100% RENEWABLE ENERGY: An Energy [R]evolution for ITALY

2020

Institute for Sustainable Futures

ABOUT THE AUTHORS

The Institute for Sustainable Futures (ISF) was established by the University of Technology Sydney in 1996 to work with industry, government, and the community to develop sustainable futures through research and consultancy. Our mission is to create change towards establishing sustainable futures that protect and enhance the environment, human well-being, and social equity. We use an inter-disciplinary approach to our work and engage our partner organisations in a collaborative process that emphasises strategic decision-making.

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ENERGY MODELS

The utility-scale solar photovoltaic and wind power potentials were mapped with [R]E-SPACE, a mapping tool developed by the Institute for Sustainable Futures of the University of Technology Sydney (ISF-UTS) based on QGIS (open source).
The long-term energy scenario software for the long-term projections and economic parameters is based on the development of the German Aerospace Centre (DLR), Institute for Technical Thermodynamics, (Pfaffenwaldring 38-40, 70569 Stuttgart, Germany) and has been applied to over 100 energy scenario simulations for global, regional, and national energy analyses.
Regional *Power Analysis* calculated with [R]E 24/7 was developed by Dr. Sven Teske (PhD), with further developments by ISF-UTS.

CITATION

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All conclusions and any errors that remain are the authors' own.

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SUMMARY FOR POLICY MAKERS

The aim of this report is to explore accelerated decarbonization pathways and to analyse their costs, employment effects, and possible implications for critical issues.

This analysis also aims to develop a possible pathway for Italy that supports a European Union (EU)-wide energy decarbonization that is ambitious enough to maintain the global temperature rise at +1.5 °C, as agreed under the Paris Climate Agreement of 2015. To achieve this, the cumulative EU CO_2 budget for the energy sector until 2050 must not exceed 44 Gt (Teske et. al 2019). To comply with this EU target, Italy's CO_2 budget would be 4.7 Gt CO_2 until 2030, and will require the full decarbonization of the energy sector by 2040.

The impact of the COVID-19: This analysis started in July 2019 has been completed mid-February 2020. The completion of the scenario research coincided with the record of the first cases of COVID-19 in Italy. By the 10th of March, Italy started a 10-week long lock-down which has a significant impact on the energy sector. At the time of writing – 9th June 2020 – official statistic for the entire time of the lock-down are not available.

However, the impact of the first weeks lock-down in March 2020 are published by the Italian National Energy Agency ENEA[1]. According to ENEA, the first 3 weeks of the 10 week lock-down reduced the electricity demand by 20%, the gas demand by 30% and the demand for gasoline and diesel – for the transport sector – by 43%. Italy's GDP is estimated to contract by 8.3% for 2020 and increase in 2021 by 4.6%. Based on this, we estimated the effect on the whole year of 2020 will lead to a reduced electricity demand of -23%, for heating (gas) -25% and the demand for transport will be minus 27%.

For the following year, we assume that the demand will go back to previous years minus the energy efficiency estimated for the years 2020 to 2025 under the three scenarios.

In this analysis, we have taken Italy's Climate and Energy Plan (PNIEC 2018) as the ***REFERENCE*** scenario and developed two more-ambitious scenarios, both with a 100% renewable energy target:

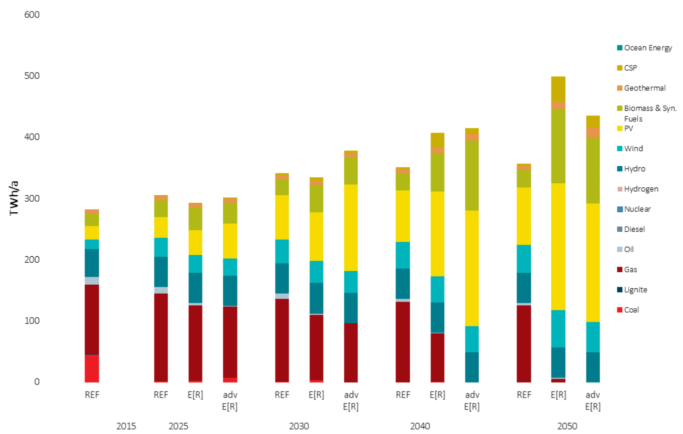
The ***Energy [R]evolution*** scenario will lead 100% renewable electricity and the complete decarbonization of the energy sector by 2050. By 2030, Italy's renewable electricity share will increase to 66%, and the renewable final energy share will reach 33%.

The ***Advanced Energy [R]evolution*** scenario is an accelerated pathway that will achieve 75% renewable electricity by 2030 and will decarbonize the electricity sector by 2040. The share of renewable final energy will increase from the current 16% to 52% in 2030 and to 100% in 2040. The Advanced Energy [R]evolution, which reflects the Greenpeace demands, will require more-ambitious efficiency and renewable energy programs than are currently suggested in the Italian Climate and Energy Plan (PNIEC 2018). Furthermore, the utilisation of gas will be significantly lower under the advanced scenario than under PNIEC.

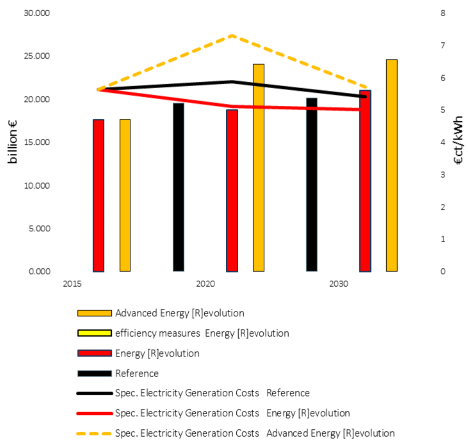
In terms of the investments required to implement the analysed scenarios, the REFERENCE scenario will require €7.35 billion, the Energy [R]evolution €7.9 billion, and the Advanced Energy [R]evolution €10.1 billion per year. The average generation costs of the REFERENCE scenario and the Advanced Energy [R]evolution will be similar by 2030, whereas the Energy [R]Evolution scenario will be the most economic scenario, with costs of around €0.05 per kilowatt-hour, about €0.01 below those of the other scenarios.

[1] ENEA – Impact of COVID-19 on Italy's energy sector (Italian): https://www.enea.it/it

Italy—Development of electricity generation structure: Reference, Energy [R]evolution, and Advanced Energy [R]evolution scenarios

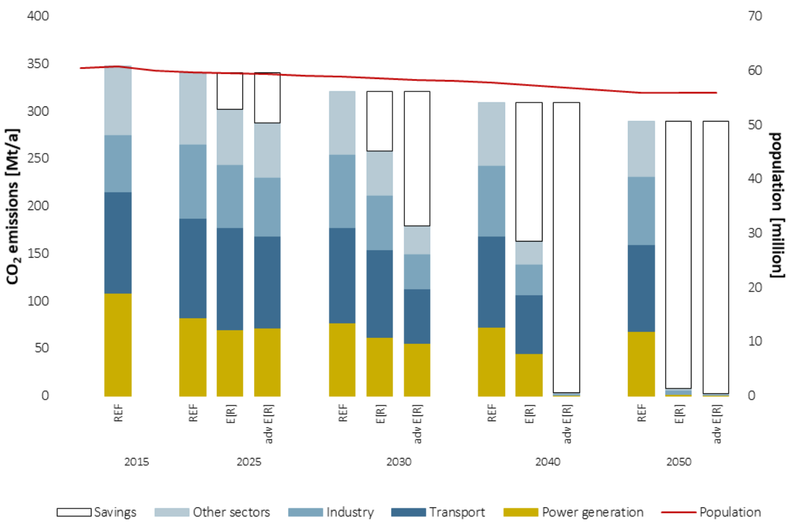


Italy—Development of total electricity supply costs and average generation costs under the three scenarios



Italy's cumulative energy-related CO_2 emissions over the entire scenario period (2015–2050) under the REFERENCE scenario will be 11.6 Gt CO_2, but 7.8 Gt CO_2 under the Energy [R]evolution scenario and 5.7 Gt CO_2 under the Advanced Energy [R]evolution scenario. Thus, the advanced scenario will halve Italy's total remaining carbon emission and fulfil the Paris Climate Agreement to remain "well under 2.0 °C".

Italy's annual energy-related CO_2 emissions under the three scenarios



Employment: The REREFENCE scenario will result in a slight increase in employment in the energy sector, from 88,000 currently to 98,000 in 2030, whereas the Energy [R]evolution scenario will increase it to 37,000 and the advanced scenario to 65,000 addition jobs compared with the REF scenario. The total employment in Italy's energy sector will reach 163,000 people under the Advanced Energy [R]evolution scenario by 2030.

Security of supply

Both Energy [R]evolution scenarios prioritize the use of Italy's renewable energy resources to reduce its dependence on energy importation and to utilize local resources. Italy will increase its power demand under each power generation scenario as a result of the implementation of electric mobility, although this is currently at a low level. Therefore, power grids must expand and power generation must increase as the load increases, under both a conventional power generation pathway and a renewable-power-dominated pathway.

Conclusion

The authors of this analysis see no substantial technical or economical barriers to implementing a more ambitious climate and energy plan, such as either Energy [R]evolution scenario. However, their successful implementation will require significant policy changes to fast track renewable project developments, especially with regard to construction permits and grid connections.

The impact of COVID-19 for the energy balance 2020 will be substantial. Table 1 shows the estimated impact on Italy's energy demand by sector for the year 2020. Our assumption is, that the documented energy demand reduction for the first 3 weeks of the lock-down in March 2020 applies for the entire 10 weeks of this measure and that the demand will "normalize" to the demand of the previous year for the rest of the year. Between 2021 and 2025, the COVID-19-related energy reduction effects will largely be offset so that in 2025 the scenario trend (REF, E [R], ADV. E [R]) that has been adopted takes effect again.

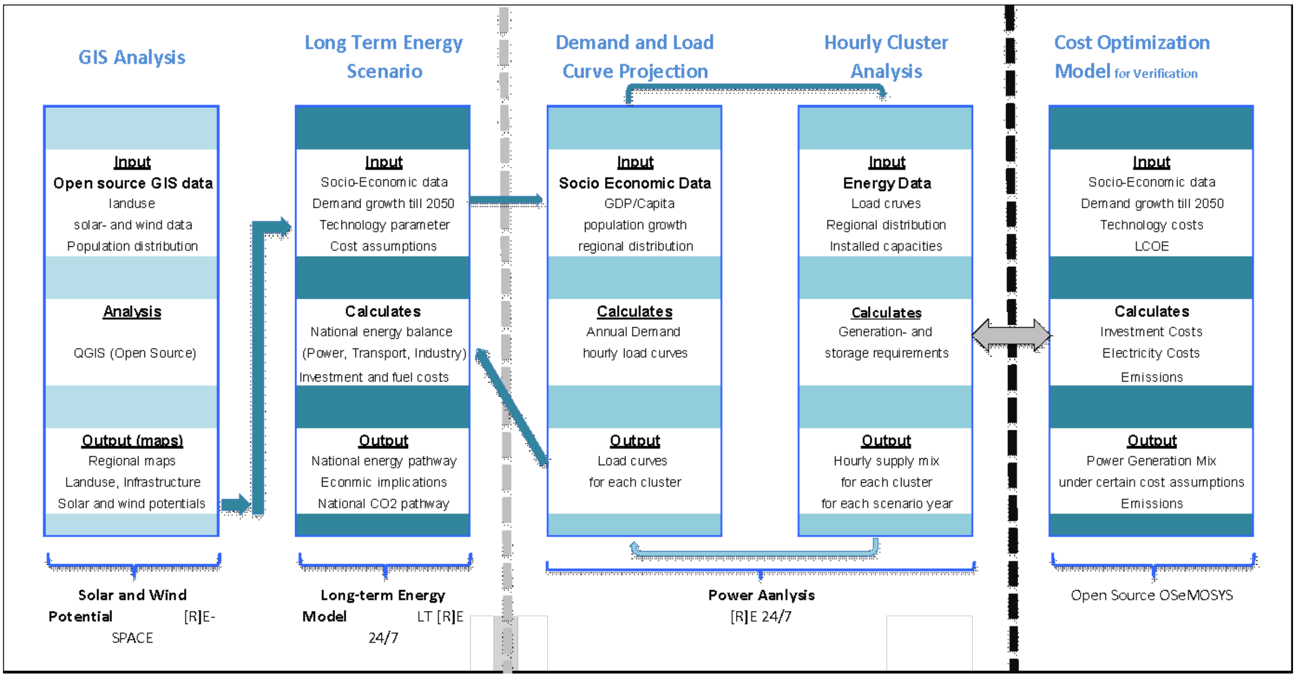
Table 1: Estimated impact of COVID-19 on Italy's energy demand in 2020

Final Energy Demand [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020
Total (incl. non-Energy use)	4,970	5,135	3,925
Total Energy use 1)	4,694	4,815	3,604
Transport	**1,523**	**1,540**	**1,116**
Industry	**1,045**	**1,078**	**819**
Other Sectors	**2,126**	**2,198**	**1,669**
Non energy use	**277**	**320**	**320**

TECHNICAL SUMMARY

Greenpeace Italy commissioned this report to provide input into Italy's plan to phase-out coal by 2025. The research was led by the University of Technology Sydney–Institute for Sustainable Futures (UTS-ISF). This report provides a technical and economic analysis of long-term energy and power development plans for Italy. The analysis is based on the [R]E24/7 energy access pathway methodology developed by the Institute for Sustainable Futures (ISF) at the University of Technology Sydney (UTS) and is based on the long-term energy scenario model of the Institute for Thermodynamics of German Aero Space Centre (DLR), energy models developed for various UTS-ISF surveys, and the [R]E 24/7 model.
Figure 1 provides an overview of the models used and their interactions.

Figure 1: Overview—Modelling concept



In the mapping analysis, a global information system (GIS) was used for the regional analysis of Italy's population density and distribution, its solar and wind resources, and the currently existing energy infrastructure (transmission power lines and power plants with over 100 MW installed capacity). This information has been used to define the cluster breakdown.

The long-term scenario—LT [R]E 24/7—has been used to re-model the existing PNIEC (see section 1) and to develop alternative national energy pathways for Italy. This model considers all sectors (power, heat, and transport) and includes cost and energy-related CO_2 calculations.

The [R]E 24/7 power sector analysis tool computes the annual demand for up to five different years (here 2020, 2030, 2040, and 2050) and the load curves for a full year (8760 h). The hourly load curves are required for the simulation of the demand and supply for each of the six market regions of Italy. The results are the development of loads, generation mix, and storage demand.

Limitations
Calculated loads are not optimised in the regard to local storage, self-consumption of decentralised producer of solar photovoltaic electricity and demand side management. Thus, calculated loads may be well below the actual values.

Socio-economic data

In 2017, Italy had a population of 60.6 million[2] and a population density of 205 persons per square kilometre[3]. Between 1950 and 1986, the population grew from 46 million to 56 million and remained at that level until 2000. The population grew again by around 2.4 million until 2010. According to the projection of Eurostat, the population of Italy will decrease slightly on average by 0.2% per year until 2035. Based on these estimates, the population will decrease to 55.8 million by 2050 (see Table 1). Italy's economic development over the past decade has been characterized by recurrent positive and negative economic growth. However, since 2013, Italy's economy has grown around 1% per year, with the exception of 2018, in which the GDP dropped by 0.8%[4]. For 2019, the economic growth rate is projected to be just positive[5]. The long-term projection for GDP from 2020 until 2050 (Table 1) is based on estimates of the EU Reference Scenario 2016 (PRIMES 2016)[6], updated data for the years 2016–2019.

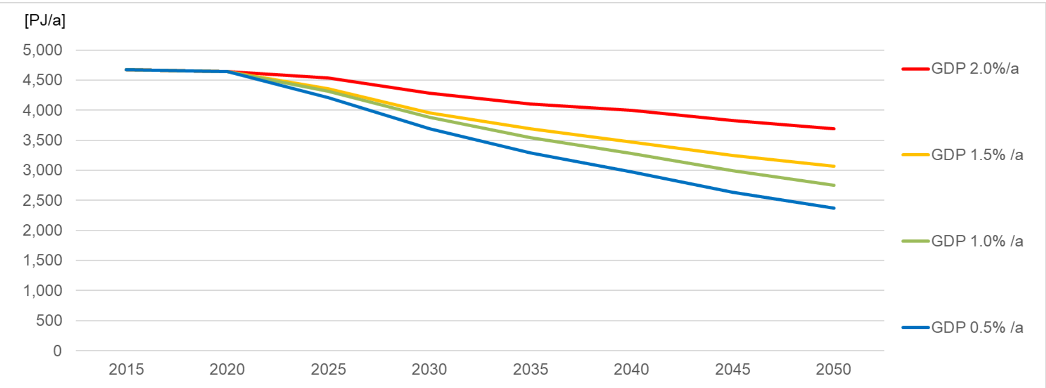
Projections of population and economic growth are important factors in the development of energy scenarios because they affect the size and composition of the energy demand, both directly and through their impact on economic growth and development. The effects of different GDP growth rates are shown in Figure 2.

Table 2: Italy–Population and GDP projections

	t	2017	2020	2025	2030	2035	2040	2045	2050
GDP	[billion Euro$_{2015}$/a]	1,599	1,589	1,685	1,787	1,926	2,049	2,215	2,395
GDP/Person	[Euro/capita]	26,438	26,525	28,253	30,325	32,930	35,482	39,015	42,885
Population	[million]	60,48	61.2	59.9	59.6	58.9	58.5	57.8	56.8
			2017–2020	**2020–2025**	**2025–2030**	**2030–2035**	**2035–2040**	**2040–2045**	**2045–2050**
Economic growth	[%/a]		0.5%	1.2%	1.2%	1.5%	1.3%	1.6%	1.6%
Population growth	[%/a]		−0.2%	−0.2%	−0.2%	−0.2%	−0.3%	−0.3%	−0.3%

The electricity demand projections documented in this section were calculated for the residential and business sectors with the [R]E 24/7 model in a bottom-up process. The further electricity demand entailed by transport (especially under the two alternative scenarios, with increased electric mobility) and by the internal electricity demand of power plants ("own consumption") and the distribution losses are calculated with the long-term model (see sections 0 and 3.2) and added to the calculated demand projections. However, the [R]E 24/7 power analysis only considers the additional electricity demand for distribution losses because the power plant consumption does not influence storage or grid requirements.

Figure 2: Development of final energy demand under four different GDP growth rates in [PJ/a]



[2] National Institute of Statistics, (PNIEC 2018)Italy and Draft Integrated National Energy and Climate Plan
Ministry of Economic Development; Ministry of the Environment and Land and Sea Protection; Ministry of Infrastructure and Transport 31/12/2018, https://ec.europa.eu/energy/sites/ener/files/documents/ec_courtesy_translation_it_necp.pdf
[3] Statistica, viewed 8th November 2019, https://www.statista.com/statistics/270469/population-density-in-italy/
[4] Macrotrend – market research and database; website viewed 11th November 2019; https://www.macrotrends.net/countries/ITA/italy/gdp-growth-rate
[5] REUTERS, 19th September 2019; https://www.reuters.com/article/us-italy-economy-budget-forecasts-exclus/exclusive-italy-cuts-2019-2020-gdp-growth-forecasts-sources-idUSKBN1W320J
[6] (PRIMES 2016), EU Reference Scenario 2016; Energy, transport and GHG emissions; Trends to 2050, Appendix 1 page 135, https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

Projected development of electricity demand

Industry and business demand development is based on the GDP breakdown (Table 2). It assumes that the overall structure of the economy does not change and that all sectors grow at rates equal to that of GDP over the entire modelling period. Table 4 shows the assumed breakdown of GDP by sub-category. The shares are based on PNIEC (2018)[10].

Table 3: Development of GDP shares by industry sector across all regions of Italy (2017)

Industry	31%
Manufacturing	20%
Mining & Energy	2%
Primary Industry	5%
Construction	4%
Services	67%
Offices	54%
Tourism	13%
Agriculture	2%
Agriculture	2%

The GDP distribution by region is based on 2017 data and is assumed to remain the same for the entire modelling period, until 2050. In the industry sector, an efficiency gain of 0.5% per year has been calculated between 2020 and 2030 and 0.75% per year between 2031 and 2050. In the service and agricultural sectors, an efficiency development of 0.5% per year until 2030 has been calculated, with 0.25% for the rest of the modelling period.

Table 4: Development of Italy's shares of GDP by region

Region	[%]
C Nord	15.2%
C Sud	13.8%
Nord	49.7%
Sud	14.1%
Sardegna	3.8%
Sicilia	3.3%

Future energy demand projection for Italy's industry sector are based on the sectorial GDP projects as documented in PNIEC 2018[10.] Table 16 shows the sectorial GDP projections for Italy's five main sectors until 2040. UTS-ISF has not done its own projections; the extension to 2050 is based on 2040 values.

Table 5: Industry sectorial GDP projection

GDP in Added Values	2017 €m (2010)	2018-2020	2020-2025	2025-2030	2030-2035	2035-2040
GDP	1,599,774	1.37%	1.18%	1.19%	1.5%	1.57%
Agriculture	28,009	0.78%	0.55%	0.34%	0.44%	0.49%
Construction	64,524	1.49%	0.93%	1.22%	1.72%	1.85%
Services	1,077,553	1.47%	1.34%	1.31%	1.63%	1.67%
Energy sector	18,931	1.26%	0.58%	0.91%	0.83%	1.2%
Industry	260,815	0.93%	0.61%	0.7%	0.9%	1.06%
Changes in GDP and sectoral added values under the BASE and NECP scenarios. Source: historical values: Eurostat, average annual growth rates: EU Reference Scenario 2016, see (PNIEC 2018) page 173, table 26						

Cost projections

The speed of an energy system transition depends, to some extent, on overcoming the economic barriers. These largely relate to the relationships between the costs of renewable technologies and those of their fossil counterparts. The projection of these costs under the various scenarios is vital to ensure that valid comparisons of energy systems are made. However, there have been significant limitations to these projections in the past in terms of investment and fuel costs. Efficiency measures also generate costs, which are usually difficult to determine, depending on the technical, structural, and economic boundary conditions. During the last decade, fossil fuel prices have seen huge fluctuations. After extremely high oil prices in 2012, we are currently in a low-price phase. Gas prices saw similar fluctuations. Therefore, fossil fuel price projections have also varied considerably and have had a considerable influence on the scenario outcomes ever since, especially those scenarios that are based on cost optimization algorithms.

