policies' requirements.

The urgent push for an **energy transition** is underscored by both technological and behavioural enablers. Massive incentives for the electrification of public transport, intermodal hubs, e-mobility infrastructure and integration, and upgrades to building stock performance are priority transformative initiatives aligned with policies like the *Energy Efficiency Directive* and the *Energy Performance of Buildings Directive* while contributing to sustainable and smart mobility. Complementing these actions are the enablers focused on proper education and skills, such as reskilling programs for green jobs and site-specific public awareness campaigns about energy-saving behaviours.

In the **circular economy** domain, enablers like shorter food supply chains and the development of car-free zones to support local markets reflect the centrality of community engagement in reducing food waste. The establishment of food councils and incentives for innovative business models further highlights the role of innovative governance in driving circularity. Finally, enablers like promoting endemic species, banning monocultures, and introducing greening standards ensure that cities contribute to the conservation of natural habitats and achieving the quality standards required by new indicators of the *Nature Restoration Regulation*. Public awareness campaigns and local initiatives, such as food councils, might complement these efforts by fostering community-level engagement in biodiversity conservation and nutritious local food accessibility. While some challenges, especially limited financial resources, are acknowledged with high degree of consensus, others are highly policy domain- and context-dependent, further reinforcing the argument against a one-size-fits-all approach for the clean transition. The results call for EU-level policies that prioritise flexibility and support local adaptation of EU ambitions. A clear need emerged to tailor solutions to boost policy implementation and address the specific challenges and priorities of different regions [798] and cities. Conversely, LRAs must ensure the alignment of ambitions and policy coherence for sustainable development while delivering site-specific priorities and meeting citizens' needs.

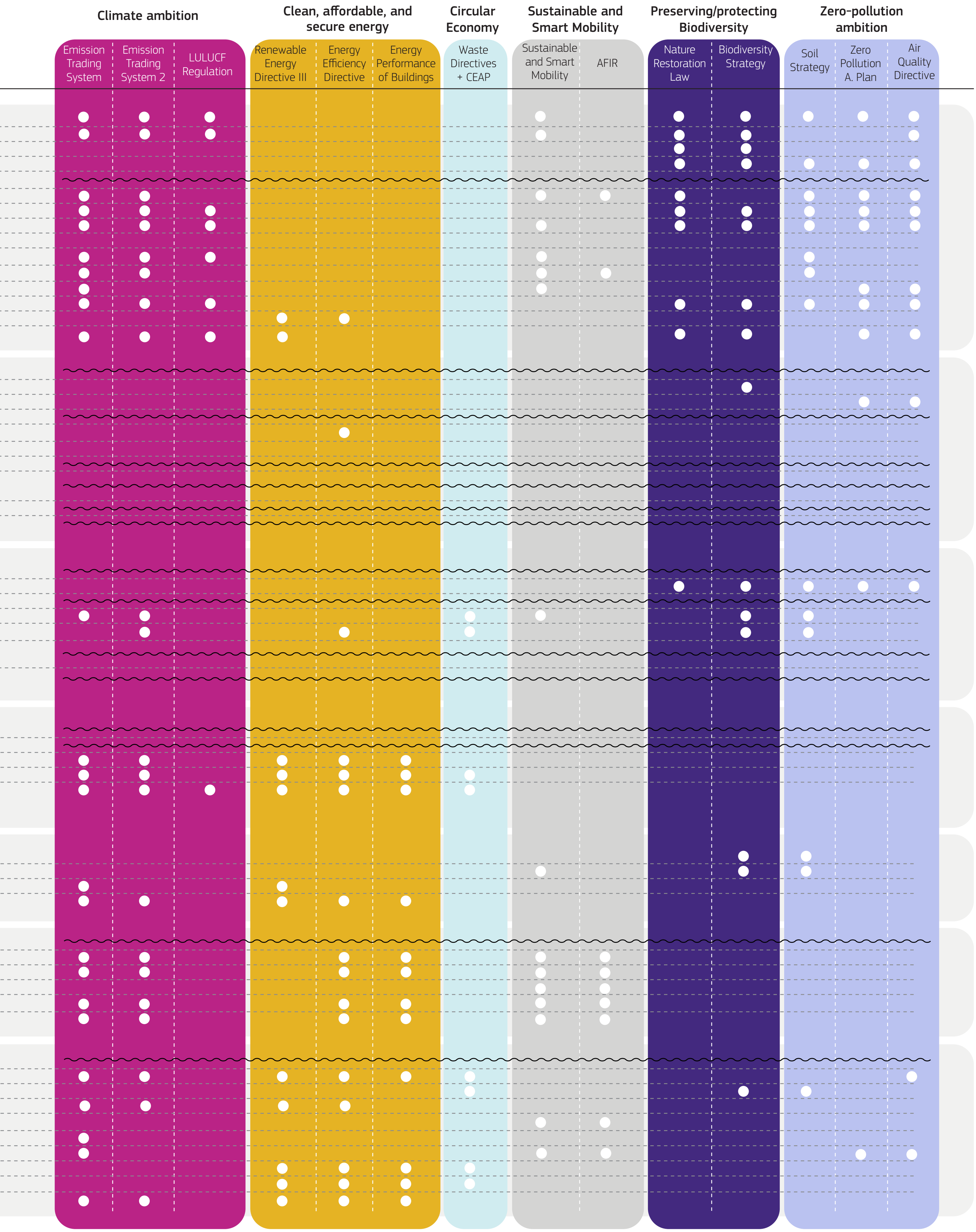
Figure 29. Enablers-policies matrix. Contribution of identified enablers against selected EGD policies.

● Possible enablers　　〜〜〜 Cross-cutting enablers

Enabling Condition	Enablers
Uupgrande of urban infrastructure and NBS uptake	3-30-300 policy
	Wild-life corridors
	Promoting endemic species
	No monocultures
	Comprehensive and systemic planning
	Converting roads to cycling lane
	Introduce greening standards (e.g. UGF) in urban regulations and promote related incentives
	Increase public green spaces
	Incorporate green facades on buildings and enhance rooftops with greenery
	Revision of urban plan to cluster functions
	Use older infrastructure like rail lines
	Provide bikes and bike-related tools to hotels and similar structures
	Establish a minimum amount of greenery
	Resilient design for buildings and cities to mitigate climate risk
	NbS approach to building infrastructure
Streamlined Communication and Information Sharing	Engage local content creators in design process similar to the step-by-step visual campaign
	Counteract/prohibit advertisement on unhealthy product
	New monitoring devices and stations
	Evidence-based policymaking and communication
	Implement and raise awareness on how to use smart monitoring technologies
	Visualising & quantifying outcome of scenarios and interactive communication of project
	Highlighting what has been accomplished and what remains to be done (social medias)
	"Europe Direct" initiative at the neighborhood level, making decision-making processes and reports understandable by translating regulations into accessible language
	Local representative ambassadors to bridge the gap between policymakers and residents
	Leverage existing events to disseminate information about city initiatives
Strengthened and Systematic Community and Citizen Engagement	Public meetings with citizens explaining what has been realised in the city
	Create awareness on the benefits of nature and biodiversity
	Equitable means of participation and sustained engagemet opportunities
	Development of car-free and pedestrian zones to support local farmers' markets
	Encouraging the establishment of gastronomy shops to promote healthier eating habits
	Involving universities, schools, and NGOs to place the human perspective at the center of urban transformation, fostering trust and engagement
	Operating at the neighborhood level
Proper Education and Skills	Involving youth and academic institutions in decision-making and participation
	Interdisciplinary skills from sociologists, anthropologists, biologists, architects, and others
	Raising awareness on optimising energy consumption (behaviours and efficiency)
	Information on isolation materials
	Upskilling and reskilling of the workforce
Innovative Governance Policymaking	Establish Food council
	Adequate policy frameworks for food system
	Breakdown of legal barriers with tailored legal framework to support energy communities
	Green procurement requirements
Coupled Energy Digital Transition	Using digital system for communication, such as digital twins
	Electrification of public transport
	Intermodal integrated hub
	One platform for all
	Incentives the e-mobility
	Allocate a percentage of energy produced in the cities for transportation in local policy
Strengthened and Systematic Community and Citizen Engagement	Get the private sector onboard and engaged and increase PPPs
	Involving industries in the green transition (partnership, cooperation)
	Shorter food supply chain
	Financial incentives for deep energy retrofitting
	One ticket for all
	Incentives for the replacement of pollution heating system
	E-mobility Infrastructure development
	Local one-stop shops establishment/business model
	Incentivise more innovation in business models, making use of best practices in the EU
	Incentives for high energy efficiency and sustainability standards

Source: Adapted from Trane et al. (2026) [793].

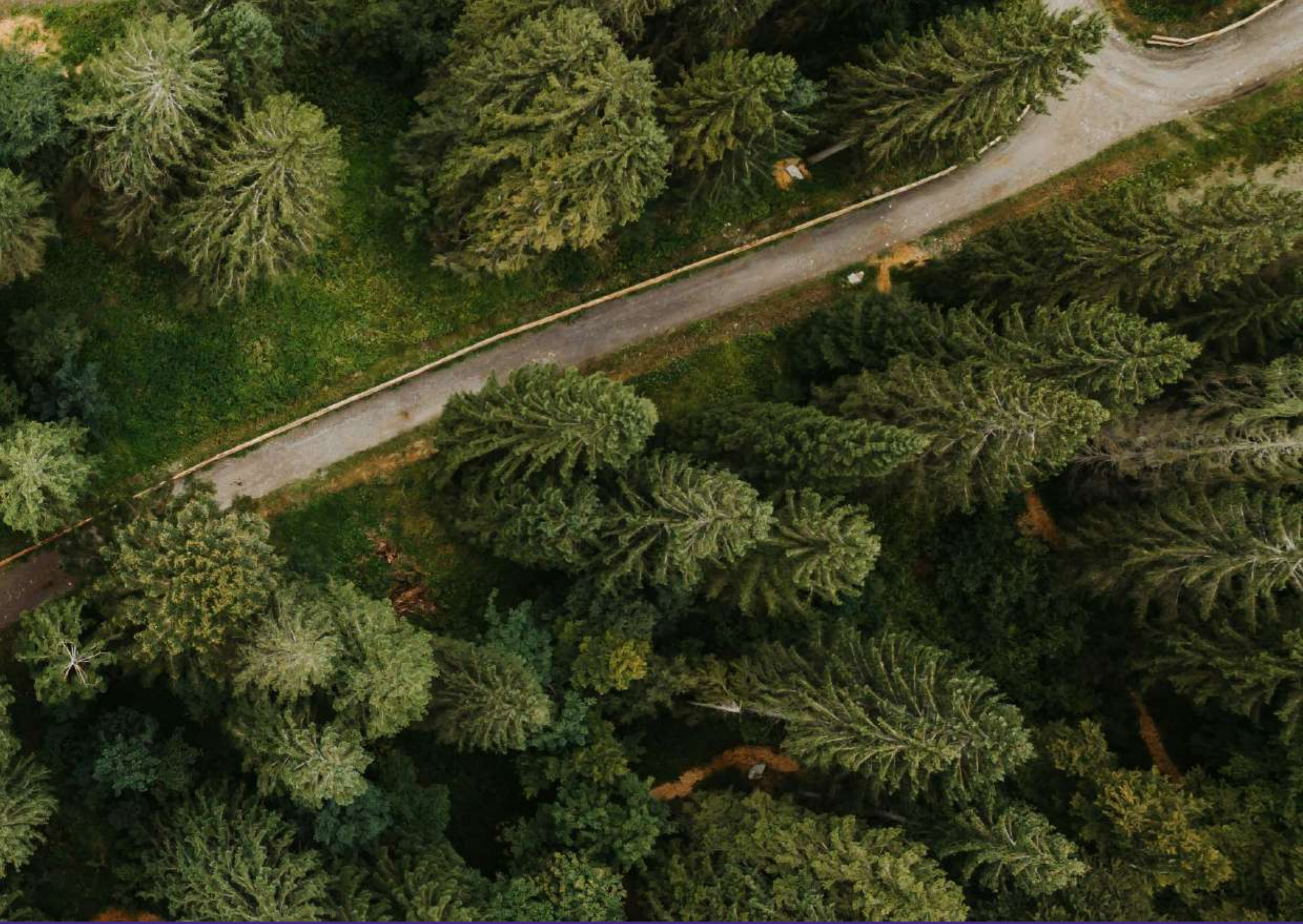
Figure 29. Enablers-policies matrix. Contribution of identified enablers against selected EGD policies.