Most renewable energy technologies provide energy with no fuel costs, so the projections of investment costs become more important than the fuel cost projections, and this limits the impact of errors in the fuel price projections. Fuel costs are only important for biomass- and future synthetic-fuels based energy generation because the cost of feedstock remains a crucial economic factor. Today, these costs range from negative costs for waste wood (based on credits when waste disposal costs are avoided), through inexpensive residual materials, to comparatively expensive energy crops.

Table 6: Italy—Summary: Investment cost assumptions for power generation plants (in Euro2019/kW) until 2050

Assumed Investment Costs for Power Generation Plants						
		2017	2020	2030	2040	2050
CHP coal	Euro/kW	2270	2270	2270	2270	2270
CHP gas	Euro/kW	908	908	908	908	908
CHP lignite	Euro/kW	2270	2270	2270	2270	2270
CHP oil	Euro/kW	1190	1171	1126	1072	1026
Coal power plant	Euro/kW	1816	1816	1816	1816	1816
Diesel generator	Euro/kW	817	817	817	817	817
Gas power plant	Euro/kW	608	454	454	454	608
Lignite power plant	Euro/kW	1998	1998	1998	1998	1998
Oil power plant	Euro/kW	863	845	808	781	745
Renewables						
CHP biomass	Euro/kW	2316	2270	2225	2134	2043
CHP fuel cells	Euro/kW	4540	4540	2270	2270	2017
CHP geothermal	Euro/kW	11,987	10,162	8073	6774	5866
Biomass power plant	Euro/kW	2179	2134	2089	1998	1916
Hydro power plant	Euro/kW	11,206	2543	2406	2270	2179
Ocean energy power plant	Euro/kW	6311	6039	3996	2815	1916
Photovoltaic, rooftop	Euro/kW	1,300	980	730	560	470
Photovoltaic, utility scale	Euro/kW	1,181	890	663	509	427
CSP power plant (incl. storage)	Euro/kW	5176	4540	3360	2770	2488
Wind turbine offshore	Euro/kW	3632	3351	2897	2570	2370
Wind turbine onshore	Euro/kW	1489	1435	1371	1317	1271
Hydrogen production	Euro/kW	1253	1108	835	636	518

*Costs for a system with a solar multiple of two and thermal storage for 8 h of turbine operation
**Values apply to both run-of-the-river and reservoir hydro power

Although fossil fuel price projections have seen considerable variations, as described above, we based our fuel price assumptions on INEC (2018)[10] and LAZARDS (2018)[7]. Although these price projections are

[7] LAZARDS (2018); Lazard's Levelized Cost of Energy Analysis—Version 12.0, November 2018

highly speculative, they provide a set of prices consistent with our investment assumptions. Bio-energy costs increase as utilisation increases and import is required after 2025.

Table 7: Italy—Summary: Development projections for fossil fuel prices

Development projections for fossil fuel prices						
All Scenarios		**2017**	**2020**	**2030**	**2040**	**2050**
Biomass	Euro/GJ	7.00	12.45	18.23	23.82	27.78
Oil	Euro/GJ	9.19	11.61	14.52	16.04	25.50
Gas	Euro/GJ	6.58	7.47	8.79	9.70	10.7
Coal	Euro/GJ	1.95	2.21	3.18	3.50	3.80

Assessment of solar and wind potential

Italy has a largely untapped potential for renewable energy, and the only resource used significantly is biomass. Biomass and geothermal resources are predominantly utilized in the power sector. There is no further potential to increase hydro power because Italy's utilization rate for hydro power plants is already at the maximum level in terms of sustainability. Solar energy is abundant, with excellent potential for utility-scale photovoltaic power stations, particularly in rural areas. Initially successful policy support schemes, such as the "Conto Energia" program started in 2005, have laid the foundations for significant growth in solar photovoltaic installations. In 2018, capacity crossed the 20 GW milestone and the "National Energy Strategy" (SEN), published in 2017, set a new target to reach 50 GW by 2030.

Table 8: Italy—Summary: Overview—Italy's utility-scale solar photovoltaic and onshore wind potential within 10 km of existing power lines by market zone

Cluster	Solar Area in km^2	Solar Potential in GW	Onshore Wind Area in km^2	Onshore Wind Potential in GW
C Nord	2,517	63	674	2.7
C Sud	4,971	124	1,473	5.9
Nord	15,764	394	4,019	16.0
Sud	4,111	103	1,376	5.5
Sardegna	7,051	176	3,429	13.7
Sicilia	3,642	91	1,182	4.7
Total	38,057	951	12,153	48,5

Assumptions for the scenarios

Italy has adopted new energy and climate goals in 2019. As required by the Regulation of the European Parliament and the Council 2016/0375 on the governance of the Energy Union, Italy submitted a draft of a 10-year strategy on energy efficiency and environmental sustainability in December 2018. This Integrated National Plan for Energy and Climate (PNIEC) contains the goal to phase out coal by 2025 and aims to expand the share of renewable energy in the final energy consumption to 28% by 2030. The REFERENCE scenario in this analysis has taken those goals into account and suggests two scenarios that go further in terms of the deployment of renewable energy and energy efficiency across all sectors.

The Energy [R]evolution (E[R]) scenario aims to decarbonize Italy's energy sector by 2050, whereas the advanced Energy [R]evolution (ADV E[R]) scenario is even more ambitious and would lead to decarbonization by 2040. The ADV E[R] is the only scenario calculated for this analysis, that achieves the Paris Climate Agreement goal in regard of Italy's overall carbon budget.

The scenario-building process for all scenarios includes assumptions about policy stability, the role of future energy utilities, centralized fossil-fuel-based power generation, population and GDP, firm capacity, and future costs

- **Policy stability:** This research assumes that Italy will establish a secure and stable framework for the deployment of renewable power generation. In essence, financing a gas power plant or a wind farm is quite similar. In both scenarios, a power purchase agreement, which ensures a relatively stable price for a specific quantity of electricity, is required to finance the project. Daily spot market prices for electricity and/or renewable energy or carbon are insufficient for long-term investment decisions for any kind of power plant with a technical lifetime of 20 years or longer. In short, the better the investment certainty, the lower the cost of capital.
- **Strengthened energy efficiency policies:** Existing policy settings (i.e., the energy efficiency standards for electrical applications, buildings, and vehicles) must be strengthened to maximize the cost-efficient use of renewable energy and achieve high energy productivity by 2030.
- **Role of future energy utilities:** With the 'grid parity' of rooftop solar photovoltaics under most current retail tariffs, this modelling assumes that energy utilities of the future will take up the challenge of increased local generation and develop new business models that focus on energy services, rather than simply on selling kilowatt-hours.
- **Population and GDP:** All three scenarios are based on the same population and GDP assumptions. The projections of population growth are taken from the Italian National Institute of Statistics[20] and the GDP projections are based on PNIEC 2018[20Error! Bookmark not defined.].

Cost assumptions: The same cost assumptions are used across all three scenarios. Because technology costs decline as the scale of deployment increases rather than with time, the renewable energy cost reduction potential in both Energy [R]evolution scenarios may be even larger than in the REFERENCE scenario because of the larger market sizes. The reverse is true for the fuel cost assumptions because all the scenarios are based on the same fossil fuel price projections. However, whereas both Energy [R]evolution scenarios have a significant drop in demand, the REFERENCE scenario assumes an increased demand, which may lead to higher fuel costs. Therefore, these costs should be considered conservative.

Key results—long-term scenario

In the executive summary, we focus on the key results for the power sector and the primary energy demand. The results for the transport and heating sectors are documented in section 3.

Electricity generation

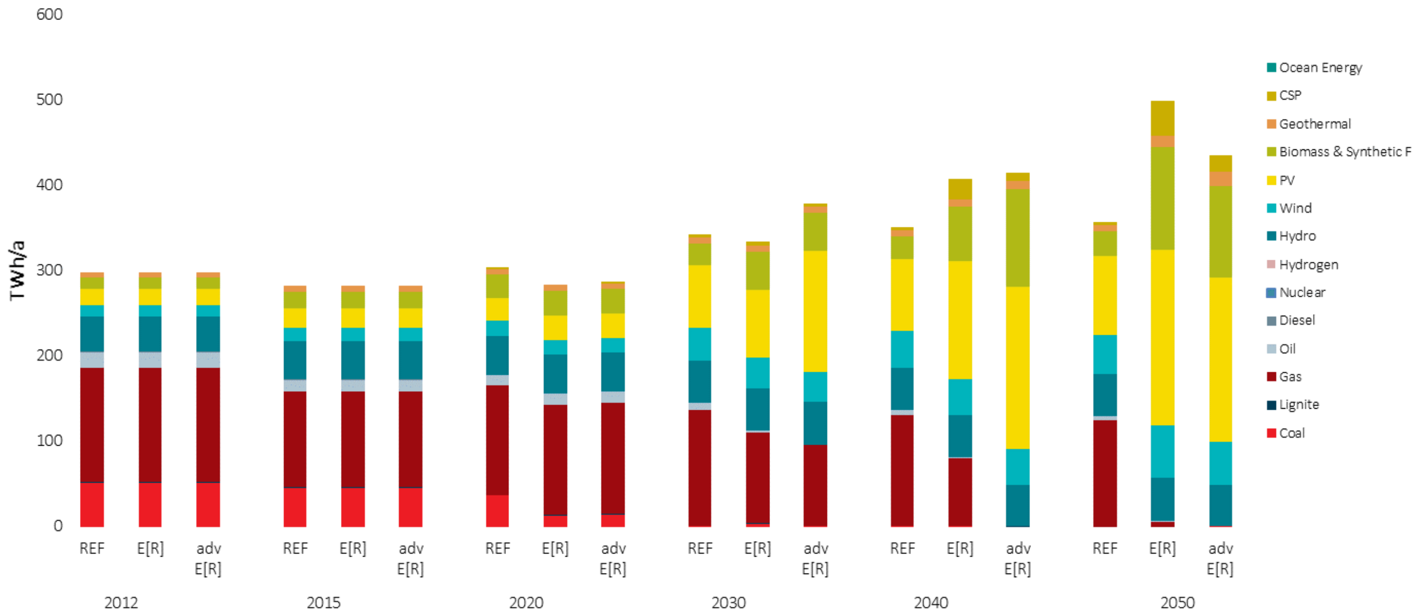
The development of the electricity supply sector will be characterized by a dynamically growing renewable energy market and an increasing share of renewable electricity. This trend will more than compensate the phase-out of coal power plants by 2025 in both alternative scenarios. By 2030, 72% of the electricity produced in Italy will come from renewable energy sources under the E[R] scenario, increasing to 100% in 2050. 'New' renewables—mainly onshore wind, solar photovoltaic, and offshore wind—will contribute 35% to the total electricity generation in 2030 and 54% by 2050. The installed capacity of renewables will reach almost 103 GW in 2030 and 230 GW by 2050.

Table 9: Italy—Summary: Projections of renewable electricity generation capacity

In GW		2015	2020	2030	2040	2050
Hydro	REF	18.863	18.863	20.423	20.423	20.423
	E[R]	18.863	18.863	20.525	20.525	20.525
	ADV. E[R]	18.863	18.863	20.525	20.320	20.320
Biomass & Synthetic Fuels	REF	4.208	4.634	5.005	5.156	5.483
	E[R]	4.208	5.181	8.186	11.697	23.329
	ADV. E[R]	4.208	5.238	8.353	21.715	20.776
Wind	REF	9.124	9.863	17.481	18.140	18.131
	E[R]	9.124	9.678	16.157	17.412	22.386
	ADV. E[R]	9.124	9.679	15.767	17.237	19.109
Geothermal	REF	0.936	0.935	1.070	1.072	1.072
	E[R]	0.936	0.988	1.091	1.362	2.075
	ADV. E[R]	0.936	0.988	1.163	1.617	2.560
PV	REF	18.892	21.908	51.951	56.013	58.892
	E[R]	18.892	24.119	56.392	92.169	130.390
	ADV. E[R]	18.892	24.119	100.487	125.421	121.846
Concentrated solar power (CSP)	REF	0.000	0.004	0.531	0.543	0.600
	E[R]	0.000	0.000	1.191	5.520	9.649
	ADV. E[R]	0.000	0.000	0.571	2.165	4.611
Ocean	REF	0.000	0.000	0.000	0.000	0.000
	E[R]	0.000	0.000	0.000	0.000	0.000
	ADV. E[R]	0.000	0.000	0.000	0.000	0.000
Total	REF	52.023	56.207	96.460	101.347	104.601
	E[R]	52.023	58.829	103.542	148.685	208.354
	ADV. E[R]	52.023	58.887	146.866	188.476	189.222

The ADV. E[R] scenario will achieve 75% renewable electricity generation in 2030 and 100% in 2040. The renewable capacity will increase to 147 GW by 2030 and 190 GW by 2050. Table 8 shows the comparative evolution of the different renewable technologies in Italy over time. The installed capacity of hydro power dominated as the major renewable power capacity for decades, but was already overtaken by solar photovoltaics already in 2018, which will remain the largest renewable power capacity throughout the entire scenario period. Wind power will grow in all scenarios to 15–20 GW, while hydro power will remain at around 20 GW as well. Both renewable scenarios will result in a high proportion of variable power generation sources (photovoltaics and wind): 35%–47% by 2030 and 54%–56% by 2050. Therefore, smart grids, demand-side management, energy storage capacities, and other options must be expanded to increase the flexibility of the power system to ensure grid integration, load balancing, and a secure supply of electricity.

Figure 3: Italy—Summary: Breakdown of electricity generation by technology



The calculated potential for utility-scale solar power plants (PV and concentrated solar power [CSP]) under all restrictions and excluding areas further than 10 km from transmission lines is 951 GW. Even the most ambitious E[R] scenario can be implemented with the utilisation of only 15% of the utility-scale solar power plant potential. As well as this potential, Italy has a significant rooftop solar photovoltaic capacity of around 70 GW. By 2030, the installed solar photovoltaic capacity under the ADV. E[R] will be almost twice as high (100 GW) as under E[R] (56 GW), due to a more rapid phase-out of gas power plants. However, by 2050, the ADV. E[R] scenario will have less solar photovoltaic power generation and wind power generation because of its higher efficiency target.

Cost of electricity generation and required investment in power plants

The costs provided in this section include all the construction costs for new power plants, the average standard operation and maintenance costs for each technology, and fuel costs. The infrastructure costs for possibly required additional coal or liquefied natural gas (LNG) capacities or grid expansion are not included because they are beyond the scope of this research. Under the REFERENCE scenario, power generation costs will remain at around €0.06 per kWh over the entire modelling period. By 2030, the average generation costs across all technologies will be €0.053 per kWh and by 2050, €0.061 per kWh. The E[R] scenario will lead to slightly lower average generation costs of €0.049 per kWh (2030) and €0.054 per kWh by 2050. The most favourable results in 2050 will be under the ADV. E[R] scenario, in which the shares of solar photovoltaic and wind power will be high, with significantly lower requirements for fuel and lower capital costs for installation. However, with the rapid increase in new renewable capacities during the first decade, the average generation costs will increase to €0.071 per kWh between 2020 and 2030 but decrease thereafter. By 2040, the ADV. E[R] scenario will have the lowest average generation costs. These costs assume no additional costs for carbon.

Because the uncertainty in the assumed fossil fuel prices increases with time, especially for the REF scenario (which has 42.5% fuel-based generation in 2030), the costs of storage and grid integration are not considered in this calculation (see further discussion of storage in Chapter 4). Under the REF scenario, the growth in demand and the increasing fossil fuel prices will result in an increase in the total electricity supply costs from €19 billion per year in 2015 to €20 billion in 2030 compared with €21 billion under E[R] and €24 billion under ADV. E[R]. The E[R] scenario has the highest electricity supply cost in 2050, because the electricity demand will be highest and the high fuel costs for bio-energy similar.

Bio energy and synthetic fuels

In this research bio energy and synthetic fuels are considered to be interchangeable fuels for power plants, combined heat- and power plants (CHP) and heating plants. The maximum amount of available sustainable biomass requires more research and was out of scope for this analysis. Synthetic fuels can be produced by renewable electricity – mainly solar and wind power –will either add to bio energy supply or replace them.

Primary energy

Under the E[R] scenario, the primary energy demand will decrease from the present level of around 6,470 PJ/a to around 6,200 PJ/a in 2030, a reduction of 5%. Compared with the REF scenario, the overall primary energy demand will be reduced by 779 PJ by 2030 under the E[R] scenario (REF: 7,039 PJ in 2030). The ADV. E[R] scenario will result in a primary energy consumption of around 5,528 PJ in 2030, and will further decrease as a result of increased electrification between 2030 and 2050.

The Energy [R]evolution scenarios aim to reduce coal, gas, and oil consumption as fast as is technically and economically possible by the expansion of renewable energy generation and the rapid introduction of very efficient vehicles to the transport sector to replace oil-based combustion engines. This will lead to an overall renewable primary energy share of 33% in 2030 and 92% in 2050 under the E[R] scenario and 96% in 2050 under the ADV. E[R] scenario (including non-energy consumption).

Power sector analysis

Table 9 shows the real loads of Italy's power market regions in 2015. The data have been provided by the Italian grid operator TERNA. They show that northern Italy requires about half the country's electricity demand and also has more than half the overall peak load. The average load in this region represents 55% of the value for the whole of Italy.

Table 10: Italy—Summary: Load, generation, and residual load in 2015 (TERNA)

Real load – measured by TERNA in 2015	Annual demand [MWh/a]	Max Load [MW]	Min Load [MW]	Average Load [MW]
C Nord	33,457,614	6,400	1,248	3,819
C SUD	48,553,674	9,386	1,750	5,543
Nord	176,458,278	34,543	9,327	20,144
Sud	29,843,302	5,332	1,673	3,407
Sardegna	9,098,917	1,523	702	1,039
Sicilia	18,854,940	3,295	1,198	2,152
Italy	316,959,112	60,236	18,588	36,183

Table 10 shows that Italy's average load is predicted to increase over the next decade by approximately 15% under the REFERENCE and Energy [R]evolution scenarios, and by 22% under the advanced Energy [R]evolution scenario. The E[R] scenario will have the highest peak load by 2050, as a result of the increased electrification of the heating and transport sectors, whereas the energy efficiency targets are similar to those under the REREFENCE scenario. The ADV. E[R] scenario has a more stringent electrification strategy, especially for the transport sector, because of the earlier phase-out target for fossil fuels, and a more-ambitious energy efficiency strategy. In comparison, the load of ADV. E[R] in 2050 will be only 10% higher than that in the REF scenario, despite an electrification rate of 75% for road and rail transport vehicles.

Although there are significant regional differences, under E[R], three regions will almost double their loads between 2020 and 2050: C Sud, Nord and Sicilia. The calculated peak loads of the REFERENCE and Advanced Energy [R]evolution scenarios are almost identical throughout the entire modelling period and across all regions. This is an indication of the need to introduce energy efficiency in parallel with the implementation of electric mobility to limit the required investment in the upgrade of Italy's power grid infrastructure. However, under any scenario and independent of the type of power generation, Italy's power grid must by expanded over the next two decades, because increased electric mobility will require additional capacity in the power grid to accommodate the higher charging loads for vehicles. However, the locations of the transmission grids will depend on the form of generation because the locations of generation and demand centres may differ for decentralized and centralized power generation. The REF scenario will lead to a significant concentration of generation capacity close to gas pipelines and LNG terminals for imported gas.

Table 11: Italy—Summary: Projections of load, generation, and residual load until 2050

Italy: Development of load and generation		REF				E[R]				ADV. E[R]			
		Max. Demand	Max. Generation	Max. Residual Load	Peak load increase	Max Demand	Max Generation	Max Residual Load	Peak load increase	Max Demand	Max Generation	Max Residual Load	Peak load increase
Italy		[GW/h]	[GW/h]	[GW/h]	[%]	[GW/h]	[GW/h]	[GW/h]	[%]	[GW/h]	[GW/h]	[GW/h]	[%]
C Nord	2020	6.6	10.4	0.4	100%	6.6	8.9	0.4	100%	6.6	8.9	0.4	100%
	2030	7.2	8.5	2.3	108%	7.1	8.0	2.8	108%	7.5	13.1	2.8	113%
	2050	7.3	8.4	4.0	110%	10.2	18.4	7.5	154%	8.0	16.4	6.5	122%
C Sud	2020	8.5	8.7	0.9	100%	8.4	8.6	0.9	100%	8.4	8.6	0.9	100%
	2030	9.8	10.1	2.4	116%	9.8	10.1	2.9	117%	10.5	15.6	3.5	125%
	2050	10.6	10.8	2.3	125%	14.5	22.2	9.7	173%	11.9	19.7	8.8	141%
Nord	2020	23.1	23.6	1.9	100%	23.0	23.5	1.9	100%	23.0	23.5	1.9	100%
	2030	27.2	27.9	1.7	118%	27.2	28.2	3.4	118%	28.7	44.6	10.0	125%
	2050	30.5	31.1	1.2	132%	41.3	64.6	28.1	179%	33.5	56.5	26.4	146%
Sud	2020	6.2	6.3	0.5	100%	6.1	6.3	0.5	100%	6.1	6.3	0.5	100%
	2030	7.3	12.3	2.7	118%	7.3	12.9	2.7	118%	7.6	17.0	3.1	124%
	2050	8.0	13.5	5.1	130%	10.9	30.9	4.9	177%	8.8	24.4	4.4	143%
Sardegna	2020	1.6	5.1	0.5	100%	1.6	4.2	0.5	100%	1.6	4.2	0.5	100%
	2030	1.8	4.1	1.0	114%	1.8	3.9	0.9	115%	1.9	4.3	1.1	120%
	2050	1.8	3.8	1.2	111%	2.5	7.9	1.3	158%	2.0	6.0	1.0	123%
Sicilia	2020	2.8	7.3	0.7	100%	2.7	8.0	0.7	100%	2.7	8.2	0.7	100%
	2030	3.1	8.8	1.6	114%	3.1	8.0	1.5	114%	3.4	7.3	1.7	124%
	2050	3.2	8.7	2.1	114%	4.5	11.5	1.2	163%	3.6	8.7	1.5	133%
Italy	2020	51.3	61.4	7.5	100%	51.0	59.5	7.5	100%	51.0	59.7	7.5	100%
	2030	56.4	71.7	14.1	114%	56.4	71.2	14.1	115%	59.7	101.9	22.2	122%
	2050	61.4	76.3	52.9	120%	83.8	155.6	52.9	167%	67.9	131.7	48.6	135%

Development of the regional exchange of capacity

The increasing electricity load in all regions will require an increase in the transmission and distribution networks in Italy. This analysis assumes that those network upgrades will be implemented as the demand increases. Because it is a technical requirement, Italy must increase its grid capacity proportionally to the increasing demand. This technical requirement to expand the grid capacity as demand increases is largely independent of the type of power generation. The inter-regional exchange of capacity is a function of the load development and generation capacity in all six regions. The [R]E 24/7 model distributes the generation capacity according to the regional load and the conditions for power generation. The locations of gas power plants are fixed and the installation of new capacities will depend on possibility of fuel supply. Renewable power generation is more modular and can be distributed according to the load in the first place. However, as the share of renewable electricity increases, and the space available for utility-scale solar and onshore wind generation facilities and the availability and quality of local resources (such as solar radiation and/or wind speed) decrease, power might be generated further from its point of consumption. This will require more transmission capacity in order to exchange generation capacities between the six regions of Italy analysed here.

In our analysis, an increase in the necessary inter-regional exchange of capacity, as well as the increase in grid capacity within the regions as demand increases, will start between 2030 and 2040, particularly in those regions with a high population density, high demand, and lower generation potential, such as C Nord, Sardegna and Sicilia. In our analysis, the main generation hub for renewable power will the northern (Nord) region, followed by southern Italy (Sud). Both regions have significant solar and wind resources, which will require significant increases in transmission capacity. However, another option would be to increase the dedicated energy communities, which would increase storage as part of their local energy plans, reducing the transmission required, but increasing the overall storage capacity. Whether increased storage or increased transmission with future storage cost is more economic was outside the scope of this study and requires further research.

Storage requirements

Table 11 gives an overview of the estimated installed storage capacity requirements for both Energy [R]evolution scenarios. The majority of storage facilities will be required in northern Italy. For the whole of Italy, the required storage capacity in 2050 will be 33% below the capacity required to avoid curtailment in the E[R] and 23% below it under the ADV. E[R] scenario. However, there will be significant regional differences. The requirement for utility-scale storage will occur between 2025 and 2030. The storage demand will vary significantly and will be a function of the regional distribution of variable power generation and the extent to which the regions can exchange load via interconnections. The estimates provided for storage requirements also presuppose that variable renewables are first in the dispatch order, ahead all other types of power generation. Priority dispatch is the economic basis for investment in utility-scale solar photovoltaic and wind projects. The curtailment rates or storage rates will be significantly higher with the priority dispatch of other types of power. This case has not been calculated because it would involve a lack of investment in solar and wind in the first place. With decreasing storage costs, as projected by Bloomberg (2019)[8], interconnections might become less economically favourable than batteries. This would increase even further the economic advantage of decentralized solar photovoltaics close to the electricity demand over centralized gas power plants. However, an expansion of the electricity network as demand increases is unavoidable under any scenario, in order to reduce the storage requirement and increase the load transfer options for Italy in response to increased electric mobility.

Table 12: Italy—Summary: Estimated electricity storage requirements for both Energy [R]evolution scenarios

Storage and H_2 Dispatch		Energy [R]evolution		Adv. Energy [R]evolution	
		Total storage throughput	Storage capacity (1)	Total storage throughput	Storage capacity (1)
Italy		[GWh/yr]	[GW]	[GWh/yr]	[GW]
C Nord	2020	0	0	0	0
	2030	373	0	3551	3
	2050	7672	6	8609	7
C Sud	2020	0	0	0	0
	2030	191	0	4256	4
	2050	6515	5	9060	8
Nord	2020	0	0	0	0
	2030	270	0	10730	9
	2050	21132	18	24533	20
Sud	2020	67	0	67	0
	2030	1800	2	4177	3
	2050	7041	6	8700	7
Sardegna	2020	171	0	171	0
	2030	1227	1	2393	2
	2050	2064	2	2960	2
Sicilia	2020	129	0	129	0
	2030	282	0	2475	2
	2050	3657	3	4296	4
Total	**2020**	367	0	367	0
	2030	4143	3	27581	23
	2050	48080	40	58159	48

(1) Calculated with an average capacity factor of 1.200 hours per year

The storage estimations provided in Table 40 are technology neutral and includes - besides lithium batteries - also flow-batteries or any kind of thermal storage options (e.g. molten salt).

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[8] Bloomberg (2019), A Behind the Scenes Take on Lithium-ion Battery Prices, Logan Goldi-Scot, BloombergNEF, March 5 2019, https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

Employment analysis

Employment development has been calculated based on the methodology described and the results for the long-term energy scenario documented in Chapter 3. The figures represent quantitative estimates and have been compared with the current workforces in Italy when information was available.

Under the REF scenario, while employment in the gas sector will remain at over 20,000 jobs, employment in the renewables sector will increase. The total number of jobs in the energy sector will decrease slightly from the current 88,200 jobs to 85,000 jobs by 2025 and increase thereafter as a result of increased renewable energy deployment to 98,000 by 2030.

Both alternative energy pathways will lead to stronger growth in the renewable sector, significantly overcompensating the losses in the gas industry. The E[R] scenario will increase overall employment in the energy sector from 88,200 today to 101,000 by 2025, and further increase it to around 135,000 jobs by 2030. Only 22% of the jobs in 2030 will be in the fossil fuel industry, whereas the remaining 78% will be in the renewables industry.

Our analysis shows higher renewable energy employment developments under the ADV. E[R] scenario: the overall number of jobs in 2025 will be 24,000 higher than under the E[R] scenario. As the development of renewables accelerates under the ADV. E[R] scenario, the construction rates will decrease after 2030, so by 2050, there will be around 5,000 fewer jobs than under the E[R] scenario, but still approximately 55,000 more than under the REF scenario.

1 METHODOLOGY AND ASSUMPTIONS

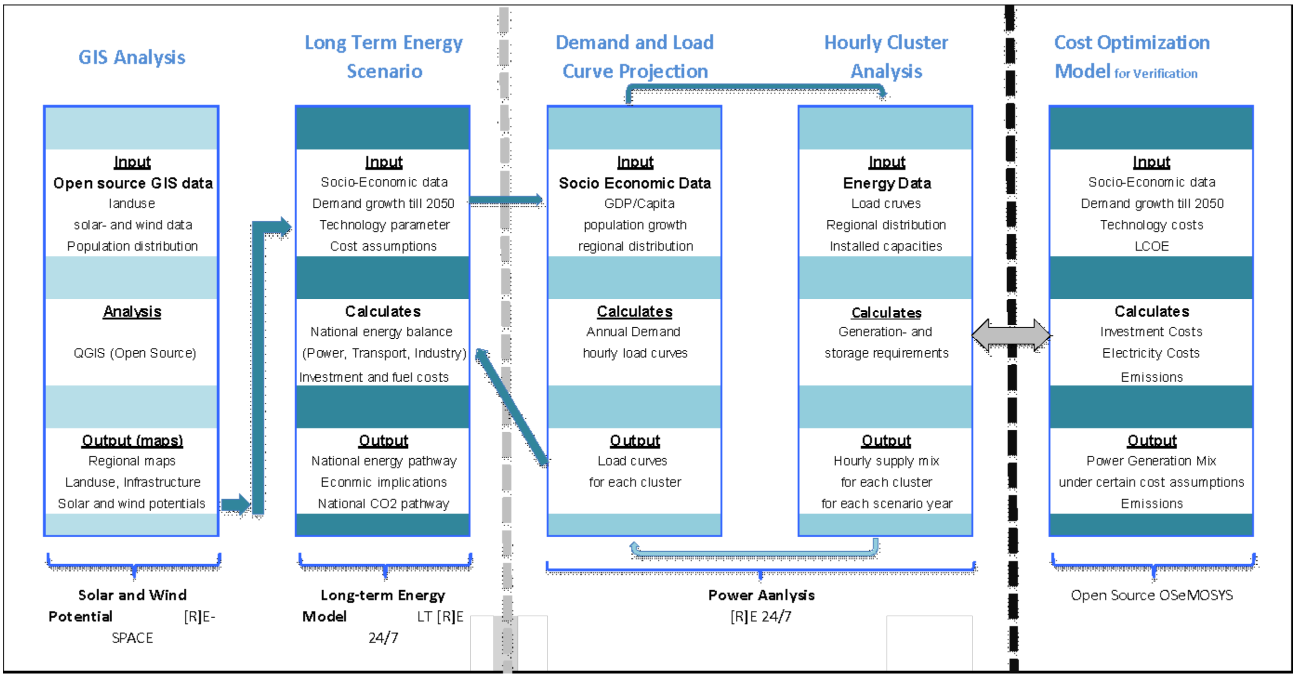
This report provides a technical and economic analysis of the long-term energy and power development plans for Italy. The analysis is based on the [R]E 24/7 energy access pathway methodology developed by the Institute for Sustainable Futures (ISF) at the University of Technology Sydney (UTS) and on the long-term energy scenario model of the Institute for Thermodynamics of German Aero Space Centre (DLR), energy models developed for various UTS-ISF surveys, and the [R]E 24/7 model. The following section explains the methodology and provides an overview of the required input parameters, basic functions, and calculated outputs. The entire modelling process is based on four modules developed by UTS-ISF. The models are described below in their order of use.

For the mapping analysis, a global information system (GIS) was used for a regional analysis of Italy's population density and distribution, its solar and wind resources, and the currently existing energy infrastructure (transmission power lines and power plants with over 100 MW of installed capacity). This information has been used to define the cluster breakdown.

The long-term scenario LT [R]E 24/7 has been used to re-model the existing power development plan and to develop alternative national energy pathways for Italy. This model takes all sectors into account (power, heat, and transport) and includes costs and energy-related CO_2 calculations.

The [R]E 24/7 power sector analysis tool computes the annual demand for up to five different years (here: 2020, 2030, 2040, and 2050) and the load curves for a full year (8760 h). The hourly load curves are required to simulate the demand and supply for each of the six market regions of Italy. The results are the development of loads, the generation mix, and the storage demand. The load curves for the base year (2015) are actual historic load curves provided by TERNA, the Italian grid operator[9].

Figure 4: Overview—Modelling concept



[9] TERNA LOAD CURVES can be downloaded from the following website: https://www.terna.it/en/electric-system/transparency-report/total-load

1.1 [R]E 24/7—GIS MAPPING TOOL

The primary purpose of GIS mapping is to ascertain the renewable energy resources (primarily solar and wind) available in Italy. It also contributes to the regional analysis of geographic and demographic parameters and the available infrastructure that can be leveraged in developing the scenarios. Mapping was performed with the computer software 'QGIS', which analyses and edits spatial information and constructs and exports graphical maps. It has been used to allocate solar and wind resources and for the demand projections for each calculated region. Population density, access to electricity, and the distribution of wealth, or the economic development projections, are key input parameters in the region-specific analysis of Italy's future energy situation.

Open-source data and maps from various sources have been used to visualize the country and its regions and districts. Further demographic data related to population and poverty, as well as transmission networks and power plants, are also plotted on the maps. The main data sources and assumptions made for this mapping are summarized in the table below.

Table 13: [R]E 24/7—GIS-mapping—data sources

Data	Assumptions	Source
Regions	Italy's power market is divided into six market regions. Those regions have been taken into account, according to data availability: Nord, Sud, Central Nord, Central Sud, Sardegna and Sicily	TERNA https://www.terna.it/en/electric-system/statistical-data-forecast/evolution-electricity-market
Land use/land cover	Land cover types of bare soil, annual cropland, perennial cropland, and grassland are included in the wind analysis. Only land cover types of bare soil, perennial cropland, and open bushland are included in the solar analysis.	World Bank: ESMAP
Elevation	For both wind and solar analyses, any land with a slope of more than 30% was ignored.	Open DEM
Bathymetry	Offshore water bodies (ocean) within 70 km of the coast and with a depth of no more than 50 m below sea level were included in the offshore wind analysis.	GEBCO
Population density	Estimates of numbers of people per pixel (ppp), with national totals adjusted to match UN population division estimates.	WorldPop
Poverty	Based on the GSO-WB poverty headcounts in percentage terms for each province.	World Bank
Power plants	The Global Power Plant Database is a comprehensive, open-source database of power plants around the world.	Global power plant database, World Resource Institute
Solar irradiance	The average yearly direct normal insolation/irradiation (DNI) values range from 1 to 5 MWh/m^2 per year.	Solar GIS
Transmission lines and network	Only those sites within 10 km of an existing transmission line were included in the analysis.	EnergyData.info
Wind speed	Wind speeds above 6 m/s were considered at a height of 80 m	Global wind atlas

The areas of land available for potential solar and wind power generation were calculated at both national and regional levels (six regions of Italy—see section 2.4) using the ellipsoidal area tool in the *QGIS* processing toolbox. Intersects were created between the transmission level layers and the solar/wind utility vector layers to break down the total land area available clusterwise. A correction was made for sites that intersected the cluster boundaries and were part of the two transmission levels. This input was fed into the calculations for the [R]E 24/7 model, as described below.

1.2 LONG-TERM SCENARIO MODELLING

Historically, heating, electricity, and mobility have been separated in terms of their energy sources, requiring different infrastructures and therefore different planning: electricity for stationary power, petrol and diesel for mobility, and onsite heat for buildings and industrial processes. This will almost certainly change, with increasing use of electricity for heating and mobility, such as in electric vehicles. This emerging *sector coupling* must be taken into account and requires an integrated approach across heat, mobility, and electricity/stationary power when developing future energy system scenarios, as is done in this model.

Three scenarios have been developed, a reference scenario and two alternative energy pathways. The assumptions for those scenarios are documented in section 2.7. The long-term (LT) modelling approach used in this research is based on the development of target-orientated scenarios. In this approach, a target is set and technical scenarios are developed to meet that target, and then compared with a reference scenario. The set target can be in terms of annual emissions and/or renewable energy shares. For Italy, an exogenous target of a coal phase-out by 2025 (see section 3 has been considered for all scenarios. The scenarios are based on detailed input datasets that consider defined targets, renewable and fossil fuel energy potentials, and specific parameters for power, heat, and fuel generation in the energy systems. The datasets are then fed into LT-[R]E 247, which is based on a DLR model that uses the MESAP/PlaNet software, an accounting framework for the calculation of the complete energy system balance to 2050.

The LT-[R]E 24/7 model simulation consists of two independent modules:

1. a flow calculation module, which balances energy supply and demand annually; and
2. a cost calculation module, which calculates the corresponding generation and fuel costs.

Note that this is not a dispatch model, such as the [R]E 24/7 power sector model used to calculate the future regional and hourly power, or a technical grid simulation (including frequency stability), such as DIgSILENT's PowerFactory, which is beyond the scope of this analysis.

The LT-[R]E 24/7 model is a bottom-up integrated energy balance model. Different modelling approaches each have their benefits and drawbacks. This model is particularly good at helping policy makers and analysts understand the relationships between different energy demand types in an economy—across all sectors and over a long time period, usually 30–40 years. In a simulation model, the user specifies the drivers of energy consumption, including the forecast population growth, GDP, and energy intensities.

Specific energy intensities are assumed for:

- electricity consumption per person;
- the ratio of industrial electricity and heat demand intensity to GDP;
- demand intensities for energy services, such as useful heat;
- energy intensities for different transport modes.

Electricity demand projections for the building and industry sectors are calculated with [R]E 24/7 (see section 4.4) as an input for the LT-[R]E 24/7 model of the alternative scenarios, but not for the REFERENCE scenario, in which they are taken from the Draft Integrated National Energy and Climate Plan[10] (Dec 2018). The electricity demand for the transport sector has been calculated with the LT-[R]E 24/7 model. For both heat and electricity production, the model distinguishes between different technologies, which are characterized by their primary energy source, efficiency, and costs. Examples include biomass or gas burners, heat pumps, solar thermal and geothermal technologies, and several power generation technologies, such as photovoltaics, wind, biomass, gas, coal, and combined heat and power (CHP). For each technology, the market share with respect to total heat or electricity production is

[10] DRAFT INTEGRATED NATIONAL ENERGY AND CLIMATE PLAN, Ministry of Economic Development. Ministry of the Environment and Land and Sea Protection, Ministry of Infrastructure and Transport, 31/12/2018, https://ec.europa.eu/energy/sites/ener/files/documents/ec_courtesy_translation_it_necp.pdf

specified based on a range of assumptions, including the renewable energy target, potential costs, and societal, structural, and economic barriers. The main outputs of the model are:

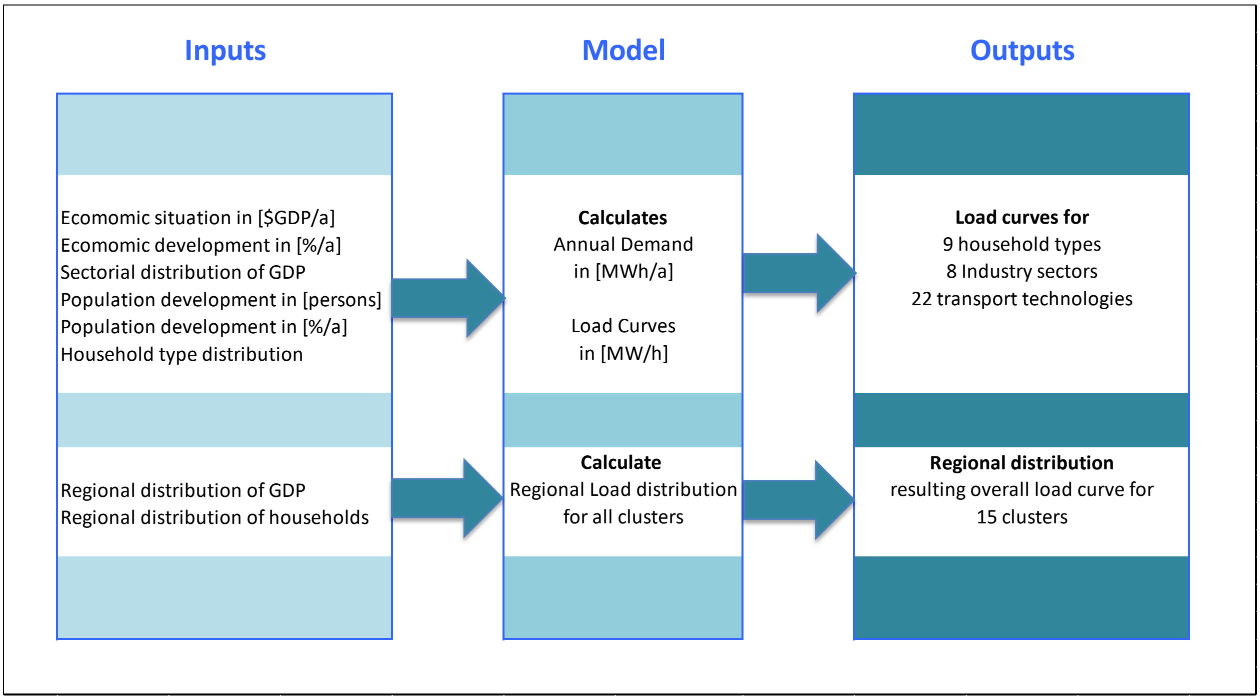
- final and primary energy demand, broken down by fuel, technology, and sector of the economy, as defined by the International Energy Agency (IEA): industry, power generation, transport, and other (buildings, forestry, and fisheries)[11];
- results broken down by the three main types of energy demand—electricity, heating, and mobility (transport); specifically, the energy required, technology deployment, and finance;
- total energy budget, or the total cost of energy for the whole energy system;
- energy-related greenhouse gas emissions over the projection period.

1.3 [R]E 24/7—POWER ANALYSIS

After the geographic analysis and the development of long-term energy pathways for Italy, the power sector was analysed in a third step with the [R]E 24/7 module.

The energy demand projections and resulting load curve calculations are important factors, especially for power supply concepts with high shares of variable renewable power generation. Calculation of the required dispatch and storage capacities is vital for the security of supply. A detailed bottom-up projection of the future power demand based on the applications used, demand patterns, and household types allows a detailed forecast of the demand. Infrastructure needs, such as power grids combined with storage facilities, require an in-depth knowledge of the local loads and generation capacities. However, this model cannot simulate frequencies or ancillary services, which would be the next step in a power sector analysis.

Figure 5: Overview—Energy demand and load curve calculation module



[11] Note these industry sectors correspond to IEA energy statistics input into the model.

1.31 METEOROLOGICAL DATA

Variable power generation technologies are dependent on the local solar radiation and wind regimes. Therefore, all the installed capacities in this technology group are connected to cluster-specific time series. The data were derived from the database *renewable.ninja* (RE-N DB 2018)[12], which allows the simulation of the hourly power output from wind and solar power plants at specific geographic positions throughout the world. Weather data, such as temperature, precipitation, and snowfall, for the year 2014 were also available. To utilize climatization technologies for buildings (air-conditioning, electric heating), the demand curves for households and services are connected to the cluster-specific temperature time series. The demand for lighting is connected to the solar time series to accommodate the variability in lighting demand across the year, especially in northern and southern regions, which have significantly longer daylight periods in summer and very short daylight periods in winter.

For every region included in the model, hourly output traces are utilized for onshore wind, offshore wind, utility solar, and rooftop solar photovoltaics. Given the number of clusters, the geographic extent of the study, and the uncertainty associated with the prediction of the spatial distribution of future-generation systems, a representative site was selected for each of the five generation types.