Source: Adapted from Trane et al. (2026) [793].

09

Conclusions: enabling a clean transition supporting EU competitiveness



The clean transition is a core component of the EU's renewed competitiveness and strategic autonomy agenda. The costs of inaction – higher health burdens, economic losses and ecosystem degradation – are already visible and will rise sharply in the coming years.

The scientific consensus is unequivocal: accelerated and coordinated action to deliver the clean transition is required to secure Europe's economic prosperity, ensure social justice, and protect the health of people and the planet. This report provides an overview of the challenges to be addressed and of the enablers that can support the clean transition while reinforcing the three pillars of the ***Competitiveness Compass*** (decarbonisation, innovation, strategic autonomy). This analysis underscores the need to accelerate the clean transition, which is a cornerstone of the EU's pathway to sustained competitiveness and preparedness. A coherent and predictable policy environment, supported by robust evidence, can empower public and private actors to fulfill their roles in reaching this ambitious common goal.

9.1 Delivering an integrated clean transition

The clean transition is a core component of the EU's renewed competitiveness and strategic autonomy agenda. The costs of inaction – higher health burdens, economic losses and ecosystem degradation – are already visible and will rise sharply in the coming years. The scientific consensus is unequivocal: accelerated and coordinated action to deliver the clean transition is required to secure Europe's economic prosperity, ensure social justice, and protect the health of people and the planet.
This report provides an overview of the challenges to be addressed and of the enablers that can support the **clean transition** while reinforcing the three pillars of the ***Competitiveness Compass*** **(decarbonisation, innovation, strategic autonomy).** This analysis underscores the need to accelerate the clean transition, which is a cornerstone of the EU's pathway to sustained competitiveness and preparedness. A coherent and predictable policy environment, supported by robust evidence, can empower public and private actors to fulfil their roles in reaching this ambitious common goal.

An integrated clean transition

Climate action is the cornerstone of the EU's clean transition. While significant progress in reducing greenhouse gas (GHG) emissions has already been achieved, implementation gaps persist, especially in the land-use, land-use-change and forestry (LULUCF) and agricultural sectors. Closing these gaps requires stronger monitoring systems, consistent regulation across all emission sources and incentives for ecosystem-based approaches. Preserving and enhancing carbon sinks is crucial, because sink degradation could offset hard-won emissions reductions elsewhere. To maintain industrial competitiveness while reducing emissions, carbon management solutions – such as Carbon Capture and Storage (CCS), Carbon Capture and Utilisation (CCU), soil-carbon sequestration, and nature-based offsets – must be backed by clear, long-term regulatory frameworks and by public-private investment pathways.

In the **energy domain**, clean, affordable, and secure energy is central to the competitiveness of EU industry. Although deployment of solar and wind has accelerated, structural challenges remain in permitting, grid capacity, and market design. The strategic scale-up of renewables, especially solar PV and offshore wind, depends on integrated planning frameworks, faster authorisation procedures and investment in flexible grid infrastructure. Building retrofits will be essential for meeting GHG-reduction targets while improving the quality and accessibility of housing. Delivering this at scale will require a skilled workforce, which, in turn, calls for updated and expanded curricula and vocational-training programmes. Robust policy instruments such as financial incentives, subsidies and green financing are crucial, along with clear deep-renovation standards. Addressing energy poverty and access disparities is also key to a socially just and inclusive transition. Finally, hydrogen and nuclear innovations, such as small-modular reactors, will require tailored, risk-based regulation and dedicated funding mechanisms.

The transition to a **circular economy** supports both climate neutrality and the EU's competitiveness ambitions. A level playing field is needed, where existing fiscal support for linear models is redirected towards secondary raw materials and circular business models. At the same time, building well-functioning secondary raw materials markets in the EU is pivotal to increasing circularity. Furthermore, understanding current shifts in trade policy principles is needed to assess the costs and benefits of pursuing a 'sourcing, using and recycling in Europe' approach, or similar initiatives, for secondary raw materials required in key strategic EU industrial sectors. Thus far, circular economy policies have been mainly used as a means of reconciling economic growth with environmental protection. Nevertheless, there is now an opportunity to adopt a more proactive stance by addressing remaining challenges to boost circularity, which could in turn support the competitiveness and resilience of the EU's economy.

Transport is undergoing a profound transformation, yet it still accounts for around a quarter of GHG emissions and remains a complex sector to decarbonise. Scaling zero-emission mobility calls for integrated infrastructure planning, support for modal shifts and the uptake of sustainable fuels. At all governance tiers, planning and policy should prioritise public transport, active mobility and mobility as a service. In combination with extensive fast-charging infrastructure and behavioural incentives that reduce transport demand, these measures are essential to meeting the EU's target of a 90% reduction in GHG emissions by 2050. Road, rail, maritime and aviation each require tailored policy mixes: electrification for road and short-haul transport, hydrogen and advanced biofuels for aviation and maritime, all backed by consistent public investment frameworks and interoperable standards. Securing battery supply chains and critical raw materials for vehicle electrification will be key to reducing the EU's external dependencies in this sector.

In the **food system**, ensuring food accessibility while addressing environmental, economic, and social sustainability in an integrated manner is key to an effective transition. The EU food system is vital to economic development and social well-being, but it remains a major contributor to environmental degradation and is increasingly vulnerable to systemic shocks. Key enablers include the adoption of agroecological and regenerative practices, improved soil health, and enhanced research and innovation in agritech. On the demand side, sustainability-oriented dietary guidelines, sustainable public procurement and supportive food environments can make healthy and sustainable food choices more accessible and attractive. These priorities align with the Commission's *Vision for Agriculture and Food*, which emphasises long-term competitiveness, resilience, and sustainability, while ensuring fair income for farmers and strengthening their position in the value chain.
At the same time, food system transformation must be economically viable for all actors. Fairer profit distribution, targeted financial support for sustainable producers and a more transparent and resilient trade strategy are required to ensure affordability, maintain competitiveness and avoid widening inequalities. Market distortions, weak bargaining power of producers, and externalised environmental costs must be addressed through a combination of policy instruments, investment strategies, and strengthened cooperative models. This requires inclusive multi-actor engagement, improved policy coherence, and enhanced data and monitoring systems. It also calls for redirecting subsidies towards sustainable practices, fostering innovation, and promoting behavioural change to reduce food waste and improve supply chain efficiency.

Protecting biodiversity and ecosystems and restoring them where needed is fundamental to both environmental sustainability and long-term economic viability. Addressing data gaps in ecosystem monitoring and aligning agricultural and marine policy with biodiversity objectives are urgent priorities, as these constitute one of the major factors hampering habitat restoration and preservation. Tackling these challenges requires urgent investment in high-quality, integrated monitoring systems, calibrated with ground data and supported by modelling tools, including bioclimatic indicators and satellite-based products. Innovation in soil and farmland restoration – through regenerative practices and nature-based solutions – should be mainstreamed beyond pilot initiatives. Mobilising private finance and enhancing accountability for biodiversity-related impacts will be critical to reverse ongoing degradation trends. Agriculture is also central to biodiversity and soil regeneration. Emerging proposals include strengthening the biodiversity conditionality of direct payments, benchmarking sustainability performance, and better aligning post-2020 biodiversity and agricultural strategies. Landscape-scale planning – integrating land-sharing and land-sparing approaches – combined with incentives and regulatory action, can help reconcile biodiversity with food production needs.

Finally, the **zero-pollution ambition** cuts across water, air and soil domains, requiring more integrated and holistic monitoring frameworks. Adopting system-wide concepts – for example, leveraging One Health and Safe and Sustainable by Design approaches - can better align health, environmental and economic priorities. Tackling nutrient pollution throughout the agri-food chain and fostering innovation in waste treatment, precision agriculture and enhanced-efficiency fertilisers can reduce diffuse pollution. Participatory and citizen-led monitoring initiatives, if appropriately institutionalised and recognised, can also improve data coverage and public accountability.
To achieve an integrated clean transition, deep interdependencies between sectors must be taken into account. Actions in one domain - such as expanding renewable energy - can unlock opportunities and accelerate progress in others, while systemic challenges often span multiple sectors. Only by maximising synergies and managing trade-offs across these pathways can the EU deliver effective, resilient and inclusive progress on its clean transition goals.

9.2 Horizontal enabling conditions: creating a level playing field for transformative change

Delivering on the clean transition ambitions sets a pathway towards **sustainable competitiveness** for the EU. Many enablers, grouped under the following horizontal conditions, can be identified to make this transition pragmatic, desirable, and scalable, contributing to the three pillars of the *Competitiveness Compass* (Figure 30).

Financing the clean transition is essential to address the current investment needs towards the EU's climate and environmental objectives. Addressing these needs will require significant contributions from private finance, while public funding will play a strategic shaping role. Unlocking and mobilising private finance calls for scaling up sustainable debt instruments, improving access to private finance for innovative companies and deploying public finance to de-risk and crowd-in investment through EU budgetary guarantees (e.g. InvestEU). The use of transition finance is key to ensuring a sustainable and competitive EU economy, and corporate climate transition plans have the potential to act as a common reference point across multiple dimensions of transition (i.e. investment decision-making, financial product design, risk management, supervision and public-private coordination). On the public side, efforts to make the EU budget more impactful also require solid methodologies to monitor where EU money flows and what is achieved with it. Furthermore, the harmonisation of climate and environmental requirements can also support the move towards a simpler and more impactful EU budget. Finally, Member States' national budgets will be key to closing the existing investment gap, and identifying options for harmonising and simplifying the landscape of 'green-related tools' can help them further foster sustainable investments.