Once the representative sites were chosen, the hourly output values for typical solar arrays and wind farms were selected with the database of Stefan Pfenninger (at ETH Zurich) and Iain Stafell (renewable.ninja; see above). The model methodology used by the renewable.ninja database is described by Pfenninger and Staffell (2016a and 2016b)[13], and is based on weather data from global re-analysis models and satellite observations (Rienecker and Suarez 2011[14]; Müller and Pfeifroth, 2015[15]). It was assumed that the utility-scale solar sites will be optimized, and as such, a tilt angle was selected within a couple of degrees of the latitude of the representative site. For rooftop solar calculations, this was left at the default 35° because it is likely that the panels matched the roof tilt.

The wind outputs for both onshore and offshore winds were calculated at an 80 m hub height because this reflects the wind datasets used in the mapping exercise. Although onshore wind and offshore wind are likely be higher than this, 80 m was considered a reasonable approximation and made our model consistent with the mapping-based predictions. A turbine model of Vestas V90 2000 was used.

Limitations: The solar and wind resources can differ within one cluster. Therefore, the potential generation output can vary within a cluster and across the model period (2020–2050).

[12] RE-N DB (2018) Renewables.ninja, onione database for hourly time series for solar and wind data for a specific geographical position, viewed and data down load took place between May and July 2018, https://www.renewables.ninja/

[13] Pfenninger, S, Staffell, I. (2016a), Pfenninger, Stefan and Staffell, Iain (2016). Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data. Energy 114, pp. 1251-1265. doi: 10.1016/j.energy.2016.08.060

Pfenninger, S, Staffell, I. (2016b), Staffell, Iain and Pfenninger, Stefan (2016). Using bias-corrected reanalysis to simulate current and future wind power output. Energy 114, pp. 1224-1239. doi: 10.1016/j.energy.2016.08.068

[14] Rienecker, M, Suarez MJ, (2011) Rienecker MM, Suarez MJ, Gelaro R, Todling R, et al. (2011). MERRA: NASA's modern-era retrospective analysis for research and applications. Journal of Climate, 24(14): 3624-3648. doi: 10.1175/JCLI-D-11-00015.1

[15] Müller, R., Pfeifroth, U (2015), Müller, R., Pfeifroth, U., Träger-Chatterjee, C., Trentmann, J., Cremer, R. (2015). Digging the METEOSAT treasure—3 decades of solar surface radiation. Remote Sensing 7, 8067–8101. doi: 10.3390/rs70608067

1.4 POWER DEMAND PROJECTION AND LOAD CURVE CALCULATION

Load curves for all six power market regions for the base year 2017 have been taken from an open data platform[16] of TERNA, the Italian grid operator, and discussed in personal conversations with Gabrieli Francescato Modesto, Senior Manager Market Analysis System Strategy at TERNA. The six market regions (Figure 6) of Italy and their current interconnection capacities have been taken into account for the [R]E 24/7 simulation.

Figure 6: Power sector market zones of Italy (provided by TERNA, Italy)

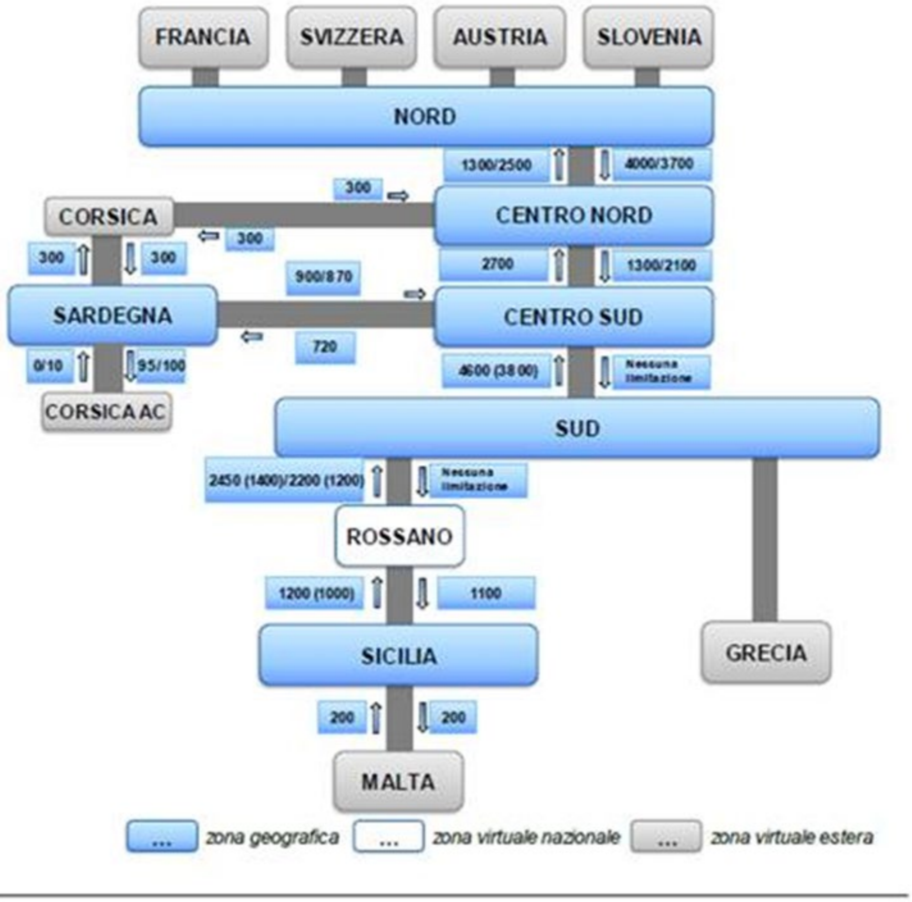


Fig. 1 – Caso Invernale

The [R]E 24/7 power analysis model calculates the development of the future power demand and the resulting possible load curves. Actual load curves, particularly for low- and middle-income countries, do not yet exist or are classified, and therefore must be calculated based on a set of assumptions. The model generates annual load curves with hourly resolution and the resulting annual power demands for three different consumer sectors:

- households;
- industry and business; and
- transport.

[16] https://www.terna.it/en/electric-system/statistical-data-forecast/evolution-electricity-market

Although each sector has its specific consumer groups and applications, the same set of parameters is used to calculate the load curves:

- electrical applications in use;
- demand pattern (24 h);
- meteorological data
  - sunrise and sunset, associated with the use of lighting appliances;
  - temperature and rainfall, associated with climatization requirements;
- efficiency progress (base year 2015) for 2020 until 2050, in 5-year steps
  - possibility that the electricity intensity data for each set of appliances will change, e.g., change from CFL light bulbs to LEDs as the main technology for lighting.

Methodology: Load curve calculation for households

The model differentiates nine household groups with various degrees of electrification and equipment:

- Rural – phase 1: Low-income household
- Rural – phase 2: Medium-income household
- Rural – phase 3: High-income household with electrical cooking, air conditioning, and partly with electric vehicles (beyond 2030)
- Urban single: Household with minimal equipment
- Urban shared flat: 3–5 persons share one apartment in the centre of a large city; fully equipped medium-income household, but without vehicles
- Urban – family 1: 2 adults and 2–3 children, middle income
- Urban – family 2: 2 adults and > 3 children, and/or higher income
- Suburbia 1: Average family, middle income, full equipment for high transport demand because of extensive commuting
- Suburbia 2: High-income household, fully equipped, extremely high transport demand because of high-end vehicles and extensive commuting.

The following electrical equipment and applications can be selected from a drop-down menu:

- Lighting: 4 different light bulb types
- Cooking: 10 different cooking stoves (2+4 burners, electricity, gas, firewood)
- Entertainment: 3 different computer, TV, and radio types
- White goods: 2 different efficiencies for washing machines, dryers, fridges, freezers
- Climatization: 2 different efficiency levels each for fan, air-conditioning
- Water heating: a selection of direct electric, heat pump, and solar

For details of the household demand projections and categories developed for the Italy analysis, see section 2.2.

Load curve calculations for business and industry

The industrial sector is clustered into eight groups based on widely used statistical categories:

- Agriculture
- Manufacturer
- Mining
- Iron and steel
- Cement industry
- Construction industry
- Chemical industry
- Service and trade

For each sector, 2–6 different efficiency levels are available. The data are taken from international statistical publications (IEA [2016][17], IRENA [2016][18], DLR [2012][19]).

For the Italy modelling project, the business and industry load curve calculations were simplified by the limited data availability and to make our calculations comparable to those of the Integrated National Energy and Climate Plan 2018. The demand and load curve calculations for industry and business are based on the following three economic sectors:

- Agriculture
- Industry and construction
- Service and trade

Thus, the industry-specific projections for *manufacturing*, *mining*, *iron and steel*, *cement industry*, *construction industry*, and the *chemical industry* are summed into one demand and one resulting load curve. For industry, the base load is assumed, whereas for agriculture and service & trade, core working hours from 6 am to 8 pm are assumed.

[17] IEA (2016), World Energy Balances, 2016

[18] Report citation IRENA (2016), REmap: Roadmap for a Renewable Energy Future, 2016 Edition. International Renewable Energy Agency (IRENA), Abu Dhabi, www.irena.org/remap

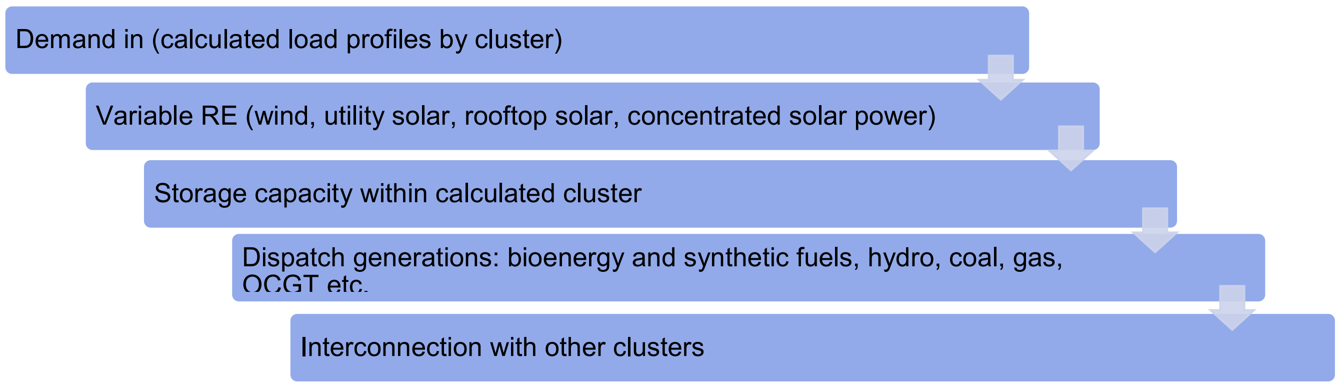
[19] DLR et. al. (2012) Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global Schlussbericht BMU - FKZ 03MAP146 (DLR), (IWES), (IFNE), 29 March 2012

1.5 THE [R]E 24/7 DISPATCH MODULE

The [R]E 24/7 dispatch module simulates the physical electricity supply with an interchangeable cascade of different power generation technologies. The cascade starts with the calculated load in megawatts for a specific hour. The first-generation technology in the exogenous dispatch order provides all the available generation, and the remaining load is supplied by the second technology until the required load is entirely met. In the case of oversupply, the surplus variable renewable electricity can be either moved to storage, moved to other regions, or—if neither option is possible—curtailed. Non-variable renewable sources reduce output. In the case of an undersupply, electricity is supplied either from available storage capacities, from neighbouring clusters, or from dispatch power plants. The key objective of the modelling is to calculate the load development by region, changing the residual loads (load minus generation), theoretical storage, and interconnection requirements for each cluster and for the whole survey region. The theoretical storage requirement is provided as "storage requirement to avoid curtailment". The economic battery capacity is a function of the storage and curtailment costs, as well as the dispatch power plant availability and costs. This analysis requires detailed local technical parameters, which were not available for this analysis.

Figure 7 provides an overview of the dispatch calculation process. The dispatch order can be changed in terms of the order of renewables and the dispatch power plant, as well as in the order of the generation categories: variable, dispatch generation, and storage. The following key parameters are used as input: generation capacity by type, the demand projection and load curve for each cluster, interconnection with other clusters, and meteorological data from which to calculate solar and wind power generation with hourly resolution. The installed capacities are derived from the long-term projections described in section 4.4, and the resulting annual generation in megawatt hours is calculated on the basis of meteorological data (in cases of solar and wind power) or dispatch requirements.

Figure 7: Dispatch order within one cluster



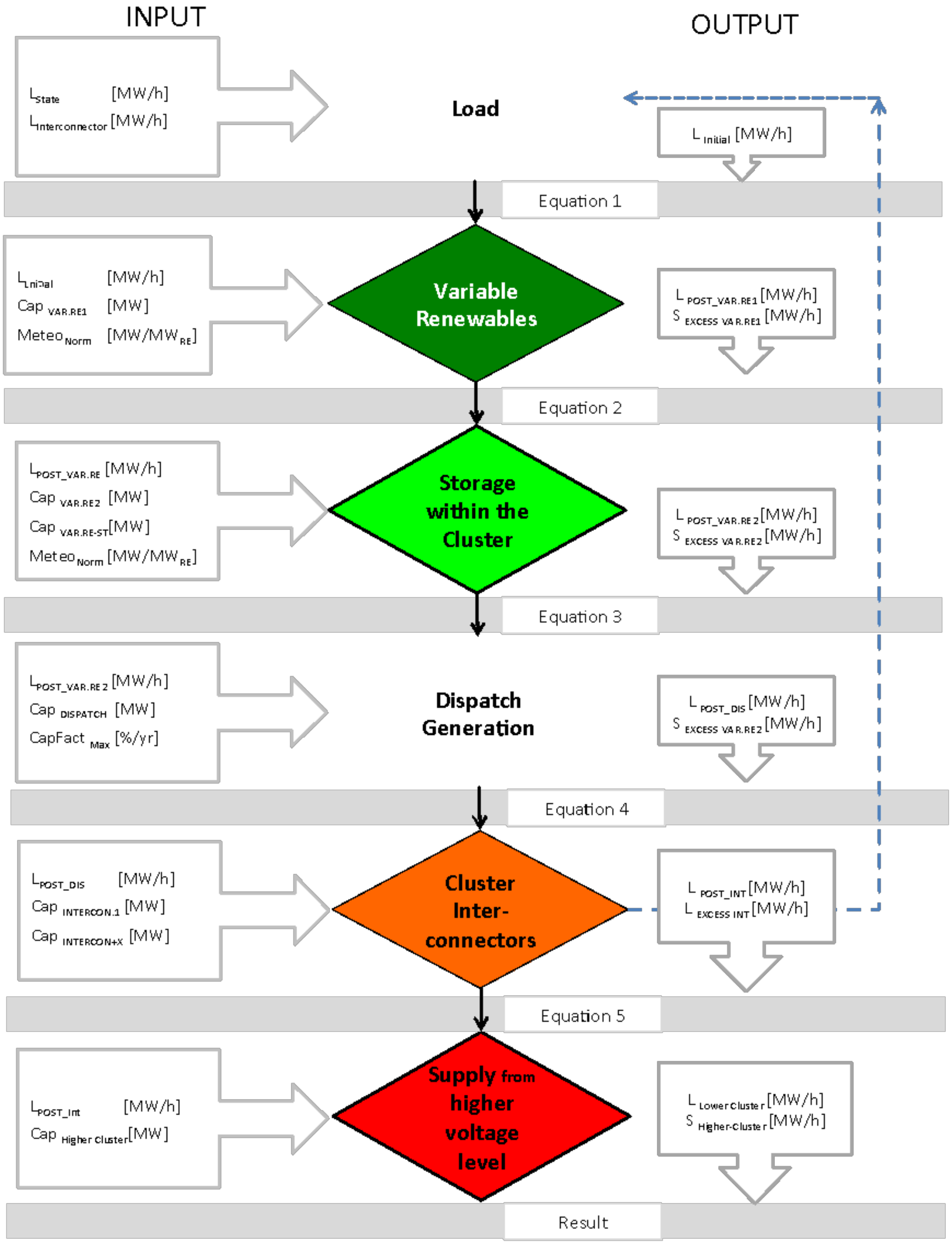
Overview: input and output—[R]E 24/7 energy dispatch model

Figure 8 gives an overview of the input and output parameters and dispatch order. Although the model allows changes in the dispatch order, a 100% renewable energy analysis always follows the same dispatch logic. The model identifies excess renewable production, which is defined as the potential wind or solar photovoltaic generation that exceeds the actual hourly demand in MW during a specific hour. To avoid curtailment, the surplus renewable electricity must be stored with some form of electrical storage technology or exported to a different cluster. Within the model, excess renewable production accumulates through the dispatch order. If storage is present, it will charge the storage within the limits of the input capacity. If no storage is included, this potential excess renewable production is reported as 'potential curtailment' (pre-storage). It is assumed that a certain number of behind-the-meter consumer batteries will be installed, independent of the system requirements.

Limitations

Calculated loads are not optimised in the regard to local storage, self-consumption of decentralised producer of solar photovoltaic electricity and demand side management. Thus, calculated loads may be well below the calculated values.

Figure 8: Overview—Input, output, and dispatch order



2 ITALY: SCENARIO ASSUMPTIONS

2.1 SOCIO-ECONOMIC PARAMETERS

Projections of population and economic growth are important factors in building energy scenarios because they affect the size and composition of the energy demand, both directly and through their impact on economic growth and development.

Socio-economic data

In 2017, Italy had a population of 60.6 million[20] and a population density of 205 persons per square kilometre[21]. Between 1950 and 1986, the population grew from 46 million to 56 million and remained at that level until 2000. The population grew again by around 2.4 million until 2010. According to the projection of Eurostat, the population of Italy will decrease slightly on average by 0.2% per year until 2035. Based on these estimates, the population will decrease to 55.8 million by 2050 (see Table 13).

Economic development

Italy's economic development over the past decade was characterized by recurrent positive and negative economic growth. However, since 2013, Italy's economy has grown around 1% per year, with the exception of 2018, in which GDP decreased by 0.8%[22]. For 2019, the economic growth rate is projected to be just positive[23]. The long-term projection for GDP from 2020 to 2050 (Table 13) is based on estimates of the EU Reference Scenario 2016 (PRIMES 2016)[24] with updated data for years 2016–2019.

Furthermore, we assumed a high GDP development trajectory – above the OECD long-term forecast – and declining population. Thus, the resulting economic activity per capita – in Euro per capita – increases significantly. Our assumption for the energy decarbonisation trajectory is therefore conservative and allow a full renewable energy supply even under higher energy demand development.

Projections of population and economic growth are important factors in the development of energy scenarios because they affect the size and composition of the energy demand, both directly and through their impact on economic growth and development.

Table 14: Italy—Population and GDP projections

	t	2017	2020	2025	2030	2035	2040	2045	2050
GDP	[billion $Euro_{2015}$/a]	1,599	1,589	1,685	1,787	1,926	2,049	2,215	2,395
GDP/Person	[Euro/capita]	26,438	26,525	28,253	30,325	32,930	35,482	39,015	42,885
Population	[million]	60,48	61.2	59.9	59.6	58.9	58.5	57.8	56.8
			2017–2020	**2020–2025**	**2025–2030**	**2030–2035**	**2035–2040**	**2040–2045**	**2045–2050**
Economic growth	[%/a]		0.5%	1.2%	1.2%	1.5%	1.3%	1.6%	1.6%
Population growth	[%/a]		−0.2%	−0.2%	−0.2%	−0.2%	−0.3%	−0.3%	−0.3%

[20] National Institute of Statistics, (PNIEC 2018)Italy and DRAFT INTEGRATED NATIONAL ENERGY AND CLIMATE PLAN Ministry of Economic Development; Ministry of the Environment and Land and Sea Protection; Ministry of Infrastructure and Transport 31/12/2018, https://ec.europa.eu/energy/sites/ener/files/documents/ec_courtesy_translation_it_necp.pdf
[21] Statistica, viewed 8th November 2019, https://www.statista.com/statistics/270469/population-density-in-italy/
[22] Macrotrend – market research and database; website viewed 11th November 2019; https://www.macrotrends.net/countries/ITA/italy/gdp-growth-rate
[23] REUTERS, 19th September 2019; https://www.reuters.com/article/us-italy-economy-budget-forecasts-exclus/exclusive-italy-cuts-2019-2020-gdp-growth-forecasts-sources-idUSKBN1W320J
[24] (PRIMES 2016), EU Reference Scenario 2016; Energy, transport and GHG emissions; Trends to 2050, Appendix 1 page 135, https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

2.2 ITALY: ELECTRICITY DEMAND DEVELOPMENT PROJECTION

The electricity demand projections documented in this section were calculated for the residential and business sectors with the [R]E 24/7 model in a bottom-up process. The further electricity demand entailed by transport (especially under the two alternative scenarios, with increased electric mobility) and by the internal electricity demand of power plants ("own consumption") and the distribution losses are calculated with the long-term model (see sections 0 and 3.2) and added to the calculated demand projections. However, the [R]E 24/7 power analysis only takes into account the additional electricity demand for distribution losses because the power plant consumption does not influence storage or grid requirements.

DEMAND PROJECTIONS FOR THE INDUSTRY AND BUSINESS SECTORS

The industry and business demand development is based on the GDP breakdown (Table 14). It assumes that the overall structure of the economy does not change and that all sectors grow at rates equal to that of GDP over the entire modelling period. Table 15 shows the assumed breakdown of GDP by sub-category. The shares are based on PNIEC 2018[10].

Table 15: Development of GDP shares by industry sector across all regions of Italy (2017)

Industry	31%
Manufacturing	20%
Mining & Energy	2%
Primary Industry	5%
Construction	4%
Services	67%
Offices	54%
Tourism	13%
Agriculture	2%
Agriculture	2%

The GDP distribution by region is based on 2017 data and is assumed to remain the same for the entire modelling period, until 2050. In the industry sector, an efficiency gain of 0.5% per year has been calculated between 2020 and 2030 and 0.75% per year between 2031 and 2050. In the service and agricultural sectors, an efficiency development of 0.5% per year until 2030 has been calculated, with 0.25% for the rest of the modelling period.

Table 16: Development of Italy's shares of GDP by region

Region	[%]
C Nord	15.2%
C Sud	13.8%
Nord	49.7%
Sud	14.1%
Sardegna	3.8%
Sicilia	3.3%

Future energy demand projection for Italy's industry sector are based on the sectorial GDP projects as documented in PNIEC 2018[10]. Table 16 shows the sectorial GDP projections for Italy's five main sectors until 2040. UTS/ISF has not done its own projections; the extension to 2050 is based on 2040 values.

Table 17: Industry sectorial GDP projections

GDP in Added Values	2017 €m (2010)	2018-2020	2020-2025	2025-2030	2030-2035	2035-2040
GDP	1,599,774	1.37%	1.18%	1.19%	1.5%	1.57%
Agriculture	28,009	0.78%	0.55%	0.34%	0.44%	0.49%
Construction	64,524	1.49%	0.93%	1.22%	1.72%	1.85%
Services	1,077,553	1.47%	1.34%	1.31%	1.63%	1.67%
Energy sector	18,931	1.26%	0.58%	0.91%	0.83%	1.2%
Industry	260,815	0.93%	0.61%	0.7%	0.9%	1.06%
Changes in GDP and sectoral added values under the BASE and NECP scenarios; Source: historical values: Eurostat, average annual growth rates: EU Reference Scenario 2016 (see PNIEC 2018, page 173, Table 26)						

ITALY: ELECTRICITY DEMAND PROJECTIONS—HOUSEHOLDS

The analysis of the current and future development of the electricity demand for Italy's households was based on information provided by Greenpeace Italy, TERNA, and statistical data. The different demand levels of households by region were converted into the nine household types. The assumed annual demand in kilowatt-hours per year for each household type is shown Table 17. Significant increases in demand, e.g., from *"Rural Phase 2"* to *"Rural Phase 3"*, are mainly attributed to the use of electrical air-conditioning. The average assumed efficiency gain across all appliances is assumed to be 0.75% per year across the entire modelling period.

Table 18: Household types used in both Energy [R]evolution scenarios and their assumed annual electricity demands

Household Type			2020 [kWh/a]
Rural - Phase 1	-	Low-income rural household	1,850
Rural - Phase 2	-	Lower-middle-income rural household	2,900
Rural - Phase 3	-	Upper-middle-income rural household	3,000
Urban – Single	-	Very-low-income urban household	1,250
Urban/Shared App.	-	Lower-middle-income urban household	2,500
Urban - Family 1	-	Middle-income-household (urban and rural)	3,200
Urban - Family 2	-	Upper-middle-income urban household	3,900
Suburbia 1	-	High-income rural household	4,400
Suburbia 2	-	High-income urban household	3,200

The estimated development of the country-wide electricity shares in the various household types is presented in Table 18. It is assumed that income levels increase and therefore shares of low-income households decrease in all three regions (rural, urban, and suburban). The developments of electricity demand for households have been discussed with various stakeholders and assumptions have been presented at a workshop in Rome in September 2019, organised by Greenpeace Italy.

Table 19: Household types—changes in electricity shares countrywide

Household Type	Countrywide Share [%] (rounded)			
	2020	2030	2040	2050
No access to electricity	0%	0%	0%	0%
Rural - Phase 1	17.5%	15.0%	10.0%	7.5%
Rural - Phase 2	22.5%	25.0%	27.5%	27.5%
Rural - Phase 3	5.0%	5.0%	7.5%	10.0%
Urban - Single	10.0%	7.5%	5.0%	2.5%
Urban/Shared App.	10.0%	12.5%	15.0%	17.5%
Urban - Family 1	10.0%	10.0%	7.5%	7.5%
Urban - Family 2	5.0%	5.0%	7.5%	7.5%
Suburbia 1	10.0%	7.5%	5.0%	2.5%
Suburbia 2	10.0%	12.5%	15.0%	17.5%
Total	100%	100.0%	100%	100%

Source: Italy Statistical Information, Greenpeace Italy survey, Rome Workshop September 2019, and UTS-ISF research

The distributions of electricity shares across the household categories can vary regionally. All shares have been rounded and calibrated to the current regional electricity demand. The authors of this report have deliberately chosen a high standard for Italy's households. The projected development of the electricity demand for Italy's households could be lower if all electrical appliances are of the best technical standard available and if electrical climatization is reduced by the use of energy-efficient solar architecture, which would reduce the overall heating and cooling demand.

2.3 TECHNOLOGY AND FUEL COST PROJECTIONS

The parameterization of the model requires that many assumptions be made about the development of the characteristic technologies, such as the specific investment required and fuel costs. Therefore, because long-term projections are highly uncertain, we must define plausible and transparent assumptions based on background information and up-to-date statistical and technical information.

BACKGROUND: FUEL PRICE PROJECTIONS

The speed of an energy system transition depends, to some extent, on overcoming economic barriers. These largely relate to the relationships between the costs of renewable technologies and those of their fossil counterparts. For our scenarios, the projection of these costs is vital, allowing valid comparisons of energy systems to be made. However, there have been significant limitations to these projections in the past in terms of investment and fuel costs. Moreover, efficiency measures also generate costs, which are usually difficult to determine, and depend on the technical, structural, and economic boundary conditions.

During the last decade, fossil fuel prices have seen huge fluctuations. Figure 9 shows the oil prices since 1997. After extremely high oil prices in 2012, we are currently in a low-price phase. Gas prices saw similar development (IEA 2017)[25]. Consequently, fossil fuel price projections have also seen considerable variations (IEA 2017[74]; IEA 2013[26]), and have considerably influenced scenario results ever since, especially those scenarios that are based on cost optimization algorithms.

Although oil-exporting countries have provided the best oil price projections in the past, institutional price projections have become increasingly accurate, with the International Energy Agency (IEA) leading the way in 2018 (Roland Berger 2018)[27]. An evaluation of the oil price projections of the IEA since 2000 by Wachtmeister et al. (2018)[28] showed that price projections have varied significantly over time. Whereas the IEA's oil production projections seem comparatively accurate, oil price projections have shown errors of 40%–60%, even when made for only 10 years ahead. Between 2007 and 2017, the IEA price projections for 2030 varied from €70 to €140 per barrel, providing significant uncertainty regarding future costs in the scenarios. Despite this limitation, the IEA provides a comprehensive set of price projections. Therefore, we based our scenario assumptions on these projections, as described below.

Because most renewable energy technologies provide energy with no fuel costs, the projections of investment costs become more important than the fuel cost projections, which limits the impact of errors in the fuel price projections. It is only for biomass that the cost of feedstock remains a crucial economic factor for renewables. Today, these costs range from negative costs for waste wood (based on credit for the waste disposal costs avoided), through inexpensive residual materials, to comparatively expensive energy crops.

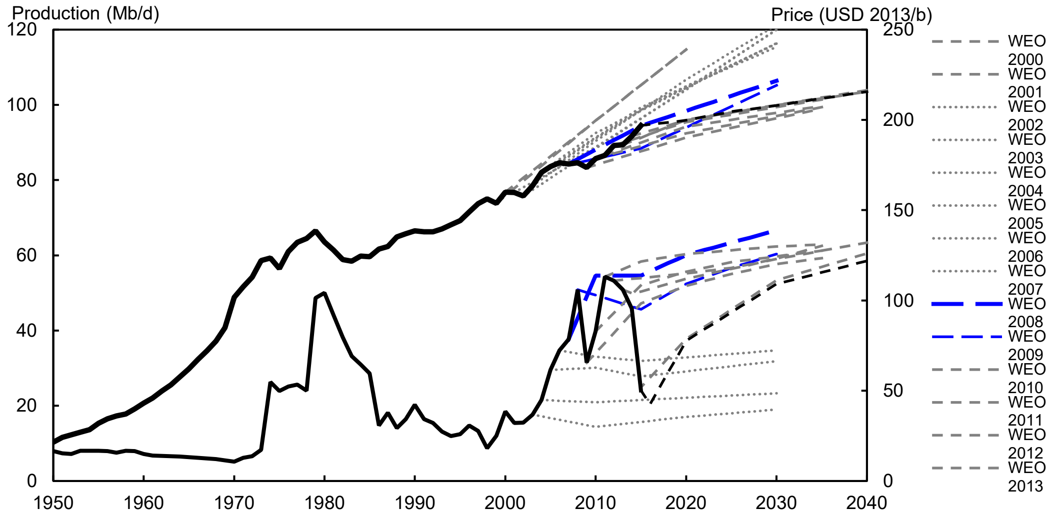


Figure 9: Historic development and projections of oil prices
by IEA according to Wachtmeister et al. (2018)

[25] IEA (2017): IEA (2017) World Energy Outlook 2017. International Energy Agency, Organization for Economic Co-operation and Development, Paris
[26] IEA 2013: IEA (2013) World Energy Outlook 2013. International Energy Agency, Organization for Economic Co-operation and Development, Paris
[27] Roland Berger (2018) 2018 oil price forecast: who predicts best? Roland Berger study of oil price forecasts. https://www.rolandberger.com/en/Publications/pub_oil_price_forecast_2015.html. Accessed 10.9.2018 2018
[28] Wachtmeister H, Henke P, Höök M (2018) Oil projections in retrospect: Revisions, accuracy and current uncertainty. Applied Energy 220:138-153. doi:https://doi.org/10.1016/j.apenergy.2018.03.013

The projection of investment costs also poses challenges for scenario development. Available short-term projections of investment costs depend largely on the data available for existing and planned projects. Learning curves are most commonly used to assess the future development of investment costs as a function of their future installations and markets (McDonald and Schrattenholzer 2001[29]; Rubin et al. 2015[30]). Therefore, the reliability of cost projections largely depends on the uncertainty of future markets and the availability of historical data. Fossil fuel technologies provide a large cost dataset, featuring well-established markets and large annual installations. They are also mature technologies, where many potential cost reductions have already been exploited.

For renewable technologies, the picture is more mixed. For example, hydro power is (like fossil fuels) well established and provides reliable data on investment costs. Other technologies, such as solar photovoltaic and wind, are currently experiencing tremendous advances in installation and cost reduction. Photovoltaic and wind power are the focus of cost monitoring, and considerable data are already available on existing projects. However, their future markets are not easily predicted, as can be seen from the evolution of IEA market projections over recent years in the World Energy Outlook series (compare, for example, IEA 2007, IEA 2014, and IEA 2017). For photovoltaic and wind energy, small differences in cost assumptions will lead to large deviations in the overall costs, so cost assumptions must be made with especial care.

Furthermore, many technologies feature only relatively small markets, such as geothermal and modern bioenergy applications, for which costs are still high and for which future markets are insecure. The cost reduction potential is correspondingly high for these technologies. This is also true for technologies that might become important in a transformed energy system but are not yet widely available. Hydrogen production, ocean power, and synthetic fuels might deliver important technological options in the long term after 2035, but their cost reduction potential cannot be assessed with any certainty today.
Therefore, cost assumptions are a crucial factor in evaluating scenarios. Because costs are an external input into the model and are not calculated internally, we have assumed the same progressive cost developments for all scenarios. In the next section, we present a detailed overview of our assumptions for power and renewable heat technologies, including the investment and fuel costs and the potential CO_2 costs, in the various scenarios.

POWER AND COMBINED HEAT AND POWER (CHP) TECHNOLOGIES

The focus of cost calculations in our scenario modelling is the power sector. We compared the specific investment costs estimated in previous studies (Teske et al. 2019[31] and Teske et al. 2015[32]), which were based on a variety of studies, including investment cost projections by the IEA (IEA 2014) and current cost assumptions by IRENA and IEA (IEA 2016c). We found that the investment costs generally converged, except for the cost of solar photovoltaic, which was higher than average.

The cost projections for power plant and co-generation technologies are taken from Teske et al. (2019)[31]. In order to achieve results comparable to those of INEC (2018) for the baseline scenario, fuel costs have been taken from INEC (2018)[10]. The technology costs (overnight costs and escalation costs due to the interest rates during construction) are given in Table 19. A discount rate of 10% was used for the cost of capital. This discount rate was used to calculate investment annuities and levelized costs of electricity over the technical lifetime of the power plant.

Several renewable technologies have seen considerable cost reductions over the last decade. This is expected to continue if renewables are extensively deployed. Fuel cells are expected to outpace other CHP technologies, with a cost reduction potential of more than 75% (from currently high costs). Hydro power and biomass will remain stable in terms of costs. Tremendous cost reductions are still expected for solar energy and offshore wind, even though they have experienced significant reductions already. However, photovoltaic costs could drop to 35% of today’s costs. Offshore wind has experienced significant cost reductions over the past decade, and could drop a further 30% over the next decade, whereas the cost reduction potential for onshore wind seems to have been exploited already to a large extent.
The investment costs provided in the table below are only the technology costs, and exclude the costs for operation and maintenance and the land fuel costs.

[29] McDonald A, Schrattenholzer L (2001) Learning rates for energy technologies. Energy Policy 29 (4):255-261. doi:https://doi.org/10.1016/S0301-4215(00)00122-1
[30] Rubin ES, Azevedo IML, Jaramillo P, Yeh S (2015) A review of learning rates for electricity supply technologies. Energy Policy 86:198-218. doi:https://doi.org/10.1016/j.enpol.2015.06.011
[31] Teske (2019), Achieving the Paris Climate Agreement Goals—Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5□C and +2.0□C, ISBN 978-3-030-05842-5, Springer, Switzerland 2019
[32] Teske S, Sawyer S, Schäfer O, Pregger T, Simon S, Naegler T, Schmid S, Özdemir ED, Pagenkopf J, Kleiner F, Rutovitz J, Dominish E, Downes J, Ackermann T, Brown T, Boxer S, Baitelo R, Rodrigues LA (2015) Energy [R]evolution - A sustainable world energy outlook 2015. Greenpeace International

Table 20: Investment cost assumptions for power generation plants (in Euro2019/kW) until 2050

Assumed Investment Costs for Power Generation Plants						
		2017	2020	2030	2040	2050
CHP coal	Euro/kW	2270	2270	2270	2270	2270
CHP gas	Euro/kW	908	908	908	908	908
CHP lignite	Euro/kW	2270	2270	2270	2270	2270
CHP oil	Euro/kW	1190	1171	1126	1072	1026
Coal power plant	Euro/kW	1816	1816	1816	1816	1816
Diesel generator	Euro/kW	817	817	817	817	817
Gas power plant	Euro/kW	608	454	454	454	608
Lignite power plant	Euro/kW	1998	1998	1998	1998	1998
Oil power plant	Euro/kW	863	845	808	781	745
Renewables						
CHP biomass	Euro/kW	2316	2270	2225	2134	2043
CHP fuel cell	Euro/kW	4540	4540	2270	2270	2017
CHP geothermal	Euro/kW	11,987	10,162	8073	6774	5866
Biomass power plant***	Euro/kW	2179	2134	2089	1998	1916
Hydro power plant**	Euro/kW	11,206	2543	2406	2270	2179
Ocean energy power plant	Euro/kW	6311	6039	3996	2815	1916
Photovoltaic, rooftop	Euro/kW	1,300	980	730	560	470
Photovoltaic—utility scale	Euro/kW	1,181	890	663	509	427
CSP* power plant (incl. storage)	Euro/kW	5176	4540	3360	2770	2488
Wind turbine offshore	Euro/kW	3632	3351	2897	2570	2370
Wind turbine onshore	Euro/kW	1489	1435	1371	1317	1271
Hydrogen production	Euro/kW	1253	1108	835	636	518

*Costs for a system with a solar multiple of two and thermal storage for 8 h of turbine operation
**Values apply to both run-of-the-river and reservoir hydro power
*** In this research bio energy and synthetic fuels are considered to be interchangeable fuels for power plants, combined heat- and power plants (CHP) and heating plants. The maximum amount of available sustainable bio mass requires more research and was out of scope for this analysis. Synthetic fuels which produced by renewable electricity – mainly solar and wind power –will either add to bio energy supply or replace them.

HEATING TECHNOLOGIES

Assessing the costs in Italy's industrial heating sector is even more ambitious than in the power sector. The costs of new installations will differ significantly between regions and are linked to construction costs and industry processes, which are not addressed in this study. Moreover, no data were available to allow the comprehensive calculation of the costs of existing heating appliances in Italy. Therefore, we concentrate on the additional costs that will result from the application of new renewable resources in the heating sector. Our cost assumptions for heat generation are based on a previous survey of renewable heating technologies across Europe, which focused on solar collectors, geothermal, heat pumps, and biomass applications. Biomass and simple heating systems in the residential sector are already mature. However, more-sophisticated technologies, which can provide higher shares of the heat demand from renewable sources, are still under development and rather expensive. Market barriers will slow the further implementation and cost reduction of renewable heating systems, especially for heating networks. Nevertheless, significant learning rates can be expected if renewable heating is increasingly implemented, as projected in our high-renewables scenarios.

Table 20 presents the investment cost assumptions for heating technologies in Europe, disaggregated by sector. Geothermal heating displays the same high costs in all sectors. In Europe, deep geothermal applications are being developed for heating purposes at investment costs ranging from €500/$kW_{thermal}$ (shallow) to €3000/$kW_{thermal}$ (deep), and the costs are strongly dependent on the drilling depth. The cost reduction potential is assumed to be around 30% by 2050 (Teske et al. 2019)[7].

Table 21: Specific investment cost assumptions (in Euro) for heating technologies in the scenarios until 2050

Investment costs for heat-generation plants in OECD Europe							
			2017	**2020**	**2030**	**2040**	**2050**
Geothermal		Euro/kW	2170	2061	1843	1635	1444
Heat pumps		Euro/kW	1625	1580	1489	1398	1300
Biomass heat plants		Euro/kW	545	527	499	463	436
Residential biomass stoves	Industrialized countries	Euro/kW	763	736	690	654	620
Residential biomass stoves	Developing countries	Euro/kW	100	100	100	100	100
Solar collectors	Industry	Euro/kW	772	745	663	590	500
	In heat grids	Euro/kW	881	881	881	881	881
	Residential	Euro/kW	963	917	826	726	600

Heat pumps typically provide hot water or space heat for heating systems with relatively low supply temperatures, or they supplement other heating technologies. Therefore, they are currently mainly used for small-scale residential applications. Costs currently cover a large bandwidth and are expected to decrease by only 20% to €1300/kW by 2050 (Teske et al. 2019)[7]. For biomass and solar collectors, we assume the appropriate differences between the sectors. There is a broad portfolio of modern technologies for heat production from biomass, ranging from small-scale single-room stoves to heating or CHP plants on a megawatt scale.

Investment costs show similar variations: simple log-wood stoves can cost from €100/kW, but more sophisticated automated heating systems that cover the whole heat demand of a building are significantly more expensive. Log-wood or pellet boilers range from €500/kW to €1300/kW. Large biomass heating systems are assumed to reach their cheapest in 2050 at around €620/kW for industry.
For all sectors, we assume a cost reduction of 20% by 2050. In contrast, solar collectors for households are comparatively simple and will become cheap at €600/kW by 2050. The cost of simple solar collectors for swimming pools might have been optimized already, whereas their integration into large systems is neither technologically nor economically mature. For larger applications, especially in heat grid systems, the collectors are large and more sophisticated. Because there is not yet a mass market for such grid-connected solar systems, we assume there will be a cost reduction potential until 2050 (Teske et al. 2019)[7].

FUEL COST PROJECTIONS

Although fossil fuel price projections have seen considerable variations, as described above, we based our fuel price assumptions on INEC (2018)[10] and LAZARDS (2018)[33]. Although these price projections are highly speculative, they provide a set of prices consistent with our investment assumptions. Bio-energy costs will increase as utilisation increases and importation will be required after 2025.

Table 22: Development projections for fossil fuel prices

Development projections for fossil fuel prices						
All Scenarios		**2017**	**2020**	**2030**	**2040**	**2050**
Biomass	Euro/GJ	7.00	12.45	18.23	23.82	27.78
Synthetic Fuels	Euro/GJ	-	-	18.23	23.82	27.78
Oil	Euro/GJ	9.19	11.61	14.52	16.04	25.50
Gas	Euro/GJ	6.58	7.47	8.79	9.70	10.7
Coal	Euro/GJ	1.95	2.21	3.18	3.50	3.80

[33] LAZARDS (2018); Lazard's Levelized Cost of Energy Analysis—Version 12.0, November 2018

2.4 ITALY: GEOGRAPHIC INFORMATION

The regional distribution of the population and the availability of energy infrastructure correlate strongly with the socio-economic situation in Italy and its future economic development. The following maps provide an overview of Italy's regional population, the locations of power lines and power plants, a regional breakdown of the energy pathways, and a power sector analysis (section 5.9).

Distribution of population and power grid

The regional breakdown used for the energy model is shown in Figure 10, and the distribution of Italy's population is shown in Figure 11. The most densely populated regions in Italy are Milan in the north, Rome and Naples in the centre west, Bari in the south, and the coastal regions along the most parts of the coastline. The population density is significantly lower further inland and in the Alps.