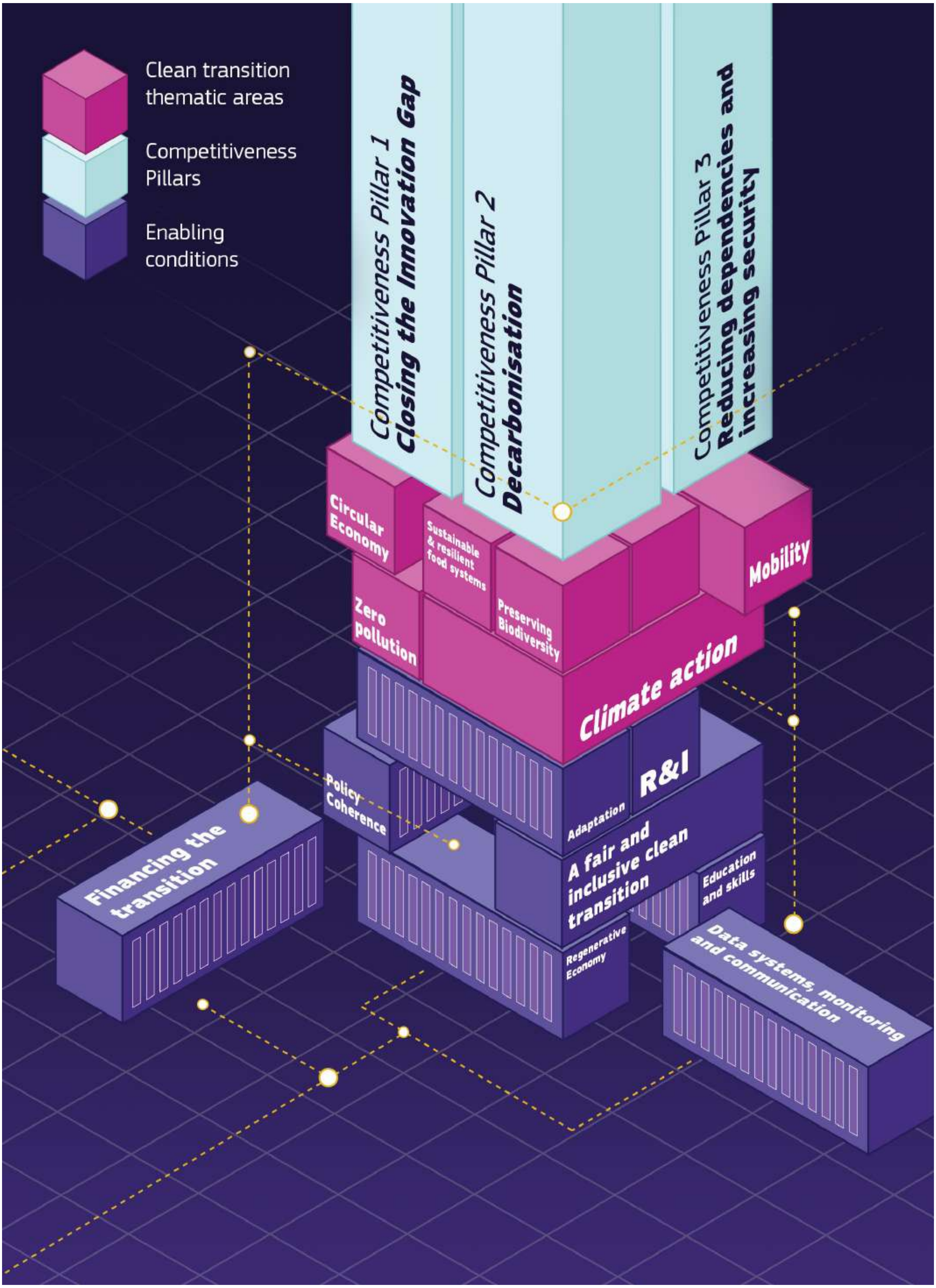
Equally critical is the role of **research and innovation** or enhanced knowledge production and sharing. As highlighted in the first pillar of the *Competitiveness Compass*, closing the innovation gap will require bold investments in R&I ecosystems, technology deployment, and the creation of enabling environments for start-ups and scale-ups. Innovation in the clean transition is not limited to hard technologies: social innovation, behavioural insights truly integrated at all policymaking stages, and place-based experimentation are vital to testing and scaling transformative solutions while promoting awareness. Barriers to experimentation, such as rigid regulation and lack of early-stage financing, must be removed to unlock the potential of both disruptive and incremental innovations.

Education and skills development is a pillar of transformation. A major reconfiguration in many policy areas, labour markets and knowledge systems (i.e., the ways people learn, share, and apply knowledge), and harmonisation across the EU is urgently needed. Tailored vocational programmes, lifelong learning strategies, and stronger synergies between research institutions and industry can address skills gaps, particularly in the energy, construction, and transport sectors. Beyond technical skills, a broader understanding of sustainability principles must be integrated across educational curricula to equip future generations with the knowledge needed to navigate and contribute to a sustainable economy and society.

Shifting towards a **regenerative economy** is essential to align economic activity with ecological resilience. Sustainable biomass use, nature-based solutions, and agroecological practices offer critical levers for this transformation. Yet, the sustainability of the bioeconomy hinges on clear criteria for biomass production and use, addressing resource competition and data gaps, especially in woody biomass flows. Nature-based solutions can support carbon removal and adaptation goals while delivering biodiversity and water co-benefits but require governance mechanisms to minimise trade-offs. In agriculture, a transition to regenerative and agroecological systems will reduce emissions and restore ecosystem functions, while ensuring food security and economic viability. Investment in innovation, integrated land-use governance, and a redefinition of productivity beyond yield maximisation can unlock this potential.

Climate preparedness and resilience cannot happen without **mainstreamed adaptation**. This can be achieved through a whole-of-government preparedness strategy that embeds climate adaptation across all relevant policy areas and investment frameworks. The escalating impacts of climate change across Europe underscore the urgent need for a proactive and systemic approach to climate adaptation. Investments in nature-based solutions, climate-resilient infrastructure, and early warning systems can deliver co-benefits in

Figure 30. Enabling conditions to achieve the EU clean transition in support of competitiveness.



Source: Authors' elaboration

public health, job creation, and regional cohesion. Strengthening cross-border cooperation on shared climate risks, supported by harmonised risk assessment standards and improved climate-related loss and damage data, is critical. The EU *Strategy on Adaptation to Climate Change* provides a foundation, but further efforts are needed to scale up data coverage, align methodologies, and unlock the enabling conditions necessary for resilient and forward-looking societies.

Improved data systems, monitoring and communication represent another cornerstone of implementation. In the face of growing complexity and uncertainty, policies must be informed by timely, granular, and interoperable data. At the same time, effective communication is essential to ensure that knowledge translates into action. Fostering public trust, addressing misinformation, and improving the accessibility and relevance of scientific evidence are necessary steps to bridge the gap between institutional intent and social uptake. Public engagement, transparency, and co-creation processes can enhance legitimacy, while building the collective literacy needed to navigate the transition.

A **fair and inclusive clean transition** is essential to ensure that its costs and benefits are equitably shared across society. Vulnerable groups and low-income households are disproportionately affected by climate impacts and transition policies, particularly in energy and transport. Addressing energy and transport poverty, supporting affordable housing, and enabling participation in energy communities are key levers to promote fairness. At the same time, carbon inequalities must be tackled through well-designed pricing policies and redistributive measures. A just transition also involves ethical food systems and inclusive support for farmers and consumers, both within and beyond the EU. Complementary to this, alternative measurement indicators such as wellbeing metrics and ecosystem accounts can help reorient policy priorities beyond GDP, making visible what economic growth alone might fail to capture along Europe's transition pathway.

Finally, **policy coherence** sets the level playing field on which actors can align their strategies while preserving place-based values and leveraging the role of sub-national authorities, where most of the policy targets will have to be implemented. Specifically, policy coherence is needed horizontally (beyond policy silos), vertically (across governance levels), and over time. Well-orchestrated policy mixes, consistent with long-term objectives, can de-risk private investment, foster competition and facilitate the diffusion of sustainable practices. Clear, stable and predictable rules over time offer the planning security needed by economic actors to compete fairly and accelerate the deployment of solutions, ensuring that the transition is not only ambitious but also economically viable. Permitting bottlenecks, fragmented responsibilities, and uneven capacities across Member States or regions slow down project deployment and deepen territorial inequalities. Streamlining administrative procedures, reinforcing multilevel coordination, and improving the absorption capacity of public funds – especially in lagging regions – can help ensure that no place is left behind. Governance, in this sense, is a supporting condition rather than a solution in itself: what matters is the institutional capacity to enable aligned action across scales and sectors.

The pathways described in this report - across climate action, clean energy, the circular economy, mobility, food systems, biodiversity, and zero pollution - are deeply interconnected, and the horizontal enabling conditions that underpin them are mutually reinforcing. No single sector or policy domain can achieve the transition on its own. What is required is a coherent, sustained, and evidence-informed effort that simultaneously drives sectoral transformation and strengthens the structural conditions that allow public authorities, businesses, workers and citizens to act. EU legislation provides a level playing field, steering when and how the clean transition unfolds, while science-based enablers translate knowledge into practical solutions. Addressing the challenges that currently hinder progress is therefore essential not only to meet the Union's climate and environmental targets but also to safeguard long-term resilience and sustainable competitiveness.

The scientific case is clear; Europe must now act with the coordination, consistency and ambition needed to secure its future prosperity and competitiveness.

9.3 Looking ahead

The analysis presented in this report represents a step forward in identifying key challenges and enablers shaping the clean transition in the light of the EU's renewed strategic priorities. To deepen this effort, targeted thematic follow-ups will be developed, zooming in on specific domains, policy areas, and regulatory frameworks.

At the same time, more cross-cutting analytical work will be carried out to identify and operationalise granular enablers that can support evidence-based implementation at all levels of governance. In parallel, the monitoring exercise conducted in the JRC 2025 flagship report "*Delivering the EU Green Deal: Progress towards targets*" will be updated in 2027 as part of the EGD monitoring exercise. This follow-up will reflect any policy revisions and continue benchmarking progress toward updated or emerging targets, drawing upon expert consultation and new data sources.

Delivering on the clean transition requires profound transformations in how societies produce, consume, and live. EU policies set a level playing field where this transition will happen. The roadmap is clear: continuous monitoring and learning are essential to steer implementation efforts. Leveraging the right enablers and establishing the structural conditions that allow all actors to fulfil their role is a prerequisite for unlocking the transformative potential of the clean transition. Addressing the challenges that could hinder progress is not only necessary to meet the EU's climate and environmental goals, but also to safeguard long-term security, resilience, and **sustainable competitiveness**.

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List of abbreviations and definitions

AFIR	Alternative Fuels Infrastructure Regulation
AI	Artificial Intelligence
AMOC	Atlantic Meridional Overturning Circulation
AMR	Antimicrobial Resistance
ASM	Artisanal and Small-Scale Mining
AV	Automated and Connected Vehicles
BESS	Battery Energy Storage Systems
BEV	Battery-Electric Vehicle
BI	Behavioural Insights
BMPs	Best Management Practices
BNEF	Bloomberg New Energy Finance
C3S	Copernicus Climate Change Service
CAP	Common Agricultural Policy
CBAM	Carbon Border Adjustment Mechanism
CCA	Climate Change Adaptation
CCM	Climate Change Mitigation
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CCUS	Carbon Capture, Utilisation and Storage
CEAP	Circular Economy Action Plan
CE	Circular Economy
CEF	Connecting Europe Facility
CF	Consumption Footprint
CFP	Common Fisheries Policy
COPD	Chronic Obstructive Pulmonary Disease
CRD	Capital Requirements Directive
CRCF	Carbon Removals and Carbon Farming
CRMA	Critical Raw Materials Act
CRMs	Critical Raw Materials
CSRD	Corporate Sustainability Reporting Directive
CSDDD	Corporate Sustainability Due Diligence Directive
DF	Domestic Footprint
DigComp	European Digital Competence Framework
DMAT	Digital Maturity Assessment Tool

DNSH	Do No Significant Harm
DPP	Digital Product Passport
EA	Ecosystem Accounting
EC	European Commission
ECB	European Central Bank
ECF	European Competitiveness Fund
EESC	European Economic and Social Committee
EEA	European Environment Agency
EE	Eastern European
EFAMA	European Fund and Asset Management Association
EFRAG	European Financial Reporting Advisory Group
EGD	European Green Deal
EIB	Environmental Investment Bank
EIR	Environmental Implementation Review
ENSREG	European Nuclear Safety Regulators Group
ENV	Environment
EoW	End-of-Waste
EPAH	European Advisory Energy Poverty Hub
EPLCA	European Platform for Life Cycle Assessment
EPR	Extended Producer Responsibility
EPS	European Ports Strategy
ERC	European Research Council
ESRS	European Sustainability Reporting Standards
ESPN	European Social Policy network
ESPR	Ecodesign for Sustainable Products Regulation
ESPAS	European Strategy and Policy Analysis System
ESS	Energy Storage Systems
ESTPs	Earth System Tipping Points
ETD	Energy Taxation Directive
ETS	Emissions Trading System
ETS2	Emissions Trading System 2
ETSON	European Technical Safety Organisations Network
EU	European Union
EU27	The 27 Member States of the European Union
EU-BMS	EU Bioeconomy Monitoring System
EUCRA	European Union Climate Risk Assessment
EUDR	EU Deforestation-free products Regulation
EuGBs	European Green bond Standards
EUR	European Utility Requirements
EV	Electric Vehicle
FAQs	Frequently Asked Questions
FCEV	Fuel Cell Electric Vehicle
FP	Framework Programme
FTE	Full-Time Equivalent
GDP	Gross Domestic Product
GEP	Gross Ecosystem Product
GHG	Greenhouse Gas