Figure 10: Regional breakdown of Italy for the power sector analysis

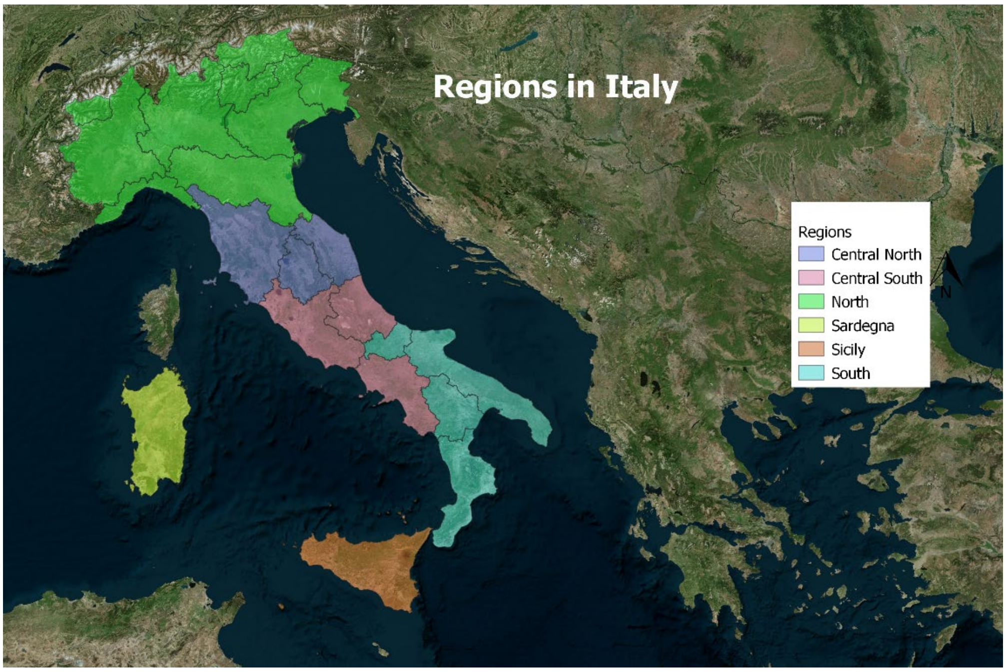
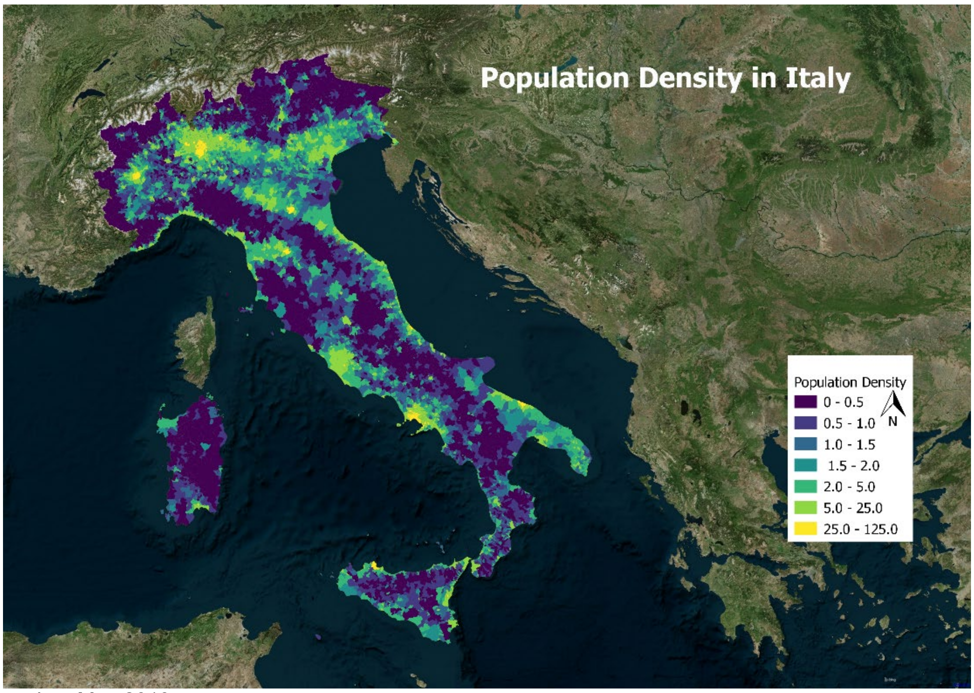


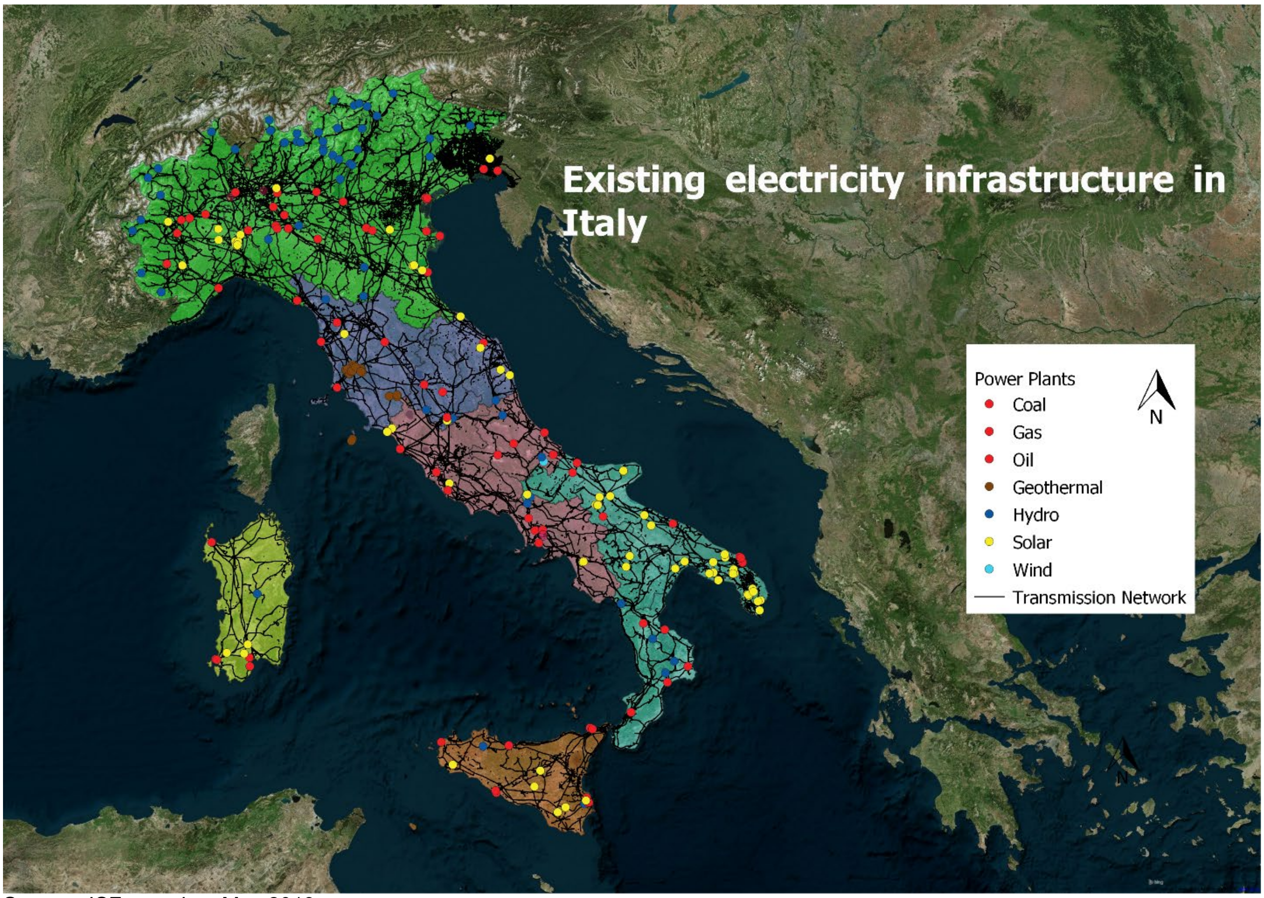
Figure 11: Distribution of population in Italy



Source: ISF mapping, May 2019

Figure 12 combines the population distribution and existing electricity infrastructure (power lines and power plants over 50 MW) with the different types of grids and power stations in the country. The different coloured dots mark grid-connected power plants—each colour stands for one technology, identified in the legend. The population density increases from light yellow (low population density) to red (high population density). The lines represent power transmission power lines with different voltage levels. No GIS-based data on existing solar photovoltaic and onshore wind power plants are available.

Figure 12: Existing electricity infrastructure by type



Source: ISF mapping, May 2019

2.5 RENEWABLE ENERGY POTENTIAL

Italy has a largely untapped potential for renewable energy, and the only resource used significantly is biomass. Biomass and geothermal resources are predominantly utilized in the power sector. There is no further potential to increase hydro power because Italy's utilization rate for hydro power plants is already at the maximum level in terms of sustainability. Solar energy is abundant, with excellent potential for utility-scale photovoltaic power stations, particularly in rural areas. Initially successful policy support schemes, such as the "Conto Energia" program started in 2005, laid the foundations for the significant growth of solar photovoltaic installation. In 2018, capacity passed the 20 GW milestone and the "National Energy Strategy" (SEN), published in 2017 set a new target to reach 50 GW by 2030 (PVPS 2018)[34].

Wind resources have been assessed by various organizations and there is medium potential for onshore wind power generation. The offshore wind potential in the region is significantly lower than, for example, in the North Sea area, despite the long coastline.

2.5.1 SOLAR POTENTIAL ANALYSIS BY UTS-ISF

The average annual solar radiation levels in Italy are 3.6–5.4 kWh/m^2 per day (SolarGIS 2019)[35]. The higher end of that range is suitable for concentrated solar power. According to the International Renewable Energy Agency, Italy had an installed solar capacity of 20,120 MW, including rooftop photovoltaics, at the end of December 2018 (IRENA 2019)[36]. Utility-scale solar photovoltaic power plants only have a minor share of the overall installations and the majority of solar PV installations are small generators below 20 kW (PV MAGAZINE 2019)[37].

Italy's solar potential has been mapped under the three different scenarios.

1. Available land—restricted by nature conservation, agricultural, commercial, or urban use (LU)

2. See above, with two additional restrictions: (1): maximum of 10 km from existing transmission lines (PT); and (2) contiguous areas (CA)—fractured areas of less than 1 km^2 are excluded.

3. See above, with an additional restriction: (3) slope > 30% (mountain areas) and additional land-use restrictions.

Solar potential restrictions	Solar area in km^2	Solar potential in GW
LU	43,851	1,096
LU + PT + CA	40,896	1,022
LU + PT + CA + S30	38,057	951

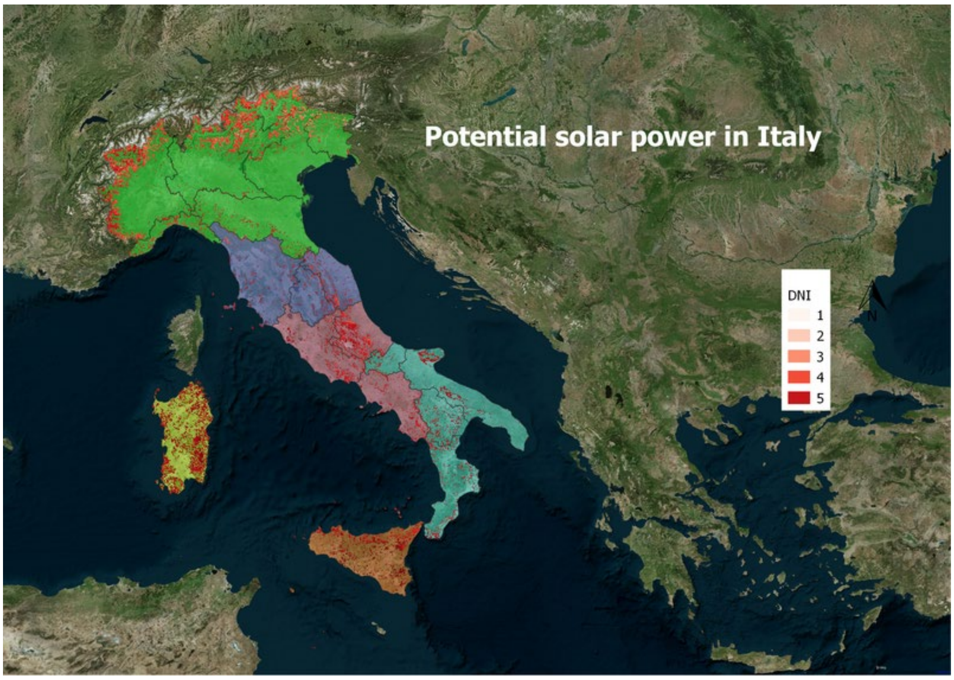
Table 23: Utility-scale solar potential for Italy under different restrictions

The calculated potential for utility-scale solar power plants (PV and CSP) under all restrictions and excluding areas further than 10 km from transmission lines is 951 GW. Even the most ambitious E[R] scenario can be implemented with the utilization of only 15% of the utility-scale solar power plant potential. AAs well as this potential, Italy has significant rooftop solar photovoltaic potential of around 70 GW. The ADV. E[R] scenario has less solar photovoltaic power generation and wind power generation because of its higher efficiency target.

[34] PVPS 2018, International Energy Agency Technical Collaboration Programme, PVPS Annual Report 2018; http://www.iea-pvps.org/?id=6
[35] SolarGIS – online database, viewed November 2019; https://solargis.com/maps-and-gis-data/download/italy
[36] IRENA (2019) – Renewable Capacity Statistics 2019, https://www.irena.org/publications/2019/Mar/Renewable-Capacity-Statistics-2019
[37] PV MAGAZINE (2019), Italy installed 105 MW of solar in Q1 2019, June 05, 2019, https://www.pv-magazine.com/2019/06/05/italy-installed-105-mw-of-solar-in-q1-2019/

Figure 13 shows the land available for utility-scale solar photovoltaics under the LU restrictions, but not with the further restrictions, such as proximity to transmission lines or topographic slope.

Figure 13: Potential for utility-scale solar energy generation in Italy



Source: ISF mapping, July 2019

When restricted by its proximity to power lines and the terrain slope, the solar potential decreases. Under this scenario, Italy has over 40,000 km^2 of land on which 1,000 GW of solar power can potentially be harvested by utility-scale solar farms. To avoid conflicts with national parks and other competing uses of the land, only perennial cropland and open bushland land-cover types were included in the analysis. Only utility-scale solar energy has been included in the analysis, and no further breakdown by technology has been done. However, the available area for concentrated solar power is only a smaller fraction of this because it requires high radiation levels with direct sunlight, which are only available in the southern part of the country.

2.5.2 Wind Potential Analysis by UTS-ISF

Wind Energy

Currently, Italy's total installed wind power capacity for onshore wind farms is about 10,310 MW. There are currently no offshore wind farms in Italian waters. However, Italy's first near-shore project is currently in development with a planned capacity of 30 MW, located near the port of Taranto in the very south of the country (WPO 2019)[38]. It is likely to be the first offshore wind project in the Mediterranean Sea.

Onshore Wind

The overall wind resources on land are moderate to good in Italy and the average annual wind speeds in most suitable land areas range between 6 and 7 m/s. Italy's wind potential has been mapped under four different scenarios.

1. Available land—restricted by nature conservation, agricultural, commercial, or urban use (LU).
2. See above, with the additional restriction: (1): maximum of 10 km from transmission lines (PT).
3. See above, with the additional restriction: (2) contiguous areas (CA).
4. See above, with the additional restriction: (3) slope > 30% (mountain areas) and additional land use restriction (S30).

[38] WPO 2019, Wind Power Offshore, Wind Power Monthly 2019, 1st March 2019; https://www.windpoweroffshore.com/article/1577566/italys-first-offshore-wind-project-gets-go-ahead

Onshore wind potential restrictions	Onshore wind area in km²	Onshore wind potential in GW
LU + WS	23,997	96
LU + WS + CA	13,427	54
LU + WS + PT + CA + S30	12,181	49

Table 24: Onshore wind potential for Italy under different restrictions

Table 23 shows that the onshore wind potential for utility-scale wind farms under the assumed land-use restrictions is as high as 96 GW (see Figure 9). If mountain areas with slopes of > 30%, fractured spaces less than 1 km², and areas more than 10 km from a power line are excluded, this potential more than halves, to 49 GW.

Offshore Wind

Italy has some offshore wind potential, with average wind speeds up to 7–9 m/s, leading to capacity factors of around 3,000 h per year. In this analysis, we used offshore wind only as an additional form of renewable power generation because the resource is significantly lower than in the main European offshore wind development regions in Northern Europe. However, if the installation costs of floating offshore wind turbines continue to fall, the authors recommend to the expansion of the offshore wind capacity to either reduce the onshore wind capacity or to produce additional synthetic fuel to replace bio-fuels.

This analysis took into account coastal areas with a maximum water depth of 50 m and a maximum distance to shore of 70 km. Within these restrictions, Italy has a technical potential of 75 GW, spread over a total 7,500 km of coastline and over 18,000 km².

Further research is required to locate the exact offshore wind areas, both in terms of their distance to shipping lines, fisheries, and marine protection areas, their access to infrastructure, such as the power grid, and their access to harbour facilities for the operation and maintenance of wind farms. The offshore gas sector can benefit from the increased deployment of offshore wind power because workers and parts of the infrastructure can be re-used (e.g., ships, supply equipment).

Figure 14: Onshore wind power potential in Italy—land-use restrictions only (75 GW)

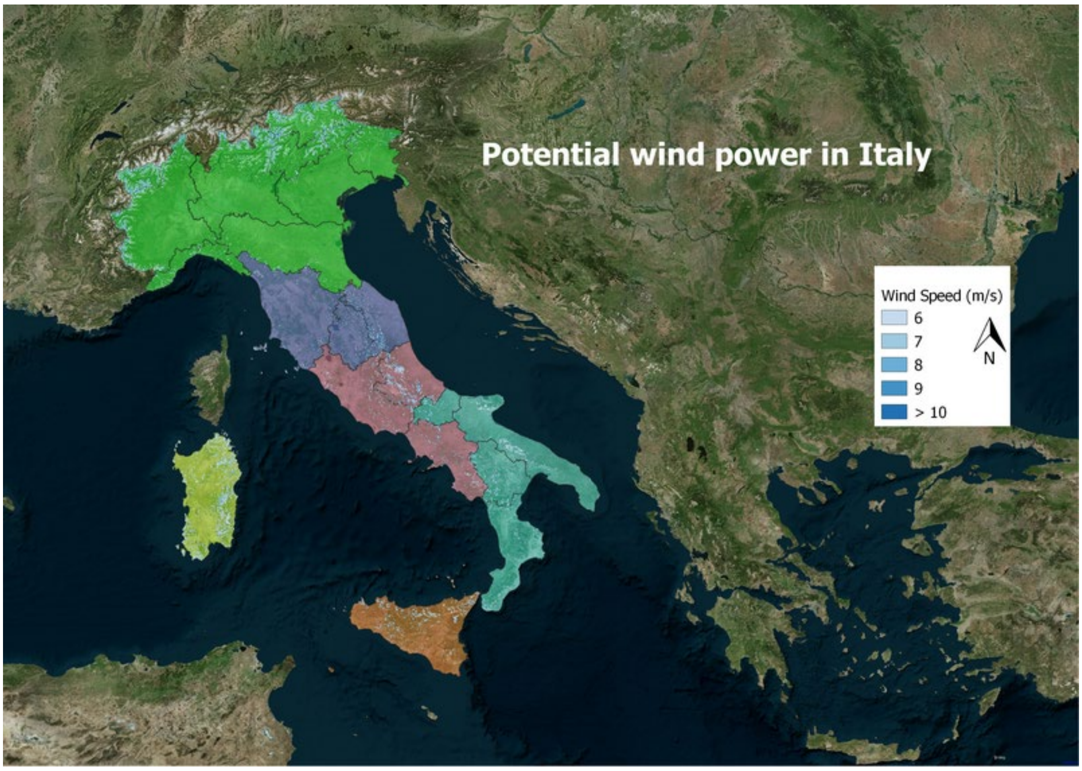
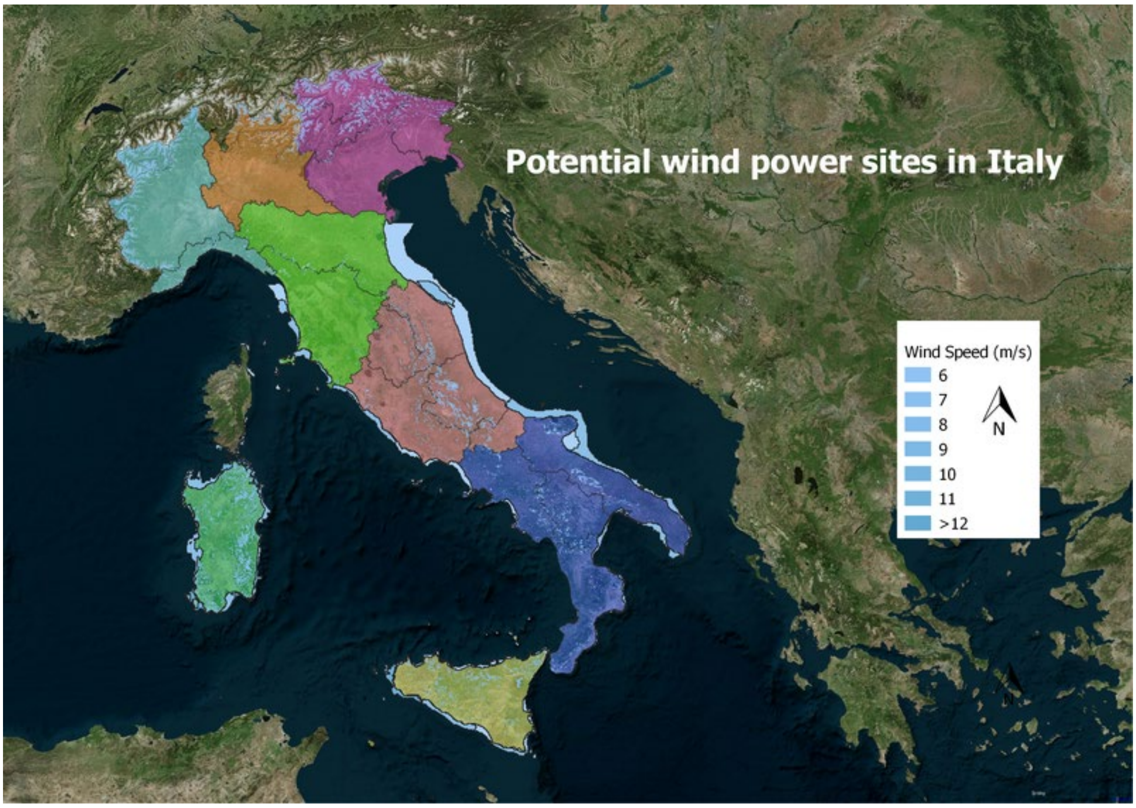


Figure 15: Offshore wind energy generation potential in Italy



Source: ISF mapping, July 2019

2.5.3 OVERVIEW OF SOLAR AND WIND POTENTIAL FOR ITALY BY REGION

Table 24 shows Italy's potential for utility-scale solar and wind power generation under the most restricted scenarios described in section 2.5.