GIF	Generation IV International Forum
GPUs	Graphical Processing Units
GPP	Green Public Procurement
GTT	Green Transition Target
GVA	Gross Value Added
GW	Gigawatt
HALEU	High-Assay Low-Enriched Uranium
HDV	Heavy Duty Vehicle
IAEA	International Atomic Energy Agency
IAS	Invasive Alien Species
ICAO	International Civil Aviation Organization
ICMA	International Capital Market Association
ICT	Information and Communications Technology
IMF	International Monetary Fund
IMO	International Maritime Organization
INCA	Integrated Natural Capital Accounting
INMAP	Integrated Nutrient Management Action Plan
IPCC	Intergovernmental Panel on Climate Change
IPCEIs	Important Projects of Common European Interest
JRC	Joint Research Centre
JRC-GEM-E3	JRC General Equilibrium Model for Energy, Climate and Environment
KCB	Knowledge Centre for Bioeconomy
KPIs	Key Performance Indicators
LCA	Life Cycle Assessment
LCoE	Levelised Cost of Energy
LDPE	Low-Density Polyethylene
LDV	Light Duty Vehicle
LFP	Lithium Iron Phosphate
LNG	Liquefied Natural Gas
LRAs	Local and Regional Authorities
LTO	Long-Term Operation
LULUCF	Land Use, Land-Use Change and Forestry
LWRs	Light Water Reactors
MaaS	Mobility-as-a-Service
MCCS	Marine Carbon Capture and Storage
MEL	Monitoring, Evaluation and Learning
MFF	Multiannual Financial Framework
Mha	Million Hectares
NAPs	National Adaptation Plans
NbS	Nature-based solutions
NC2I	Nuclear Cogeneration Industrial Initiative
NEA	Nuclear Energy Agency
NEB	New European Bauhaus
NEC	National Emission Reduction Commitments
NECPs	National Energy and Climate Plans
NDICI	Neighbourhood, Development and International Cooperation Instrument – Global Europe

NGOs	Non-Governmental Organisations
NIRs	National Plans for Infrastructure Build-up
NMC	Nickel Manganese Cobalt
NPPs	Nuclear Power Plants
NRPPs	National and Regional Partnership Plans
NW	North-Western
NZIA	Net-Zero Industry Act
NbS	Nature-based Solutions
OCT	Overseas Countries and Territories
OECD	Organisation for Economic Co-operation and Development
OPS	Onshore Power Supply
OR	Outermost Regions
PBA	Prussian Blue Analogue
PAYT	Pay-As-You-Throw
PEM	Proton Exchange Membrane
PET	Polyethylene Terephthalate
PFAS	Per- and Polyfluoroalkyl Substances
PP	Polypropylene
PPWR	Packaging and Packaging Waste Regulation
PS	Polystyrene
PTSD	Post-Traumatic Stress Disorder
PV	Photovoltaics
QA	Quality Assurance
R&D	Research and Development
R&I	Research and Innovation
RED	Renewable Energy Directive
RFNBOs	Renewable Fuels of Non-Biological Origin
RLCF	Renewable and Low-Carbon Fuels Value Chain (Industrial Alliance)
RRF	Recovery and Resilience Facility
SAFE	Survey on the Access to Finance of Enterprises
SCF	Social Climate Fund
SCMp	Soil Carbon Management Practices
SCPs	Social Climate Plans
SDGs	Sustainable Development Goals
SE	Southern Europe
SEEA	System of Environmental-Economic Accounting
SET Plan	Strategic Energy Technology Plan
SFDR	Sustainable Finance Disclosure Regulation
SIWb	Sustainable and Inclusive Well-being
SLBP	Sustainability-Linked Bond Principles
SMEs	Small and Medium Enterprises
SMRs	Small Modular Reactors
SNETP	Sustainable Nuclear Energy Technology Platform
SOC	Soil Organic Carbon
SOTEU	State of the European Union
SRMs	Secondary Raw Materials

STEAM	Science, Technology, Engineering, Arts and Mathematics
STEM	Science, Technology, Engineering and Mathematics
SUMPs	Sustainable Urban Mobility Plans
TA	Thematic Area
TCO	Total Cost of Ownership
TEU	Treaty on European Union
TPUs	Tensor Processing Units
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VSME	Voluntary Sustainability Reporting Standard for non-listed Micro, Small and Medium-sized Enterprises
WEEE	Waste Electrical and Electronic Equipment
WEF	World Economic Forum
WFD	Water Framework Directive
WHO	World Health Organization
WWF	World Wide Fund for Nature
ZEV	Zero-Emission Vehicle
ZLEV	Zero- and Low-Emission Vehicle

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Annex I. Methodological approach

This report is a follow-up to the 2025 JRC flagship report [Delivering the EU Green Deal - Progress towards targets] [8], which tracked progress towards the EU's clean transition across a broad range of environmental policy domains: climate action; clean, affordable and secure energy; circular economy; sustainable and smart mobility; food systems; preserving and protecting biodiversity; towards zero-pollution ambition for clean air, water and soil. Building on that evidence base, the present report Building on that evidence base, the present report focuses specifically on those areas of the clean transition where progress needs to accelerate or trends need to be reversed to achieve stated targets and ambitions. It provides in-depth analysis of areas where the progress assessment identified gaps, risks or persistent challenges.

To this end, the report adopts an integrated mixed-methods approach, combining a scoping literature review, quantitative environmental modelling and structured expert consultation to integrate the most recent knowledge and data available from in-house and recognised scientific research into a targeted evidence synthesis. This approach brings together scientific evidence, institutional reporting, modelling results and expert knowledge mobilisation to support policy-relevant and implementation-oriented insights.

This evidence synthesis draws on a structured review of in-house JRC science for policy, selected peer-reviewed publications, EU institutional documents and technical reports, gathered and assessed thematically across the report's chapters to identify areas of scientific consensus, emerging knowledge, and remaining uncertainty. This systematic methodology reflects the approach used in other major scientific assessments, such as the IPCC Assessment Reports, where evidence from a large number of independent studies is synthesised, evaluated and assessed. As with other scientific publications, this report cites sources throughout the text, with the extensive body of references provided at the end of the report to allow readers to consult the original materials.

Specifically, several sections draw directly on dedicated JRC research developed in support of EU policies. Examples include work on Sustainable and Inclusive Wellbeing (Chapter 7), costs of inaction (PESETA) (Chapter 1), public sentiment analysis (Chapter 1), Sustainable Development Goals (Chapter 1), Environmental and Consumption Footprints (Chapter 3), and the biomass mandate (Chapter 4). The quantitative component consists of an integrated environmental assessment (Chapter 3) based on Life Cycle Assessment (LCA) methodology, using the Consumption Footprint and Domestic Footprint models, as detailed in [329] and Annex III of this report. The analysis evaluates selected European Green Deal targets and ambitions against projected environmental outcomes by 2030 using physical environmental indicators.

Due to the cross-cutting nature of the report, the methodology required the intersection of multiple independent scientific fields. To this end, the consultation process involved more than 150 JRC contributing authors. Experts were asked to identify key challenges and enablers relevant to their thematic domains, substantiated with references, case studies, or ongoing exercises in support of policies. Responses were subsequently reviewed and synthesised by the lead authors, with thematic selection reflecting patterns of convergence across expert inputs. This was complemented by editorial judgement to ensure coherence, policy relevance (with respect to current policy priorities and targets for which acceleration is needed according to [8]), and alignment with the report's overall analytical framework. Specifically, through the thematic graphic navigators, challenges were clustered into political-institutional, knowledge-operational, sociocultural-behavioural, technological-infrastructural, and financial-economic categories, adopting a classification reflected in the domain literature. The evidence collection process also incorporated an iterative "snowballing" approach for both literature identification and expert mobilisation. This was used to identify additional relevant evidence and expertise beyond the initial set of sources and contributors.

For literature evidence, snowballing consisted of tracing references cited in key JRC outputs, Commission documents, peer-reviewed articles and other international reports, such as those by the World Bank, already included in the review. Additional sources were retained: (i) when they were directly relevant to the implementation challenges or enablers under analysis, (ii) when they provided updated evidence, or (iii) when they helped fill evidence gaps in specific thematic areas. For expert mobilisation, snowballing consisted of progressively expanding the pool of consulted experts through recommendations from already involved JRC scientists and thematic coordinators. This made it possible to reach additional contributors with expertise in specific policy domains or implementation issues.

Additional references, thematic sources and institutional reports were progressively identified through cross-referencing within the reviewed material, as well as through recommendations emerging from expert consultations and thematic exchanges. Similarly, the identification of experts and contributors evolved iteratively throughout the development of the report, building on existing JRC thematic networks, domain expertise, previous collaborations and input from involved scientists across different policy and research areas. This approach supported the expansion and diversification of the evidence base, facilitating cross-sectoral integration and the inclusion of complementary scientific perspectives.

Finally, the report was subject to an exhaustive and rigorous review process, involving several iterations with all involved JRC experts and key Commission services to ensure coherent messaging, clarity, and a comprehensive, objective and transparent assessment.

Scope and limitations

Several methodological considerations should be acknowledged. First, the report does not constitute an ex-post policy evaluation, a causal impact assessment or a comprehensive systematic review of all available literature. Second, due to the evolving nature of the EU clean transition policy framework and geopolitical context, many implementation outcomes remain uncertain and depend on future policy developments, investment trajectories, geopolitical dynamics and technological progress.

Third, the analysis across the thematic areas covered in Chapters 2 and 3 starts from the set of policies developed during the 2019-2024 EC mandate (under the ***European Green Deal*** headline priority), focusing on where efforts need to be concentrated to achieve these ambitions. These policies are taken as representative of the EU's clean transition.
While the report incorporates multiple quantitative sources and new modelling exercises where available, its primarily aim is to synthesise evidence and identify implementation-relevant insights rather than to generate new integrated forecasts or macroeconomic simulations. It adopts a science-for-policy perspective that prioritises policy relevance, systemic interpretation and operational applicability. Consequently, the analytical emphasis is placed on actionable implementation insights and enabling conditions, rather than exhaustive academic categorisation.

In the authors' view, the combination of these approaches strengthens the report's analytical breadth. The literature scanning is necessarily selective, given the breadth of topics covered; the LCA-based modelling is subject to scenario and data uncertainties; and JRC expert contributions reflect the state of knowledge at the time of drafting. Together, these methods provide a coherent and transparent basis for the report's findings, while acknowledging that the evidence base in several areas continues to evolve.

Annex II. How EGD targets contribute to SDGs

Table 5 lists all the 154 EGD targets and their connection to the SDG framework (both at goal and target level). The assessment of progress towards the EGD targets is based on the exhaustive analysis carried out by JRC [8]: the green targets (green circles) are on track to be achieved; the yellow targets are showing progress but not enough to be reached by 2030, thus acceleration is needed; the red targets are not progressing (they are stagnating or either moving in the opposite direction). For the grey targets there are not sufficient information so far for evaluating their progress. The last column shows the EGD thematic areas pertaining to the targets, and the arrows indicate the direction towards the SDG achievement. For most of the SDGs, the EGD assessment reveals the presence of both progress and existing challenges (minor or major) in the path towards the SDG achievement.

The results of this analysis are aligned with the 2025 Eurostat monitoring report on progress towards the SDGs. Eleven of the targets assessed are in common with the EGD policy targets:

- Area under organic farming (SDG 2): moderate progress towards the target.
- Use and risk of chemical pesticides (SDG2): on track to reach the target.
- Premature deaths due to exposure to fine particulate matter (SDG 3): on track.
- Share of renewable energy in gross final energy consumption (SDG 7-13): moderate progress.
- Primary and final energy consumption (SDG 7): moderate progress.
- Recycling rate of municipal waste (SDG 11): insufficient progress towards the target.
- Circular material use rate (SDG 12): insufficient progress.
- Net greenhouse gas emissions (SDG 13): moderate progress.
- Net greenhouse gas emissions from LULUCF (SDG 13): movement away from the target.
- Marine protected areas (SDG 14): insufficient progress.
- Terrestrial protected areas (SDG 15): insufficient progress.