Table 25: Italy—Summary: Overview—Italy's utility-scale solar photovoltaic and onshore wind potentials within 10 km of existing power lines by market zone

Cluster	Solar Area in km²	Solar Potential in GW	Onshore Wind Area in km²	Onshore Wind Potential in GW
C Nord	2,516	63	674	2.7
C Sud	4,970	125	1,473	5.9
Nord	15,769	394	4,019	16.0
Sud	4,110	103	1,376	5.5
Sardegna	7,051	176	3,429	13.7
Sicilia	3,641	90	1,182	4.7
Total	38,057	951	12,153	48,5

2.5.4 BIO-ENERGY

Mapping the bio-energy resources for Italy was beyond the scope of this research. Therefore, we used data from a literature search. The bio-energy potential ranges from 469 PJ/a to 1055 PJ/a (Table 25) according to Scarlat et al. (2013)[39]. Both alternative scenarios (see section 4) will require around 2,200 PJ/a bio-energy and synthetic fuels for use in the power, heating, and transport sectors by 2050. The different scenarios assumed various developments in land-use, future nutrition and agricultural industries. The most ambitious bio-energy deployment scenario identified Italy's potential for SRC as 1,051 PJ/a and for biogas as high as 377 PJ/a, both for the year 2050 (DBFZ 2008)[40]. The Italian bio-energy potential will be exhausted between 2025 and 2030 and we assume that the remainder will be imported as synthetic fuels produced by renewable electricity.

Table 26: Biomass potential in Italy and available biomass [PJ].

	NREAP 2011[41]	Scarlat et al. 2011[42]	Rettenmaier et al. 2010[43]	Dallemand et al. 2009[44]	Motola et al. 2009[45]	EEA 2006[46]
Forestry	167	38	180	247	121	544
Direct wood	167	38	138	176	100	448
Indirect wood	0	0	38	71	21	96
Agriculture	272	406	502	611	285	234
Crops	67	406	373	188	13	4
By-products	205	0	130	423	272	230
Waste	100	25	113	201	176	67
Municipal solid waste	75	25	50	75	92	17
Industrial	25	0	50	100	42	42
Sewage sludge	0	0	13	25	8	8
Total	540	469	783	1055	553	846

The highest demand for bio- and synthetic fuels under the Energy [R]evolution scenario will occur in 2050 with 2,229 PJ/a, whereas the Advanced Energy [R]evolution scenario will have a peak demand for bio- and synthetic fuels in 2040 of 2,267 PJ/a (primary energy). The reason for this short-term high consumption of bio-and synthetic fuels is the transition from fossil to renewable energy in the transport sector and for industrial process heat when biofuels and synthetic fuels replace fossil fuels.

In this research bio energy and synthetic fuels are considered to be interchangeable fuels for power plants, combined heat- and power plants (CHP) and heating plants. The maximum amount of available sustainable bio mass requires more research and was out of scope for this analysis. Synthetic fuels which produced by renewable electricity – mainly solar and wind power –will either add to bio energy supply or replace them. If these synthetic fuels were to be produced in Italy, then the demand for electricity would gradually increase. This could then be generated in additional wind or solar power plants. For hydrogen fuel production, technical efficiencies up to 75% are possible, while for synthetic fuels, efficiencies are low and estimated to range between 40% and 50%. Thus, the production of 100 PJ/a hydrogen fuel requires around 37 TWh/a electricity while synthetic fuel production requires approximately 66 TWh/a.

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[39] Scacarlat et. al 2013, Bioenergy production and use in Italy: Recent developments, perspectivesand potential N. Scarlat, European Commission, Joint Research Centre, Institute for Energy, Via E. Fermi 2749, TP 450, 2102 Ispra (Va), Italy, ELSEVIER, RENEWABLE ENERGY, March 2013

[40] DBFZ 2008; Deutsches Biomasse Forschungszentrum, Report – Global Biomass Potentails, Thilo Seidenberger, Daniela Thraen, Ruth Offermann, Ulrike Seyfert, Marcel Buchhorn, Juergen Zeddies, commissioned by Greenpeace International, June 2008

[41] NREAP 2011; National Renewable Energy Action Plans, 2011. Available at: http://ec.europa. eu/energy/renewables/action_plan_en.htm, [

[42] Scarlat et al. 2011; Scarlat N, Blujdea V, Dallemand JF. Assessment of the availability of agricultural and forest residues for bioenergy production in Romania. Biomass and Bioenergy 2011;35:1995e2005.

[43] Rettenmaier et al. 2010; Rettenmaier N, Schorb A, Köppen S. Status of biomass resource assessments; 2010. Biomass energy Europe report.

[44] Dallemand et. al. 2009; Dallemand JF, Leip A, Rettenmaier N. Biocarburants liquides pour le transport: de défi d'une correcte évaluation du bilan environnemental. In: Pollution Atmosphérique; April 2009.

[45] Motola et al. 2009; Motola V., Colonna N., Alfano V., Gaeta M., Sasso S., De Luca V., et al., Censimento potenziale energetico biomasse, metodo indagine, atlante Biomasse su WEB-GIS Report RSE/2009/167.

[46] EEA 2006; European Environment Agency, How much bioenergy can Europe produce without harming the environment?, Report no. 7/2006, Isbn: 92-9167-849-X20

2.6 ECONOMIC AND POLICY ASSUMPTIONS

Italy has adopted new energy and climate goals in 2019. As required by the Regulation of the European Parliament and of the Council 2016/0375 on the governance of the Energy Union, Italy submitted a 10-year strategy on energy efficiency and environmental sustainability in December 2018. This Integrated National Plan for Energy and Climate (PNIEC) contains the goals to phase out of coal by 2025 and to expand the share of renewable energy in its final energy consumption to 28% by 2030. The reference scenario in this analysis has taken those goals into account, and we suggest two scenarios that go further in terms of the deployment of renewable energy and energy efficiency across all sectors.

With the reductions in prices for solar photovoltaics and onshore wind that have occurred in recent years, renewables have become an economic alternative to building new gas power plants. Consequently, renewables have achieved a global market share of over 60% of all newly built power plants since 2014. Italy has significant solar and wind resources and some additional potential for offshore wind.

The costs of renewable power generation are generally lower in situations with greater solar radiation and higher wind speeds. However, constantly shifting policy frameworks often lead to high investment risks, and therefore to higher project development and installation costs for solar and wind projects relative to those in countries with more stable policies.

The scenario-building process for all scenarios includes assumptions about policy stability, the role of future energy utilities, centralized fossil-fuel-based power generation, population and GDP, firm capacity, and future costs.

- **Policy stability:** This research assumes that Italy will establish a secure and stable framework for the deployment of renewable power generation. In essence, financing a gas power plant or a wind farm is quite similar. In both cases, a power purchase agreement, which ensures a relatively stable price for a specific quantity of electricity, is required to finance the project. Daily spot market prices for electricity and/or renewable energy or carbon are insufficient for long-term investment decisions for any kind of power plant with a technical lifetime of 20 years or longer. In short, the better the investment certainty, the lower the cost of capital.
- **Strengthened energy efficiency policies:** Existing policy settings (i.e., the energy efficiency standards for electrical applications, buildings and vehicles) must be strengthened to maximize the cost-efficient use of renewable energy and to achieve high energy productivity by 2030.
- **Role of future energy utilities:** With the ‘grid parity’ of rooftop solar photovoltaics under most current retail tariffs, this modelling assumes that energy utilities of the future will take up the challenge of increased local generation and develop new business models that focus on energy services, rather than simply on selling kilowatt-hours.
- **Population and GDP:** All three scenarios are based on the same population and GDP assumptions. The projections of population growth are taken from the Italian National Institute of Statistics[20] and the GDP projections are based on PNIEC 2018[Error! Bookmark not defined.].
- **Cost assumptions:** The same cost assumptions are used across all three scenarios. Because technology costs decline as the scale of deployment increases rather than with time, the renewable energy cost reduction potential in both Energy [R]evolution scenarios may be even larger than in the REFERENCE scenario because of the larger market sizes. The reverse is true for the fuel cost assumptions because all the scenarios are based on the same fossil fuel price projections, but whereas both Energy [R]evolution scenarios predict a significant drop in demand, the REFERENCE scenario assumes an increased demand, which may lead to higher fuel costs. Therefore, these costs should be considered conservative. The cost assumptions are documented in section 5.3.

2.7 ASSUMPTIONS FOR SCENARIOS

2.7.1 REFERENCE SCENARIO

The aim of the present report is to analyse a decarbonization scenario for Italy to be reached by 2040, according to the Greenpeace demand for the European Union target. Industrialised countries, and the EU, must decarbonize more rapidly in order to maintain the 1.5 °C threshold for the global climate. Given that longer-term scenario, the report takes the Italian NECP proposal (PNIEC, 2018) as the reference scenario. The present climate political debate, in fact, focuses on the 2030 targets, which are under revision at the European level in view of the new National Determined Contributions to be presented according the Paris Agreement rules. Therefore, the objective of the present report is also to review the Italian 2030 targets under the accelerated decarbonization strategy required for the 1.5 °C global scenario.

For this purpose, we have adjusted some of the basic parameters for the 2050 projections: the GNP forecast is the OECD long-term projection for Italy with a GNP increase of less than 1.2% per annum on average, compared with the 1.5% per annum assumed PNIEC. For population, the reference data are from the Eurostat projections to 2050, which are substantially lower than the PNIEC assumptions.

2.7.2 ASSUMPTIONS FOR BOTH ENERGY [R]EVOLUTION SCENARIOS

Both the E[R] and ADV. E[R] scenarios are built on a framework of targets and assumptions that strongly influence the development of individual technological and structural pathways for each sector. The main assumptions made in this scenario-building process are detailed below.

- **Emissions reductions:** The main measures undertaken to reduce CO_2 emission in the E[R] and ADV. E[R] scenarios include strong improvements in energy efficiency, resulting in an increase in energy productivity of 30% between 2020 and 2030, and the dynamic expansion of renewable energy across all sectors.
- **Renewables industry growth:** The dynamic growth of new capacities for renewable heat and power generation is assumed, based on current knowledge of potentials, costs, and recent trends in renewable energy deployment (see energy potentials, discussed in section 2.5). Communities will play a significant role in the expansion of renewables, particularly in terms of project development, the inclusion of local populations, and the operation of regional and/or community-owned renewable power projects.
- **Future power supply:** The capacity of large hydro power and bio-energy facilities will grow slowly and within economic and ecological limits. The supply from all bio-energy facilities supported by sustainable biofuels and synthetic fuels is a key issue and may come from either within Italy or from certified imports. Wind power (on- and offshore) and solar photovoltaic power are expected to be the main pillars of the future power supply, complemented by contributions from bio-energy and gas power plants. The solar photovoltaic figures combine both rooftop and utility-scale photovoltaic plants. The potential for offshore wind is significantly higher than that for onshore wind, so the majority of wind power under both Energy [R]evolution scenarios will be offshore wind. The solar resources for concentrated solar power are insufficient and are therefore not included in the analysis.
- **Firm capacity:** The scale of each technology deployed and the combination of technologies in each of the scenarios are designed to target a firm capacity. Firm capacity is the “proportion of the maximum possible power that can reliably contribute towards meeting the peak power demand when needed.”[47] Firm capacity is important to ensure a reliable and secure energy system. Note that variable renewables also have a firm capacity rating, and the combination of technology options increases the firm capacity of a portfolio of options. Storage will add to the firm capacity as the share of variable power generation increases.
- **Security of energy supply:** The scenarios limit the share of variable power generation and maintain a sufficient share of controllable, secured capacity. This includes storage technologies. Power generation from biomass or hydro power, and a share of gas-fired back-up capacity and storage, are considered important for the security of supply in a future energy system, and are related to the output of firm capacity discussed above.
- **Sustainable biomass levels:** The sustainable level of biomass used in Italy is assumed to be limited. Low-tech biomass use, such as inefficient household wood-burners, is largely replaced in the Energy

[47] http://igrid.net.au/resources/downloads/project4/D-CODE_User_Manual.pdf

[R]evolution scenarios by state-of-the-art technologies, predominantly highly efficient co-generation plants.

- **Electrification of transport**: Efficiency savings in the transport sector will result from fleet penetration by new highly efficient vehicles, such as electric vehicles, but also from assumed changes in mobility patterns and the implementation of efficiency measures for combustion engines. The RE scenarios assume a limited use of biofuels for transportation, given the limited supply of sustainable biofuels.

  Hydrogen and synthetic fuels: Hydrogen and synthetic fuels, generated by electrolysis using renewable electricity, are introduced as a third renewable fuel in the transportation sector, complementing biofuels, the direct use of renewable electricity, and battery storage. Hydrogen generation can have high energy losses. However, the limited potential of biofuels and probably also of battery storage for electric mobility means it will be necessary to have a third renewable option in the transport sector. Alternatively, renewable hydrogen could be converted into synthetic methane and liquid fuels, depending on the economic benefits (storage costs versus additional losses) and the technological and market developments in the transport sector (combustion engines versus fuel cells). Hydrogen and synthetic fuels will be imported. In the industry sector, hydrogen can be an additional renewable fuel option for high-temperature applications, supplementing biomass in industrial processes whenever the direct use of renewable electricity is not possible. In this analysis Synthetic fuels are introduced after 2030 as replacement for natural gas as imported from abroad. In the ADV E[R] some hydrogen enters in the scenario by 2050

2.7.2.1 Assumptions for Energy [R]evolution

The Energy [R]evolution scenario (E[R]) is designed to meet Italy's energy-related targets and to lead towards a pathway of 100% renewable energy by 2050. Coal power plants will be phased-out by 2025 and replaced by renewables, not gas power plants as in the REFERENCE scenario. Both the heating and the transport sectors will start to replace fossil fuels with electricity where it is economically possible. Thermal renewables for heating, mainly solar- and bio-energy-based generation, will replace fossil fuels.

Energy efficiency and renewable energy generation technologies will follow moderate implementation growth rates during the first decade until 2030. Electric mobility will grow steadily over the entire modelling period (until 2050) and will replace combustion engines entirely by 2050. The Energy [R]evolution scenario aims to reduce energy-related CO_2 emissions to 60% of 1990 levels (25% lower than in 2017) by 2030 and to decarbonize the energy sector by 2050.

2.7.2.2 Assumptions for the Advanced Energy [R]evolution

The Advanced Energy [R]evolution scenario (ADV. E[R]) is more ambitious than the E[R] scenario, but follows the same technology pathways. The decarbonization of the power and heating sectors will be achieved in 2040, 10 years ahead of the E[R] scenario. Energy efficiency will play an accelerated role and leads to a lower final energy demand (16% below that under E[R]).

The Advanced Energy [R]evolution will decarbonize Italy's energy sector entirely by 2040.

3 KEY RESULTS FOR ITALY: LONG-TERM ENERGY SCENARIO

In this section, we outline the key results across a range of areas, in terms of both the impacts and the costs of the different scenarios. First, we consider stationary energy, focusing on electricity generation, capacity, and breakdown by technology. We then examine the energy supply for heating, focusing on industrial heat supply. This is followed by a discussion of the impacts and costs of the different scenarios on transport and the development of CO_2 emissions. The chapter ends with an examination of the final costs, and an outline of the required energy budget.

This chapter provides an overview to the three energy pathways for Italy until 2050, focusing on the 2030 results. The scenarios describe a holistic approach to the entire energy sector—power, heat, process heat, and transport. Increased electrical mobility and the electrification of heating processes will lead to "*sector coupling*" or the interconnection of historically rather separate energy sectors. As a result, the electricity demand will increase, even under ambitious electricity efficiency assumptions. Therefore, the following chapter, Chapter 4—power sector analysis—focuses entirely on the electricity sector.

3.1 ITALY'S FINAL ENERGY DEMAND

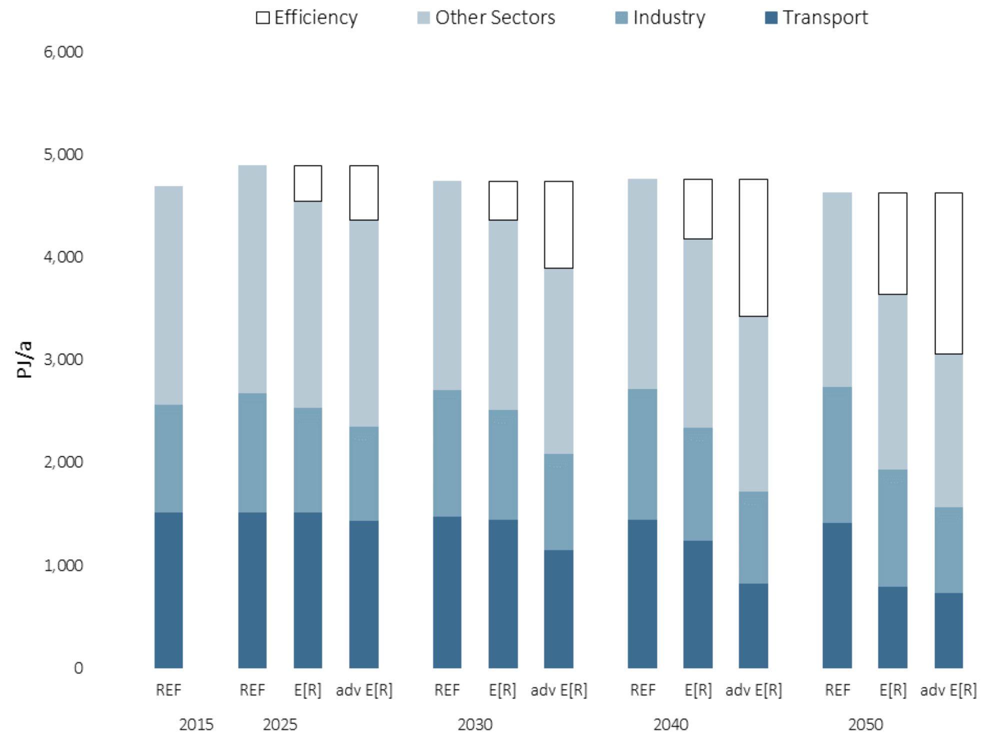
We combined the projections for population development, GDP growth, and energy intensity to generate the future development pathways for Italy's final energy demand. This includes the electricity demand development, which was calculated with a bottom-up analysis. The final energy demands are shown in Figure 16 for the REFERENCE and Energy [R]evolution scenarios. Under the REFERENCE scenario, the total final energy demand will decrease by 6%, from 4,900 PJ/a in the base year to 4,600 PJ/a in 2050. In the E[R] scenario, the final energy demand will increase at a much lower rate (by 27%) compared with current consumption, and is expected to reach 3,600 PJ/a by 2050. The ADV. E[R] scenario will result in some additional reductions that result from a higher proportion of electric cars (see section 3.4).

Under both alternative scenarios, the overall electricity demand is expected to increase in response to economic growth, higher living standards, and the electrification of the transport sector, despite efficiency gains in all sectors (see Figure 17). The total electricity demand will increase from about 300 TWh/a in the base year to 490 TWh/a by 2050 in the E[R] scenario. Compared with the REF scenario, efficiency measures in the industry, residential, and service sectors under E[R] will avoid the generation of about 30 TWh/a.

This reduction can be achieved, in particular, by introducing highly efficient electronic devices, using the best available technology, in all demand sectors. It is assumed that the implementation of efficient devices across all sectors will mainly occur in response to strict and ever-evolving efficiency standards. The Japanese "top-runner" model was particularly successful because it included competitive incentives for the private sector and avoided additional subsidies. The advanced ADV. E[R] scenario includes more-ambitious electrification, particularly of the transport sector, but implement stricter efficiency standards. As result, the electricity demand will increase to 402 TWh/a by 2040 and remain at that level until 2050. Electricity will become the major renewable 'primary' energy, not only for direct use for various purposes, but also for the generation of synthetic fuels to substitute for fossil fuels. Around 137 TWh will be used in 2050 for electric vehicles and rail transport (excluding bunkers) under the ADV. E[R] scenario.

Efficiency gains in the heating sector will be even larger than those in the electricity sector. Under the ADV. E[R] scenario, energy consumption equivalent to about 350 PJ/a will be avoided as a result of efficiency gains by 2030 compared with the REF scenario. This reduction is mainly attributed to increased efficiency measures in process heat for industry. The development of the energy intensity for the industry sector is assumed to decrease faster in both alternative scenarios than in the REF scenario.

Figure 16: Projections of total final energy demand by sector (excluding non-energy use and heat from CHP auto-producers)



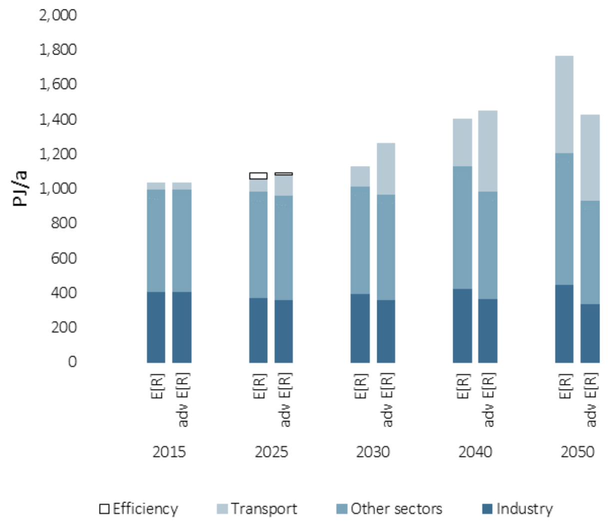


Figure 17: Development of the electricity demand by sector in both Energy [R]evolution scenarios

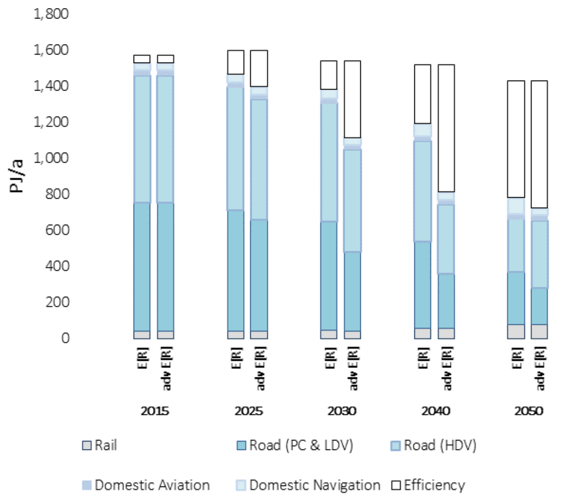


Figure 18: Development of the final energy demand for transport by sector in the Energy [R]evolution scenarios

3.2 ELECTRICITY GENERATION

The development of the electricity supply sector will be characterized by a dynamically growing renewable energy market and an increasing share of renewable electricity. This trend will more than compensate the phase-out of coal power plants by 2025 in both alternative scenarios. By 2030, 72% of the electricity produced in Italy will come from renewable energy sources in the E[R] scenario, increasing to 100% in 2050. 'New' renewables—mainly onshore wind, solar photovoltaic, and offshore wind—will contribute 35% of the total electricity generation in 2030 and 54% by 2050. The installed capacity of renewables will reach close to 103 GW in 2030 and 230 GW by 2050.