Beyond these targets and indicators already aligned, linking every EGD target to the SDG framework allows identifying the potential contribution of EGD ambitions to the SDG implementation, showing how the two are interrelated and mutually reinforcing.

Table 5. Detail of EGD targets contribution to SDGs, specifying the level of progress towards the targets.

2 ZERO HUNGER		2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land		
		7 EGD targets in TA5 and TA6		
		Reduce overall EU sales of for farmed animals and in aquaculture by 50% by 2030		Farm to Fork
		At least 25% of agricultural land is under ***organic farming management*** *ecological practise is significantly increased by 2030*		
		use and risk of chemical pesticides		
		hazardous pesticides		
		The losses of nutrients from are reduced by 50%, resulting in the reduction of the use of fertilisers by at least 20%		
		At least 10% of agricultural area is under ***diversity landscape***		Bio diversity
		Member States shall put in place measures which shall aim to achieve an increasing trend at national level of at least two out of the three following ***agricultural ecosystems****: (a) grassland butterfly index; (b) stock of organic carbon in cropland mineral soils; (c) share of agricultural land diversity landscape features.*		
3 GOOD HEALTH AND WELL-BEING		3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination		
		Improve air quality to reduce the number of premature		Pollution
6 CLEAN WATER AND SANITATION		6.1 By 2030, achieve universal and equitable access to safe and affordable drinking		
		Member States shall take the measures necessary to ensure that ***for human consumption*** *is wholesome and clean, by meeting the following requirements: (a) water free from any micro parasites and from any substances which, in numbers or concentrations, constitute a potential danger to human health; (b) water meets minimum*		Pollution
		6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for defecation, paying special attention to the needs of women and girls and those in vulnerable situations		
		access to sanitation for all *vulnerable and marginalised, while aligning with the ZPAP and EGD climate and energy objectives. Member States will ensure the application of: Tertiary treatment, for the removal of nitrogen and phosphorus (by 2039) Quaternary treatment, for the removal of a broad spectrum of micropollutants (by 2045)*		Pollution
		6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of wastewater and substantially increasing recycling and safe reuse globally		
		water quality by reducing waste*, plastic litter at sea (by 50%) and microplastics released into the environment (by 30%), by 2030*		Pollution
		Setting new high standards for a series of chemical substances of concern to ***chemical pollution in water***		
		Encourage and facilitate in the EU by harmonised minimum		

		water quality requirements for the safe reuse of treated urban wastewaters		
		6.6 By 2020, protect and restore water related ecosystems, including mountains, wetlands, rivers, aquifers and lakes		
		Member States shall make an inventory of artificial barriers to connectivity of surface waters and remove them, taking into account their socio functions, to contribute to the achievement of the restoration targets and of the objective of restoring at least 25.000 km of rivers into		Bio diversity
7 AFFORDABLE AND CLEAN ENERGY		7.1 By 2030, ensure universal access to affordable, reliable and modern energy		
		biofuels and biogas produced *from the feedstock in the energy content of fuels and electricity supplied to the transport sector shall, except in Cyprus and Malta, be limited to 1.7%*		Mobility
		7.2 By 2030, increase substantially the share of renewable energy in the global		
		19 EGD targets in TA2 and TA4		
		Member States shall collectively ensure that the share of in the Union's gross final consumption of energy in 2030 is at least 42.5 %		
		The amount of renewable fuels and renewable electricity supplied to the ***share of renewable energy*** *within the final consumption of energy in the transport sector of at least 29 % by 2030; or greenhouse gas intensity reduction of at least 14,5 % by 2030, compared to the baseline, in accordance with an indicative trajectory set by the Member*		
		By 2022 achieve 18% of the total ***increase in the share of*** *between that Member State's binding 2020 national target, and its contribution to the 2030 target of the share of energy from renewable sources in gross final consumption of energy.*		
		Member States shall set an indicative target for ***innovative renewable*** *of at least 5% of newly installed renewable energy*		
		*Each Member State shall increase the share of r****enewable energy in the heating and cooling sector*** *by at least 0.8 percentage points as an annual average calculated for the period 2021 to 2025 and by at least 1.1 percentage points as an annual average calculated for the period 2026 to 2030, starting from the share of renewable energy in the sector in 20*		Energy
		Indicative target of at least a 49% share of energy from ***renewable sources in the building sector*** *in the Union's final energy consumption in buildings*		
		Member States shall endeavour to increase the share of in the amount of energy sources used for final energy and non ***in the industry sector*** *by an indicative increase of at least 1.6 percentage points as an annual average calculated for the periods 2021 to 2025 and 2026 to 2030.*		
		Member States shall ensure that the contribution of ***renewable fuels of*** *used for final energy and non be at least 42% of the hydrogen used for final energy and non by 2030, and 60% by 2035*		
		, on average, approximately 45 to reach the share of 45% of energy coming from set out in the RePowerEU Plan		
		based energy community		

		municipality with a population higher than 10.000		
		Bring online over 320 GW of by 2025 and almost 600		
		Energy demand to be covered by ***solar heat and geothermal***		
		renewable energy in the electricity mix *60%, and projections show a share of around 84% by 2050*		
		offshore goals of installed capacity		
		The strategy sets targets for an installed capacity of at least 1 GW of by 2030 and 40 GW by 2050		
		REPowerEU sets a target of 10 million tonnes of ***hydrogen production*** *10 million tonnes of renewable hydrogen*		
		Achieve an annual production of ***sustainable biomethane***		Mobility
		Each Member State shall set an obligation on fuel suppliers to ensure that: (B) the combined share of ***advanced biofuels and biogas*** *the feedstock listed and of renewable fuels of nonbiological origin in the is at least 1% in 2025 and 3,5% in 2030, of which a share of at least 1 percentage point is from renewable fuels biological origin in 2030*		
		Member States with maritime ports should endeavour to ensure that from biological origin (RFNBOs) in the total amount of energy supplied to the ***maritime transport***		
		7.3 By 2030, double the global rate of improvement in energy efficiency		
		13 EGD targets in TA2 and TA4		Energy
		Member States shall collectively ensure a ***reduction of energy*** *of at least 11.7 % in 2030 so that the Union's final energy consumption amounts to no more than 763 Mtoe*		
		Member States shall make efforts to collectively contribute to the indicative ***primary energy consumption*** *target amounting to no more than*		
		Member States are required to achieve cumulative ***use energy savings*** *from 2021 to 2030, equivalent to new annual savings of at least 0.8% of final energy consumption in 2021 2023, at least 1.3% in 2024 2027 and 1.9% in 2028*		
		Each Member State shall ensure that at least 3% of the total floor area of heated and/or cooled buildings that are owned by public bodies is renovated each year to be transformed into at least		
		Member States shall ensure that the total final ***energy consumption*** *combined is reduced by at least 1.9 % each year, when*		
		Member States shall ensure that the average primary ***residential building stock*** *least 16% compared to 2020 by 2030; and by at least 20*		
		Member states will have to ***residential buildings*** *by 2030 and, by 2033, the worst through minimum energy performance requirements.*		
		The national measures will have to ensure that at least 55% of the is achieved through the renovation of the		
		buildings' final energy consumption *by 14% compared to 2015*		

		buildings' energy consumption for heating and cooling *compared to 2015 levels*	●	
		At least double the annual ***energy renovation rate*** *by 2030 and to foster deep energy renovations*	●	
		deployment rate of individual heat pumps *in a cumulative 10 million units by 2027 and 30 million units by 2030*	●	
		are encouraged to continue the positive trend, as observed for ***reducing fuel intensity*** *fuel consumption per kg of landed product for at least an additional 15% for the period 2019*	●	Mobility
		By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil fuel technology, and promote investment in energy		➡
		By 2025, each Member State shall agree to establish a with one or more other Member States for the production of renewable energy, subject to the following: by 31 December 2030, Member States shall endeavour to agree on establishing at least two joint projects; by 31 December 2033, Member States with an ann electricity consumption of more than 100 TWh shall endeavour to agree on establishing a third joint project	●	Energy
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE		9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and being, with a focus on affordable and equitable access for all		➡
		targets in TA2, TA4, TA5		
		In the first phase, from 2020 up to 2024, the strategic objective is to install ***renewable hydrogen electrolysers*** *production of up to 1 million tonnes of renewable hydrogen. In the second phase, from 2025 up to 2030, the strategic objective is to install at least 40 GW of renewable hydrogen electrolysers*	●	Energy
		Member States shall ensure that T core and comprehensive networks, publicly accessible deployed in each direction of travel with a maximum distance of 60 between them offering a power output of at least 600 kW and including at least one recharging point with an individual power output of at	●	
		By 2030, along the TEN ***duty electric vehicles*** *direction of travel with a maximum distance of 60 km between them. T comprehensive road network, recharging pools dedicated to heavy duty electric vehicles are deployed in each direction of travel with a maximum distance of 100 km between them and each recharging pool offers a power output of at least 1 500 kW and includes at least one recharging point with an individual power output of at least 350 kW*	●	
		By 2030, in each urban node publicly accessible ***dedicated to heavy duty electric vehicles*** *with an aggregated power output of at least 1 800 kW are deployed, provided by recharging stations with an individual power output of at least 150 kW*	●	Mobility
		By 2030, in each safe and secure ***recharging stations*** *with an individual power output of at least 100 kW are deployed*	●	
		Member States shall ensure that, at the end of each year, the following targets are met cumulatively: (a) for each light registered in their territory, a total power output of at least 1.3 kW is provided through publicly accessible recharging stations; (b) for registered in their territory, a total power output of at least 0.80 kW is provided through publicly accessible	●	

		Member States shall ensure that a minimum ***side electricity supply*** *for seagoing container ships and seagoing passenger ships is provided in . To that end, by 31 December 2029 TEN comprehensive maritime ports [...] are equipped to provide each year shore side electricity supply for at least 90% of the total number of port calls of seagoing container ships above 5.000 gross tonnes tha quayside at the maritime port concerned and 90% of the total number of calls of seagoing passenger ships above 5 000 gross tonnes and seagoing speed passenger craft above 5 000 gross tonnes that are moored at the quayside at the maritime port concerned.*	grey	
		Member States shall ensure that at least one installation providing shore ***electricity supply to inland waterway vessels*** *core inland waterway ports by 2025; at all TEN T comprehensive inland waterway ports by 2030*	grey	
		Member States shall ensure that, by 2030, at least one publicly accessible ***hydrogen refuelling station***	yellow	
		Member States shall ensure that by 2030 publicly accessible designed for a minimum cumulative capacity of 1 tonne per day and equipped with at least a 700 bar dispenser are deployed with a maximum distance of 200 km between them along the	yellow	
		Member States shall ensure that, at all T comprehensive network, the provision of stationary aircraft is ensured by 31 December 2029, at all aircraft remote stands used for commercial air transport operations to embark or disembark passengers or to load or unload goods	grey	
		Reduce the average door ***cost of combined transport operations*** *by at least 10% within 7 years*	grey	
		fast broadband to all farmers *achieve the objective of 100% access by 2025*	yellow	Farm to Fork
		9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries accordance with their respective capabilities		↗ | →
		4 EGD targets in TA2, TA3		
		electricity interconnection	yellow	Energy
			yellow	
		manufacturing capacity *approaches or reaches a benchmark of at least 40% of the Union's annual deployment needs*	grey	Industry & Circular Economy
		At least 20% of the carbon used in the chemical and plastic products should by 2030, in full consideration of the EU's biodiversity and circular economy objectives and of the upcoming policy framework for bio based, biodegradable and compostable plastics	grey	
11 SUSTAINABLE CITIES AND COMMUNITIES		11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons		→
		Reduce the share of people chronically disturbed by	yellow	Pollution
		11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste		↗ | ↘
		2 EGD targets in TA3 and TA7		
		the amount of residual (non	red	Industry & Circular Economy

		air quality standards *for 12 air pollutants for Member States to not exceed: sulphur dioxide, nitrogen dioxide / nitrogen oxides, particulate matter (PM10, PM2.5), ozone, benzene, lead, carbon monoxide, arsenic, cadmium, nickel, and benzo(a)pyrene*		Pollution
		11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with		
		, Member States shall ensure that there is , and of urban tree canopy cover in		Bio diversity
		Member States shall achieve thereafter an ***area of urban green space****, including through integration of urban green space into buildings and infrastructure, in urban ecosystem areas, measured every six years , until a satisfactory level is reached*		
		Member States shall achieve, in each urban ecosystem area an cover, measured every six years until the satisfactory level is reached		
		11.b By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters		
		Cities with at least 20.000 inhabitants have an ambitious		Bio diversity
12 RESPONSIBLE CONSUMPTION AND PRODUCTION		12.2 By 2030, achieve the sustainable management and efficient use of natural		
		extraction capacity *is capable of extracting the ores, minerals or concentrates needed to produce at least 10% of the Union's annual consumption of strategic raw materials, to the extent possible in light*		Industry & Circular Economy
		processing capacity*, including for all intermediate processing steps, is capable of producing at least 40% of the Union's annual consumption of strategic raw materials*		
		Union recycling capacity*, including for all intermediate recycling steps, is capable of producing at least 25% of the Union's annual consumption of strategic raw materials and is capable of recycling significantly increasing amounts of each strategic raw material from waste*		
		imports of strategic raw materials *ensuring that, by 2030, the Union's annual consumption of each strategic raw material at any relevant stage of processing can rely on imports from several third countries or from overseas countries or territories and that no third ccounts for more than 65% of the Union's annual consumption of such a strategic raw material*		
		12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains,		
		3 EGD targets in TA3 and TA5		
		Reduce the generation of ***food waste in processing and manufacturing*** *by 10% in comparison to the amount generated in 2020*		Farm to Fork
		Reduce the generation of ***food waste per capita*** *jointly in retail and other distribution of food, in restaurants and food services and in households, by 30 % in comparison to the amount generated in 2020*		
		Reduce food waste. Prevent food loss and waste. Halve per capita ***at retail and consumer levels***		
		12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to		

minimize their adverse impacts on human health and the environment		
5 EGD targets in TA5, TA7		Farm to Fork
***Reduce nutrient losses** by at least 50%, while ensuring no deterioration on*		
Improve soil quality by reducing nutrient losses and chemical pesticides' use ***soil quality and pesticides***		Pollution
Improve soil quality by reducing nutrient losses and chemical pesticides' use ***water quality and pesticides***		
Improve water quality by reducing waste, *released into the environment (by 30%)*		
Reduce by 25% the EU ecosystems where		
12.5 By 2030, substantially reduce waste generation through prevention, reduction,		
*Recycling shall achieve at least the following targets for **recycling efficiency*** *No later than 31 December 2025* *75% by average weight of lead* *80% by average weight of nickel* *average weight of other waste batteries* *No later than 31 December 2030* *80% by average weight of lead*		
*Recycling shall achieve at least the following targets for **recycling efficiency*** *No later than 31 December 2025* *65% by average weight of* *No later than 31 December 2030* *70% by average weight of lithium*		
All recycling shall achieve at least the following targets for *No later than 31 December 2027* *90% for cobalt, copper, lead and nickel,* *No later than 31 December 2031:* *95% for cobalt, copper, lead, and nickel,*		
All recycling shall achieve at least the following targets for *No later than 31 December 2027* *No later than 31 December 2031:*		Industry & Circular Economy
Producers of SLI batteries, industrial batteries and electric vehicle batteries or producer responsibility organisations, shall take back, free of charge and without an obligation on the end user to buy a new battery, nor to have bought the battery from them, and shall ensure that *, waste industrial batteries and waste electric vehicle batteries regardless of their nature, chemical composition, condition, brand, or origin of the respective category that they have made available on th* *first time in the territory of that Member State are **collected separately***		
*Producers of portable batteries or producer responsibility organisations, shall attain, and maintain durably, at least the following collection targets for **waste portable batteries**: 45% by 31 December 2023; 63% by 31 December 2027; 73% by 31 December 2030.*		
*Producers of Light Means of Transport (LMT) batteries or producer responsibility organisations, shall attain, and maintain durably, at least the following collection targets of **waste LMT batteries**: 51 % by 31 December 2028; 61 % by 31 December 2031.*		
For industrial batteries with a capacity greater than 2kWh, except those with exclusively external storage, electric vehicle batteries and SLI batteries that contain cobalt, lead, lithium or nickel in active materials, the minimum		

		model per year and per manufacturing plant shall be: *From 18 August 2031, 16% cobalt; 85% lead; 6% lithium; and 6% nickel;* *From 18 August 2036, 26% cobalt; 85% lead; 12% lithium; and 15% nickel.*		
		Any natural or legal person that places on the market products incorporating shall ensure that those batteries are ***removable and replaceable*** *user at any time during the lifetime of the product. That obligation shall only apply to entire batteries and not to individual cells or other parts included in such batteries.*		
		placed on the market shall be		
		The plastic part in packaging shall contain the following minimum percentage consumer plastic waste, per packaging type and format: *(i) 30 % for contact sensitive packaging, except single use beverage bottles, made from polyethylene terephthalate (PET) as the major component;* *(ii) 10% for contact sensitive made from plastic materials other than PET, except single use plastic bottles;* *(iii) 30% for single use plastic beverage bottles;* *(iv) 35% for other plastic packaging.*		
		Member States shall take measures to achieve a sustained ***lightweight plastic carrier bags*** *sustained reduction is considered to be achieved if the annual consumption does not exceed 40 lightweight plastic carrier bags per person, or the equivalent target in weight, by 31 December 2025, and subsequently by 31*		
		Each Member State shall ***reduce the packaging waste generated*** *capita, as compared to the packaging waste generated per capita in 2018 by 5% by 2030; 10% by 2035; 15% by 2040.*		
		Member States shall take the necessary measures to attain the targets of 65% by weight of all generated by 2025; and of 70% by weight of all packaging waste generated by 2030.		
		Member States shall take the necessary measures to attain a target of 50% of plastic by weight of ***plastic contained in packaging*** *generated by 2025; and of 55% by weight of plastic in packaging waste generated by 2030.*		
		Member States shall take the necessary measures to attain a target of 25% of wood by weight of ***wood contained in packaging waste*** *generated by 2025 and of 30% by 2030*		
		Member States shall take the necessary measures to attain a target of 70% of ferrous metals by weight of ***ferrous metals contained in*** *generated by 2025 and of 80% by 2030*		
		Member States shall take the necessary measures to attain a target of 50% of aluminium by weight of ***aluminium contained in*** *generated by 2025 and of 60% by 2030*		
		Member States shall take the necessary measures to attain a target of 70% of glass by weight of ***glass contained in packaging waste*** *generated by 2025 and of 75% by 2030*		
		Member States shall take the necessary measures to attain a target of 75% of paper and cardboard by weight of ***paper and cardboard contained in packaging waste*** *generated by 2025 and of 85% by 2030*		
		belonging to a vehicle type [...] shall be constructed so that it is: ***reusable or recyclable*** *to a minimum of 85 % by mass;* *(b) reusable or recoverable to a minimum of 95 % by mass.*		
		plastic contained in each *type [...] shall contain a minimum of 25 % of plastic recycled by weight from post consumer plastic waste.*		
		At least 25% of the target shall be achieved by including in the vehicle type concerned.		

		Member States shall ensure that the following targets are met by the waste management operators: **reuse and recovery**, as calculated together, shall be a minimum of 95%, by average weight per , excluding batteries, and year; (b) the reuse and recycling, as calculated together, shall be a minimum of 85%, by average weight per vehicle, excluding batteries, and year.	green	
		Member States shall ensure that waste management operators achieve a yearly target for the recycling of plastics of at least 30 % of the total weight **plastics contained in the vehicles** delivered to the waste management	green	
		circular material use rate	red	
13 CLIMATE ACTION		13.2 Integrate climate change measures into national policies, strategies and		↗ | ↘
		20 EGD targets in TA1, TA2 and TA4		
		by 2050 (+ interim 2040 climate target) compared to 1990 levels, by 2030	yellow	
		methane emissions of 35% if compared to 2005 levels, by 2030	yellow	
		The contribution of the sectors covered by the existing ***EU Emission trading*** with respect to the EU Climate ambition should be of 62% compared to 2005 (increasing the linear emissions reduction factor from 2.2% per year up to 4.4%), by 2030	green	
		ETS2. Contribution of the ***buildings and road transport emission reductions*** by 2030 compared to 2005 and of the additional sectors, a combined cost efficient contribution of 42% emission reductions by 2030 compared to 2005	grey	
		ESR. Upgrade national targets in line with an EU ***reduction of 40% in*** compared to 2005. Member States contribute to the overall EU reduction in 2030 with targets ranging from level (sectors: transport, buildings, agriculture and waste)	yellow	
		greenhouse gas removal for the land use, land use change and forestry (	red	
		. For the period from 2021 to 2025 each ensure that greenhouse gas emissions from the sector do not exceed greenhouse gas removals, calculated as the sum of total emissions and total removals on its territory in all of the land accounting categories. The accounting benchmark for the EU i	yellow	
		MS specific targets. A budget for each Member State for the years 2026 2029, based on a linear trajectory between 2022 (as an average of 2021	grey	
		Methane emissions related to energy production and consumption should be reduced by 58% compared to the level in 2020	yellow	Energy
		of renewable fuels and renewable electricity supplied to the (i) share of renewable energy within the final consumption of energy in the transport sector of at least 29 % by 2030; or ***greenhouse gas intensity reduction*** of at least 14,5 % by 2030, compared to the baseline, in accordance with an indicative trajectory set by	yellow	
		energy neutrality in the wastewater treatment sector by 2040. To reach energy neutrality and the additional treatment of nitrogen, GHG emissions would be reduced by 4.86 million tonnes (37.32 % of the avoidable emissions from the sector)	green	
		Reduce buildings' greenhouse gas (compared to 2015), and reach climate neutrality by 2050	yellow	
		emissions of transport sector	yellow	

	during a reporting period shall be reduced, compared to the reference value eq/MJ) by: 2 % from 1 January 2025; 6 % from 1 January 2030; 14.5 % from 1 January 2035; 31 % from 1 January 2040; 62 % from 1 January 2045; 80 % from 1 January 2050.		
	Aviation fuel suppliers shall ensure that all aviation fuel made available to aircraft operators at each Union airport contains the **minimum shares of Sustainable Aviation Fuels (SAF)**. The share of SAF should be from 2025, each year a minimum of 2%, from 2030 a minimum of 6%, from 2035 a minimum of 20%, from 2040 a minimum of 34%, from 2045 a minimum of 42%, from 2050 a minimum of 70%		
	Of the SAF targets reported above, **synthetic aviation fuels** represent a minimum share of 1.2% from 2030, 5% from 2035, 10% from 2034, 15% from 2045, and 35% from 2050.		
	quantity of aviation fuel uplifted by a given aircraft operator at a given Union airport shall be at least 90% of the yearly aviation fuel required, to avoid tankering practices which would bring additional emissions		Mobility
	road special purpose vehicles shall be reduced by the following percentages compared to the average CO emissions of the reporting period of the year 2019: LH for the reporting periods of the years 2025 to 2029; (b) 45% for all vehicle sub groups other than vocational vehicles for the (c) 65% for all vehicle sub groups for the years 2035 to 2039; (d) 90% for all vehicle sub groups for the year 2040 onwards.		
	" manufacturers shall comply with the 90% (in the 2034) and 100% (as from 2035) minimum their fleet of new heavy		
14 LIFE BELOW WATER	14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans		
	coastal and freshwater ecosystems		
	Member States shall put in place the restoration measures that are necessary **improve to good condition areas of habitat types** good condition. Such measures shall be in place: (a) on at least 30% by 2030 of the total area of all habitat types listed in Annex I that is not in good condition; (b) on at least 60% by 2040 and on at least 90% by 2050 of the ch group of habitat types listed in Annex I that is not in good		
	Member States shall put in place the restoration measures that are necessary **establish the habitat types** listed in Annex I in areas not covered by those habitat types with the aim to reach their favourable reference area. Such measures shall be in place on areas representing at least 30% of the additional overall surface needed to reach the total favourable of each group of habitat types listed in Annex I, by 2030, at least 60% of that surface by 2040, and 100% of that surface by 2050.		Bio diversity
	Member States shall put in place the **restoration measures for coastal and freshwater habitats** of the species and of the terrestrial, coastal and freshwater habitats of wild birds that are, in addition to the restoration measures, necessary to improve the quality and quantity of those habitats, including by re establishing them, and to enhance ctivity, until sufficient quality and quantity of those habitats is achieved.		
	Member States shall ensure that there is: (a) an **increase of habitat area** for habitat types listed in Annex I until at least 90% is in good condition and until the favourable reference area for each habitat type		

		in each biogeographic region of the Member State concerned is reached; (b) an increasing trend towards the sufficient quality and quantity of the terrestrial, coastal and freshwater habitats of the species.		
		Marine ecosystems		
		Member States shall put in place effective and area with the aim to jointly cover, as a Union target, throughout the areas and ecosystems, by 2030, at least 20% of restoration and, by 2050, all ecosystems in need of restoration		
		Member States shall put in place the restoration measures that are necessary ***improve to good condition areas of habitat types*** *which are not in good condition. Such measures shall be in place: (a) on at least 30% by 2030 of the total area of groups 1 6; (b) on at least 60% by 2040 and on at least 90% by 2050 of the area of each of the groups 1 t two thirds of the percentage by 2040 of the area of group 7 of*		
		Member States shall put in place the restoration measures that are necessary ***establish the habitat*** *6 in areas, at least 30% of that surface by 2030, at least 60 % by 2040, and 100 % by 2050.*		
		14.4 By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science based management plans, in order to restore fish stocks in the shortest time least to levels that can produce Maximum Sustainable Yield (MSY) as determined by their biological characteristics		
		In accordance with the CFP, it is crucial to continue and accelerate the work of rebuilding and keeping **fish stocks above MSY levels**		Bio diversity
		14.5 By 2020, conserve at least 10 cent of coastal and marine areas, consistent international law and based on the best available scientific		
		a minimum of 30% of the		Bio diversity
		Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve to enhance the contribution of marine biodiversity to the development of developing countries		
		for at least 90% of area distributed overall habitat types listed in Annex I by 2030 and 100% by 2040.		
		) Member States shall ensure, by 2030 at the latest, that for at least 50% of the area distributed over all habitat types listed in groups 1 6. The condition of all areas of groups 1 habitat types shall be known by 2040. Member States shall also ensure, by 2040 at the latest, that the condition is known for at least 50% of the area distributed over all habitat types listed in group 7. The condition of all areas of group 7 of habitat types shall be known by 2050.		Bio diversity
15 LIFE ON LAND		15.1 By 2020, ensure the conservation, restoration and sustainable use of and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements		
		Member States shall put in place effective and area with the aim to jointly cover, as a Union target, by 2030, at least ***of land areas in need of restoration*** *and, by 2050, all ecosystems in*		Bio diversity
		Member States shall put in place the restoration measures that are necessary ***improve to good condition areas of habitat types*** *good condition. Such measures shall be in place: (a) on at least 30% by 2030*		

		of the total area of all habitat types listed in Annex I that is not in good condition; (b) on at least 60% by 2040 and on at least 90% by 2050 of the area of each group of habitat types listed in Annex I that is not in good		
		Member States shall put in place the restoration measures that are necessary ***establish the habitat types*** *listed in Annex I in areas not covered by those habitat types with the aim to reach their favourable reference area. Such measures shall be in place on areas representing at least 30% of the additional overall surface needed to reach the total favourable of each group of habitat types listed in Annex I, by 2030, at least 60% of that surface by 2040, and 100% of that surface by 2050.*		
		Member States shall put in place the ***restoration measures for terrestrial, coastal and freshwater habitats*** *of the species and of the terrestrial, coastal and freshwater habitats of wild birds that are, in addition to the restoration measures, necessary to improve the quality and quantity of those habitats, including by re establishing them, and to enhance ctivity, until sufficient quality and quantity of those habitats is achieved.*		
		Member States shall ensure that the area distributed overall habitat types listed in Annex I by 2030 and 100% by 2040 (terrestrial, coastal and freshwater ecosystems)		
		Member States shall ensure that there is: (a) an ***increase of habitat area*** *for habitat types listed in Annex I until at least 90% is in good condition and until the favourable reference area for each habitat type in each biogeographic region of the Member State concerned is reached; (b) an increasing trend towards the sufficient quality and quantity of the terrestrial, coastal and freshwater habitats of the species.*		
		a minimum of 30% of the		
		Strictly protect at least a third of the ***EU'S protected areas***		
		Strictly protect all remaining ***EU primary and old***		
		15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally		
		When identifying and implementing the restoration measures, Member States shall aim to contribute to the commitment of		
		Member States shall achieve an increasing trend at national level of at least six out of seven of the following indicators of biodiversity of within the Member State concerned.: (a) standing deadwood (b) lying deadwood (c) share of forests with uneven aged structure; (d) forest connectivity; (e) stock of organic carbon; (f) share of forests dominated by native tree species; (g) tree species div		Bio diversity
		Member States shall achieve an increasing trend at national level of the ***common forest bird index***		
		15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land		
		3 EGD targets in TA6 and TA7		
		Member States shall put in place measures which shall aim to constituting drained peatlands, on at least: (a) 30% of such areas by 2030, of which at least a quarter shall be rewetted; (b) 40% by 2040, of which at least a third rewetted; (c) 50% by 2050, of which at least a third rewetted.		Bio diversity
		Reach no net land take		
		Have all soils in healthy condition by 2050		Pollution

		15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species		
		Member States shall improve pollinator diversity and ***reverse the decline of pollinator populations*** *at the latest by 2030 and achieve thereafter an increasing trend of pollinator populations.*		Bio diversity
		Member States shall put in place restoration measures to ensure that the ***common farmland bird index*** *at national level reaches the following levels: (a) 110 by 2030, 120 by 2040 and 130 by 2050, for Member States listed in Annex V with historically more depleted populations of farmland birds; (b) 105 by 2030, 110 by 2040 and 115 by 2050, for Member State Annex V with historically less depleted populations of farmland birds.*		

Assessment of progress towards the EGD

- Target on track to being achieved
- Progress but insufficient to meet the target
- No progress or moving away from the target
- data or insufficient for assessment

Progress towards the SDGs in relation to EGD targets

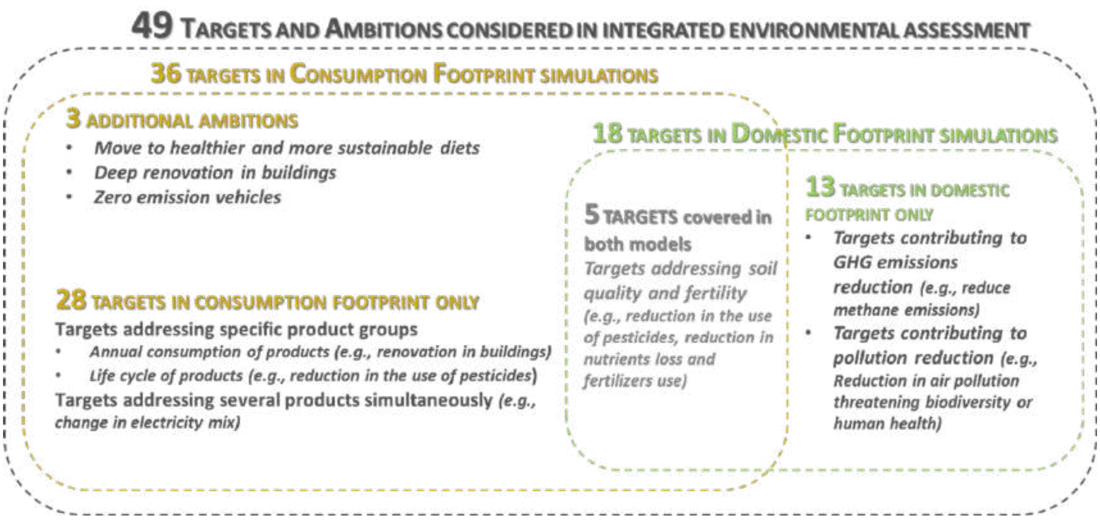
- Coexisting improvements and challenges

Source: Authors' elaboration.

Annex III. How EGD targets contribute to SDGs

The JRC stock-taking exercise on progress towards the EGD [8] is based on 154 EGD targets retrieved in both legally binding and non-legally binding policy documents. They have been classified depending on their progress in three categories:
(1) **on track to be achieved**, if the observed progress follows a positive trend and is expected to be achieved by 2030,
(2) **acceleration needed**, when progress is observed, but this is not sufficient to reach the target by 2030,
(3) **no progress**, i.e. the target is not expected to be achieved, and no positive progress is expected by 2030.
Of these targets, a total of **49 targets and ambitions** were modelled for the purpose of this chapter, i.e. evaluating expected environmental impacts of different clean transition scenarios in light of selected policy targets (Note that in the reference study [329], the authors have modelled an additional target relative to landfilling, which is already embedded in other targets linked to circular economy). First, **a pool of 46 targets** (hereafter referred to as Green Transition Targets - GTT) were taken into consideration for the present quantitative exercise. These include **33** targets modelled in the Consumption Footprint (CF), **18** targets modelled in the Domestic Footprint (DF), and **5** targets considered in both models. In addition, **3 ambitions** (i.e., aspirational objectives of selected EGD policies, not strictly quantifiable in their wording but considered in the JRC progress report on the EGD) were included in the CF model assessment as shown in **Figure 31** and in **Table 6**.
The selection of targets for this integrated environmental assessment considered the following: 7 targets could not be estimated quantitatively, 35 did not relate to environmental aspects which are under the scope of the model, 47 could not be modelled due to a lack of product disaggregation in the model (e.g., cover heavy duty transport as part of the transportation of other products, but not specifically modelled as products themselves), 27 could not be considered as not covered by the Environmental Footprint indicators (e.g., overfishing), and 5 were deemed not relevant due to the timeline (e.g., new EUR7 requirements). While some targets could be modelled in the sub-components of the different areas of consumption of food, mobility, and housing, **19** targets were considered as cross cutting, thus covering more than one area of consumption.
It is worth noting that the CF and DF models produce complementary indicators. Specifically, the DF is based on a collection of environmental statistics on EU territory. Instead, the CF model is based on 164 representative products with associated environmental impacts of their whole supply chains. In so doing, some targets can be covered in one model and not in the other, with greater granularity for product oriented targets in the CF model (e.g. housing consumption reduction, but without capturing the climate target as a whole), and with more aggregated targets (e.g. model total GHG reduction without giving conclusion on specific sectors such as housing) using the DF model.

Figure 31. Overview of the 49 selected clean transition targets and additional ambitions modelled in the CF and DF for this integrated environmental assessment.



Source: [329]

Table 6. EGD Green transition targets and ambitions modelled, by thematic area (TA) and area of consumption.

Policy Thematic Areas	Areas of Consumption in the Consumption Footprint model				Domestic Footprint	Total targets by TA
	Food	Housing	Mobility	Cross cutting		
Climate					7 targets (carbon emission)	7
Energy		4 targets (energy use in buildings, renovation wave)		7 targets (renewables in the energy mix, wind solar, geothermal energy expansion)	1 target (emissions of buildings)	12
Circular economy				12 targets (recycling material in batteries, recycling of packaging including PET bottles)		12
Mobility			2 targets (sustainable fuel in aviation and road transport)		2 targets (emissions of transport, and heavy duty vehicles)	4
Food system	4 targets (pesticides reduction, food waste related)				(+2) targets (pesticides reduction*)	4
Biodiversity	3 targets (organic farming expansion, fertilisers and nutrient losses reduction)				1 (+2) targets (no net land take, fertilisers and nutrient losses reduction*)	4
Zero pollution	1 target (reduction in pesticides)				2 (+1) target (improve air quality, ecosystem services, reduction in pesticides*)	3
Additional Clean transition Ambitions	1 ambition (sustainable and healthy diets)	1 ambition (achieving deep renovation in buildings)	1 ambition (expansion of electric cars)			3
Total targets by area of consumption	9	5	3	19	13 (+5)	49

Source: Authors' elaboration. Note: some of the targets in the Domestic Footprint model (the ones in brackets) are also represented in the Consumption footprint model and are in common in different thematic areas, thus are counted only once.

The inclusion in the various scenarios of the **18 targets** modelled in the DF is shown in **Table 7** with additional detail provided in Annex 3 of [329]. It is worth noting that **3 targets** linked to the reduction in use of pesticides, **2 targets** for the reduction of air pollution and their impact on human health and ecosystems are assumed to be achieved in the **GTT on Track** scenario, and **4 targets** linked **to reduction in nutrient loss, reduction in fertilizer use, land use change,** and **10 targets** linked to **climate neutrality** are included in the **GTT ambitions** scenario. It is worth noting that the **No GTT** scenario may, or may not, achieve the targets that are included in the other scenarios due to the assumptions where **No GTT** follows past trend which show declining rates already in the historical data. For example, the continuation of trends in the impact category Acidification may be reached already in the No GTT scenario.

Table 7. Modelled green transition targets in the Domestic Footprint.

Modelled Target in Domestic Footprint	**Status [8]**	**Legally binding**	**GTT on track**	**GTT ambitions**
Reduce by 50% the use and risk of chemical pesticides (*Due to the large coverage of this target in different policy documents, it embeds the modelling of 3 GTT as detailed in Annex 3 of [329]*)	On track to be achieved	No	X	X
Improve air quality to reduce the number of premature deaths caused by air pollution by 55%.	On track to be achieved	No	X	X
Reduce by 25% the EU ecosystems where air pollution threatens biodiversity	On track to be achieved	No	X	X
Reduction of 55% greenhouse gas (GHG) emissions compared to 1990 levels (*Due to the large coverage of this targets it embeds the modelling of 10 GTT as detailed in Annex 3 of [329]*)	Acceleration needed	Yes		X
Reach no net land take	No progress	No		X
Reduction of 50% of nutrient losses	Acceleration needed	No		X
Reduction of 20% of the use of fertilizers	Acceleration needed	No		X

Source: Authors' elaboration.

The CF is a full bottom-up LCA model, meaning it relies on supply chain perspective which models the different life cycle stages (from extraction to end of life) of every product, to model the environmental impact of a unit of that product. Such value is multiplied by the annual consumption of a product which provides a macroscale perspective on the environmental impact of consumption. While the annual consumption is projected to 2030 with the method described in Annex 4 of [329], the life cycle inventory of the model is equipped with parameters that control the allocation of resources along life cycle stages, and can be varied to test different scenarios as well as uncertainties. For example, the production of food products requires certain quantities of pesticides per kilogram of output, which leads to the associated emissions to land as well as environmental impact due to the manufacturing and supply of those pesticides.

As a result, the modelling of the No GTT scenario assumes the continuation of trends of annual consumption on the one side, while it considers the parameters controlling the environmental impacts in the life cycle inventory of the models as non-influential to past performance, thus providing a reference condition in 2030 as if no clean transition policy efforts were considered. These parameters are activated in the GTT on track and GTT ambitions scenarios, thus describing the achievement of the selected targets presented that are detailed in the tables below and in Annex 4 of [329].

Mobility. In the context of mobility, 3 targets are considered, and are cumulatively included one per scenario (Table 8). The achievement of targets on advanced biofuels and biogas in GTT on track scenario, and the targets on sustainable aviation fuels and the ambition of achieving 30 million electric cars on the road is considered in the GTT ambitions scenario.

Food. A total of 9 green transition targets and ambitions are modelled in the food basket of products of the CF model (Table 9). The reduction in use of pesticides (which covers 4 targets due to its presence in different policy documents) is included in the GTT on track scenario, and 6 targets linked to reduction in nutrient loss, expansion of organic farming, reduction in food waste, as well as the move to a healthier and more sustainable diet ambition are included in the GTT ambitions scenario.

Housing. In the context of housing, 5 targets and ambitions are considered (Table 10). One target linked to the use of renewable energy in buildings was considered to be achieved in the GTT on track scenario, and 4 targets that represent the ambition of *Renovation Wave* (i.e., reducing final energy and heat energy consumption in buildings, as well as increasing the rate of expansion of energy efficient building until achieving deep renovation in 35 million building) were modelled in the GTT+ scenario. It is worth noting that the use phase (e.g. space heating) of housing represents the major hotspot for the environmental impact of buildings for livelihood, leading to the greatest opportunity for clean transition at the EU level.

Cross cutting: energy, transport, waste treatment, recycling and packaging. Table 11 shows the 19 cross-cutting targets (i.e., targeting more than one basket of products in the CF). Due to the high importance of energy and circular economy for environmental impact 5 targets linked to energy expansion and recycling are considered as on track to be achieved, and included in the GTT on track scenario. Specifically, the changes in energy mix due to the expansion of renewable energy, with high promises for solar energy is a major driver of the impacts in the analysis of this scenario, as well as they impact all basket of products, and specifically in their production and manufacturing life cycle stages. On the other hand, the GTT+ scenario also assumes the achievement of circular economy intervention which target the recycling of packaging made in plastic as well as sub-products (e.g., batteries in cars and phones), policies which influence landfill and incineration of wasted products, as well as further expansion of renewable energy and wind energy as part of the renewable energy mix.

Table 8. Modelled green transition targets in the Mobility Basket of Products of the Consumption Footprint.

Modelled Target in Consumption Footprint	Status [8]	Legally binding	GTT on track	GTT ambitions
Each Member State shall set an obligation on fuel suppliers to ensure that: the combined share of advanced biofuels and biogas produced from the feedstock listed in Part A of Annex IX and of renewable fuels of non-biological origin in the energy supplied to the transport sector is at least 1 % in 2025 and 5,5 % in 2030	On track to be achieved	Yes	X	X
Starting from 2025, at least 2% of aviation fuels will be green, with this share increasing every five years: 6% in 2030, 20% in 2035, 34% in 2040, 42% in 2045 and 70% in 2050. Hydrogen and fuel produced from cooking oil or waste gases considered green	No progress	Yes		X
There will be at least 30 million zero-emission cars and 80.000 zero-emission lorries in operation	Not considered	No (ambition)		X

Source: Authors' elaboration.

Table 9. Modelled green transition targets in the Food Basket of Products of the Consumption Footprint.

Modelled Target in Consumption Footprint	Status [8]	Legally binding	GTT on track	GTT ambitions
Reduce by 50% the use and risk of chemical pesticides (*Due to the large coverage of this target in different policy documents, it em*beds the modelling of 3 GTT as detailed in Annex 4 of [329])	On track to be achieved	No	X	X
Reduce the generation of food waste in processing and manufacturing by 10% in comparison to 2020	Acceleration needed	Yes (2026 update)		X
Reduce the generation of food waste per capita, jointly in retail and other distribution of food, in restaurants and food services and in households, by 30 % in comparison 2020.	Acceleration needed	Yes (2026 update)		X
Increase organic farming with the aim to achieve at least 25% of total farmland under organic farming by 2030	Acceleration needed	No		X
The losses of nutrients from fertilisers are reduced by 50%, resulting in the reduction of the use of fertilisers by at least 20% (*Due to the large coverage of this target in different policy documents, it embeds the modelling of 2 GTT as detailed in Annex 4 of [329]*)	Acceleration needed	No		X
Move to healthier and more sustainable diets	Not considered	No (Ambition)		X

Source: Authors' elaboration.

Table 10. Modelled green transition targets in the Housing Basket of Products of the Consumption Footprint.

Modelled Target in Consumption Footprint	Status [8]	Legally binding	GTT on track	GTT ambitions
Member States shall determine an indicative national share of renewable energy produced on-site or nearby as well as renewable energy taken from the grid in final energy consumption in their building sector in 2030 that is consistent with an indicative target of at least a 49 % share of energy from renewable sources in the building sector in the Union's final energy consumption in buildings in 2030	No data	Yes		X
Reduce buildings' final energy consumption by 14%	Acceleration needed	No		X
Reduce buildings' energy consumption for heating and cooling by 18%	Acceleration needed	No		X
At least double the annual energy renovation rate of residential and non-residential buildings by 2030 and to foster deep energy renovations	Acceleration needed	No		X
Indicative national targets aiming to achieve the deep renovation of at least 35 million building units by 2030 to support reaching an annual energy renovation rate of 3 % or more for the period till 2050	Not considered	No (ambition)		X

Source: Authors' elaboration.

Table 11. Modelled green transition targets in the energy, transport and waste treatment of the Consumption Footprint.

Modelled Target in Consumption Footprint	Basket of Products	Status [9]	Legally binding	GTT on track	GTT ambi-tions
Bring online over 320 GW of solar photovoltaic by 2025 and 600 GW by 2030	Food, Mobility, Housing, Appliances, Household goods	On track to be achieved	No	X	X
Over this decade, the EU will need to install, on average, approximately 45 GW per year of PV to reach the share of 45% of energy coming from renewables set out in the RePowerEU Plan	Food, Mobility, Housing, Appliances, Household goods	On track to be achieved	No	X	X
Recycling shall achieve at least the following targets for recycling efficiency: […] No later than 31 December 2030 80% by average weight of lead-acid batteries.	Mobility, Appliances	On track to be achieved	Yes	X	X
All recycling shall achieve at least the following targets for recovery of materials. […] No later than 31 December 2031: (iii) 95% for cobalt, copper, lead, and nickel.	Mobility, Appliances	On track to be achieved	Yes	X	X
Recycling of aluminium in packaging: 60% Recycling of ferrous metals in packaging: 80% Recycling of glass in packaging: 75% Recycling of paper and cardboard in packaging: 85% Recycling of wood in packaging: 30%	Food, Appliances, Household goods	On track to be achieved	No	X	X
By 2030, the share of renewable energy in the electricity mix should double to 55-60%, and projections show a share of around 84% by 2050. The remaining gap should be covered by other low-carbon options	Food, Mobility, Housing, Appliances, Household goods	Acceleration needed	No		X
Energy demand to be covered by solar heat and geothermal should at least triple (currently rate at 1,5%)	Food, Mobility, Housing, Appliances, Household goods	Acceleration needed	No		X
Member States shall collectively ensure that the share of energy from renewable sources in the Union's gross final consumption of energy in 2030 is at least 42,5%.	Food, Mobility, Housing, Appliances, Household goods	Acceleration needed	No		X
The strategy sets targets for an installed capacity of at least 60 GW of offshore wind by 2030.	Food, Mobility, Housing, Appliances, Household goods	Acceleration needed	No		X
Recycling shall achieve at least the following targets for recycling efficiency: […] No later than 31 December 2030 70% by average weight of lithium-based batteries.	Mobility, Appliances	Acceleration needed	Yes		X
Recycling or preparing for re-use 65% of all packaging waste by 2025, 70% by 2030 (*Due to the large coverage of this target in different policy documents, it embeds the modelling of 4 GTT as detailed in Annex 4 of [329]*)	Food, Appliances, Household goods	Acceleration needed	Yes		X

Source: Authors' elaboration.

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