Table 27: Projections of renewable electricity generation capacity

In GW		2015	2020	2030	2040	2050
Hydro	REF	18.863	18.863	20.423	20.423	20.423
	E[R]	18.863	18.863	20.525	20.525	20.525
	ADV. E[R]	18.863	18.863	20.525	20.320	20.320
Biomass & Syn. Fuels	REF	4.208	4.634	5.005	5.156	5.483
	E[R]	4.208	5.181	8.186	11.697	23.329
	ADV. E[R]	4.208	5.238	8.353	21.715	20.776
Wind	REF	9.124	9.863	17.481	18.140	18.131
	E[R]	9.124	9.678	16.157	17.412	22.386
	ADV. E[R]	9.124	9.679	15.767	17.237	19.109
Geothermal	REF	0.936	0.935	1.070	1.072	1.072
	E[R]	0.936	0.988	1.091	1.362	2.075
	ADV. E[R]	0.936	0.988	1.163	1.617	2.560
PV	REF	18.892	21.908	51.951	56.013	58.892
	E[R]	18.892	24.119	56.392	92.169	130.390
	ADV. E[R]	18.892	24.119	100.487	125.421	121.846
CSP	REF	0.000	0.004	0.531	0.543	0.600
	E[R]	0.000	0.000	1.191	5.520	9.649
	ADV. E[R]	0.000	0.000	0.571	2.165	4.611
Ocean	REF	0.000	0.000	0.000	0.000	0.000
	E[R]	0.000	0.000	0.000	0.000	0.000
	ADV. E[R]	0.000	0.000	0.000	0.000	0.000
Total	REF	52.023	56.207	96.460	101.347	104.601
	E[R]	52.023	58.829	103.542	148.685	208.354
	ADV. E[R]	52.023	58.887	146.866	188.476	189.222

The ADV. E[R] scenario will achieve 75% renewable electricity generation in 2030 and 100% in 2040. The renewable capacity will increase to 147 GW by 2030 and to 190 GW by 2050. Table 26 shows the comparative evolution of the different renewable technologies in Italy over time. The installed capacity of hydro power dominated as the major renewable power capacity for decades, but was overtaken by solar photovoltaics in 2018, which will remain the largest renewable power capacity throughout the entire scenario period. Wind power will grow in all scenarios to 15–20 GW, whereas hydro power will remain at around 20 GW as well. Both renewable scenarios will result in a high proportion of variable power generation sources (photovoltaics and wind): 35%–47% by 2030 and 54%–56% by 2050. Therefore, smart grids, demand-side management, energy storage capacities, and other options must be expanded to increase the flexibility of the power system to ensure grid integration, load balancing, and a secure supply of electricity.

Figure 19: Breakdown of electricity generation by technology

The calculated potential for utility-scale solar power plants (PV and CSP) under all restrictions and excluding areas further than 10 km from transmission lines is 951 GW. Even the most ambitious E[R] scenario can be implemented with the utilization of only 15% of the utility-scale solar power plant potential. As well as this potential, Italy has significant rooftop solar photovoltaic potential of around 70 GW. By 2030, the installed solar photovoltaic capacity under the ADV. E[R] will be almost twice as high (100 GW) as under the E[R] (56 GW), due to the more rapid phase-out of gas power plants. However, by 2050, the ADV. E[R] scenario will have less solar photovoltaic power generation and wind power generation because of its higher efficiency target.

In terms of onshore wind, both alternative scenarios use the onshore wind potential with the highest restrictions (described in section 2.5.2) until 2030. Thereafter, areas further than 10 km from current transmission lines must be considered. The offshore wind potential is almost seven times larger than the most ambitious scenario requires.

3.3 ENERGY SUPPLY FOR HEATING AND INDUSTRIAL PROCESS HEAT

Today, renewables meet around 13% of Italy's energy demand for heating, with the main contribution from biomass. Dedicated support instruments are required to ensure the dynamic development of renewables, particularly for renewable technologies and renewable process heat production in the industry sector. In the E[R] scenario, renewables will already provide 41% of Italy's total heat demand in 2030, 71% in 2040, and 100% in 2050.

- Energy efficiency measures will help to reduce the currently growing energy demand for heating by 11% in 2030 (relative to the REF scenario), despite the increased industry energy demand arising from economic growth.
- In the industry sector, solar collectors, geothermal energy (mainly heat pumps), and electricity will increasingly substitute for fossil-fuel-fired systems.
- A shift from coal and oil to natural gas in the remaining conventional applications will lead to a further reduction in CO_2 emissions.

Figure 20: Projection of heat supply by energy carrier (REF, E[R], and ADV. E[R])

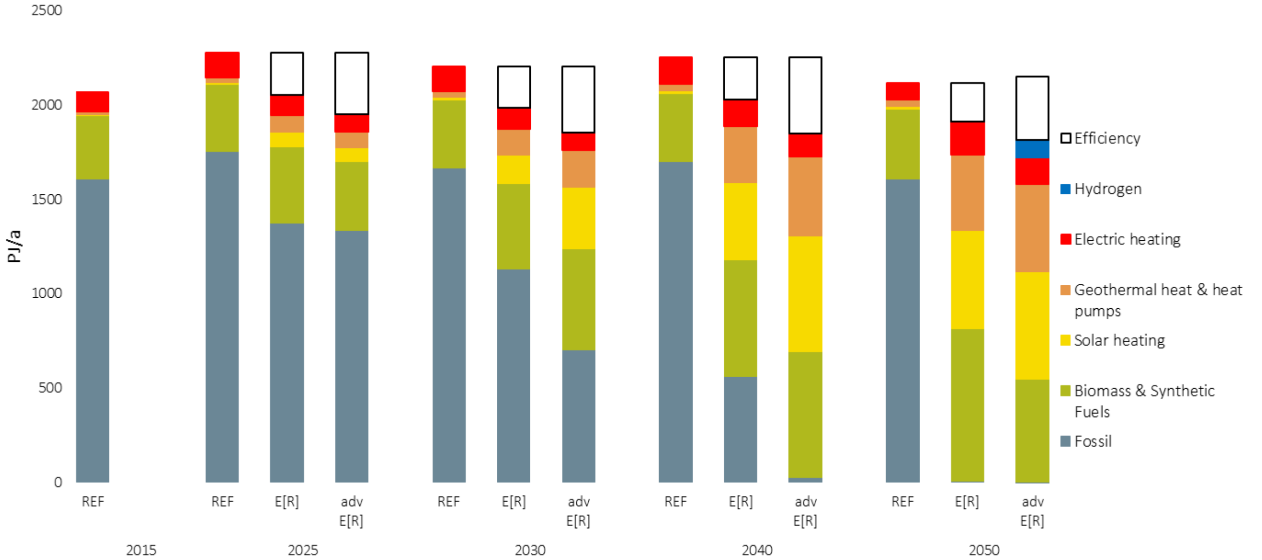


Table 28: Projection of renewable heat supply

in PJ/a		2015	2025	2030	2040	2050
Biomass & Syn. Fuels[48]	REF	336	353	361	363	369
	E[R]	253	404	451	618	811
	ADV. E[R]	253	364	536	667	546
Solar heating	REF	8	10	11	12	13
	E[R]	7	78	152	406	519
	ADV. E[R]	7	75	330	610	570
Geothermal heat & heat pumps	REF	16	28	33	37	36
	E[R]	15	91	136	301	404
	ADV. E[R]	15	85	193	425	463
Hydrogen	REF	0	0	0	0	0
	E[R]	0	0	0	0	0
	ADV. E[R]	0	0	0	0	95
Total	REF	360	391	404	412	418
	E[R]	275	572	738	1,325	1,735
	ADV. E[R]	275	524	1,059	1,702	1,675

Table 27 shows the development of different renewable technologies for heating in Italy over time. Biomass will remain the main contributor, with increasing investment in highly efficient modern biomass technologies. After 2025, a massive growth in solar collectors and increasing proportions of geothermal and environmental heat and heat from renewable hydrogen will further reduce the dependence on fossil fuels. The ADV. E[R] scenario will result in the complete substitution of the remaining gas consumption, mainly by renewable electricity, by 2040.

Table 29: Installed capacities for renewable heat generation

in GW		2020	2030	2040	2050
Biomass & Synthetic. Fuels	REF	58	58	53	50
	E[R]	54	60	72	94
	ADV. E[R]	54	72	86	46
Geothermal	REF	2	4	4	4
	E[R]	2	3	3	2
	ADV. E[R]	3	5	13	16
Solar heating	REF	5	7	8	8
	E[R]	5	41	118	153
	ADV. E[R]	5	498	180	168
Heat pumps	REF	2	2	2	2
	E[R]	2	24	56	77
	ADV. E[R]	2	36	66	73
Total	REF	67	70	66	63
	E[R]	63	128	249	326
	ADV. E[R]	63	210	346	303

[48] **Bio energy and synthetic fuels:** In this research bio energy and synthetic fuels are considered to be interchangeable fuels for power plants, combined heat- and power plants (CHP) and heating plants. The maximum amount of available sustainable bio mass requires more research and was out of scope for this analysis. Synthetic fuels which produced by renewable electricity – mainly solar and wind power –will either add to bio energy supply or replace them.

3.4 TRANSPORT

A key target in Italy is to introduce incentives for people to drive smaller cars and buy new, more efficient vehicles. In addition, it will be vital to shift transport use to efficient modes like rail, light rail, and buses, especially in the expanding large metropolitan areas. The transport energy demand is projected to decrease after 2020 in all scenarios. However, the shift to electrification in the transport sector will take more than a decade, so the transport scenarios will show small differences until 2030. To avoid increases in—mainly oil-based—transport energy beyond 2030, the alternative scenarios implement a number of measures. It is vital to shift transport use to efficient transport modes, such as rail, light rail, and (electric) buses, especially in the large expanding metropolitan areas. Together with rising prices for fossil fuels, these changes will reduce the stable number of car sales projected under the REF scenario. The energy demand from the transport sector is expected to remain stable in the REF scenario at around 1,500 PJ/a until 2030, with a slight decrease thereafter to 1,300 PJ/a in 2050. In the E[R] scenario, efficiency measures and modal shifts will save 10% of the energy demand (168 PJ/a) by 2030 and 44% (630 PJ/a) by 2050 relative to the REF scenario.

Additional modal shifts and technology switches will lead to even higher energy savings in the ADV. E[R] scenario of 48% (680 PJ/a) in 2050 compared with the REF scenario. Highly efficient propulsion technology with hybrid, plug-in hybrid, and battery-electricity-powered trains will bring large efficiency gains. By 2030, electricity will provide 7% of the transport sector's total energy demand in the E[R] scenario, whereas in 2050, the share will be around 68% in both scenarios. Hydrogen and other synthetic fuels generated with renewable electricity may be complementary options that further increase the renewable share in the transport sector.

Table 30: Projection of the transport energy demand by mode (excluding pipeline transport)

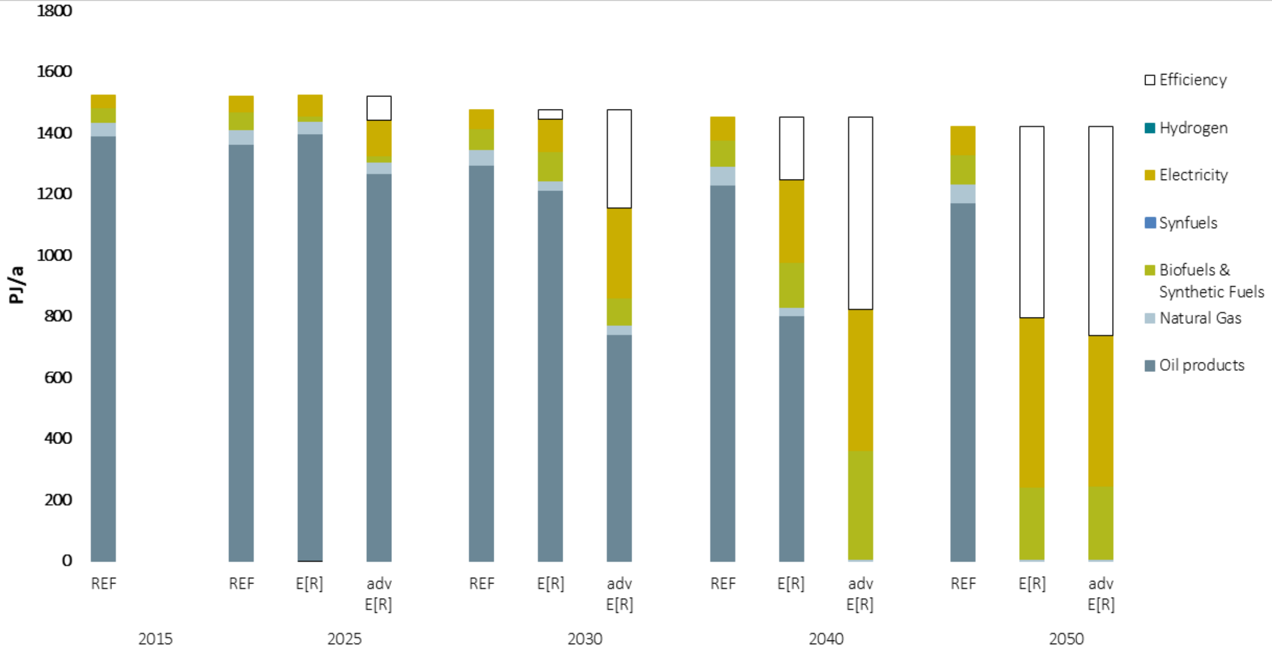
in PJ/a		2015	2025	2030	2040	2050
Rail	REF	40	41	41	43	45
	E[R]	41	42	46	59	77
	ADV. E[R]	41	40	43	58	77
Road	REF	1,466	1,490	1,435	1,412	1,315
	E[R]	1,404	1,352	1,259	1,037	586
	ADV. E[R]	1,404	1,289	1,007	688	578
Domestic aviation	REF	29	26	26	27	29
	E[R]	29	26	26	27	29
	ADV. E[R]	29	26	26	27	29
Domestic navigation	REF	39	40	40	40	40
	E[R]	41	48	54	69	91
	ADV. E[R]	41	40	40	40	41
Total	REF	1,574	1,598	1,542	1,522	1,429
	E[R]	1,515	1,468	1,385	1,192	782
	ADV. E[R]	1,515	1,396	1,115	812	725

Our estimate of around 7% electric vehicles by 2030 is conservative compared with the estimate of Coordinamento *FREE*[49], published in October 2018. According to FREE, Italy's potential for electric vehicles will be as high as 4.5 million by 2030. Based on the current number of vehicles in Italy (2016: 37 million cars), 4.5 million vehicles represent 12% of the total fleet.

Electric vehicle– potential in Italy by 2030	
Vehicle Type	**Potentially in use**
Cars (Light vehicles)	3.540.000
Commercial vehicles (Light duty vehicles)	640.000
Taxi and car sharing	300.000
Total	4.480.000
Market share by technology	60% Battery electric vehicles (BEV) 40% Plug-in hybrid vehicles (PHEV)

[49] FREE 2018, IL PIANO NAZIONALE ENERGIA E CLIMA; LE PROPOSTE DEL COORDINAMENTO FREE, Coordinamento FREE; Lungotevere dei Mellini, 44 – 00193 Roma - Tel. 0642014701; Codice Fiscale 97737750584, www.free-energia.it, mail: info@free-energia.it

Figure 21: Final energy consumption by transport under the scenarios

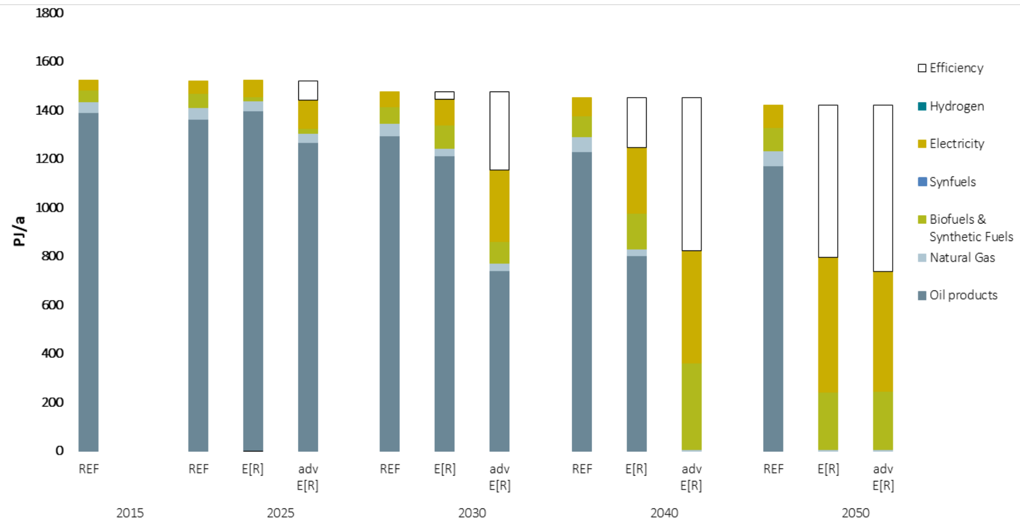


3.5 PRIMARY ENERGY CONSUMPTION

The primary energy consumptions under both Energy [R]evolution scenarios and the REFERENCE scenario, based on the assumptions discussed above, are shown in Figure 22. Under the E[R] scenario, the primary energy demand will increase from the present level of around 6,470 PJ/a to around 6,200 PJ/a in 2030, a reduction of 5%. Compared with the REF scenario, the overall primary energy demand will be reduced by 779 PJ by 2030 under the E[R] scenario (REF: 7,039 PJ in 2030). The ADV. E[R] scenario will result in a primary energy consumption of around 5,528 PJ in 2030, and will further decrease as a result of increased electrification between 2030 and 2050.

The Energy [R]evolution scenarios aim to reduce coal, gas, and oil consumption as fast as is technically and economically possible by the expansion of renewable energy generation and the rapid introduction of very efficient vehicles to the transport sector to replace oil-based combustion engines. This will lead to an overall renewable primary energy share of 33% in 2030 and 92% in 2050 under the E[R] scenario and 96% in 2050 under the ADV. E[R] scenario (including non-energy consumption).

Figure 22: Projection of total primary energy demand by energy carrier (incl. electricity import balance)



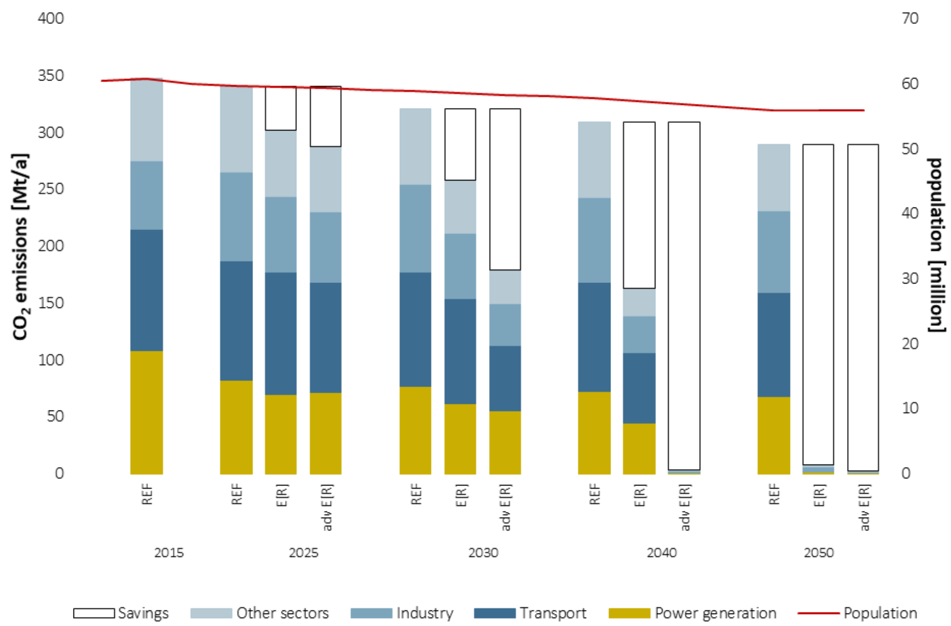
3.6 CO_2 EMISSIONS TRAJECTORIES

Italy's energy-related CO_2 emissions will decrease only slightly, from 348 million tonnes to 321 million tonnes, between 2015 and 2030 under the REF scenario. The E[R] scenario will result in a more substantial reduction to 258 million tonnes by 2030, while the population will decrease from 60 to 59 million people in the same period. Therefore, the annual per capita emissions will drop by 2 tonnes to 4 tonnes of CO_2 in 2030. The power demand will increase by 10% in the E[R] scenario between 2020 and 2030, whereas the overall CO_2 emissions from the electricity sector will decrease by around 40% as a result of the coal phase-out in 2025 and increased renewable electricity deployment. In the long run, efficiency gains and the increased use of renewable electricity in vehicles will also dramatically reduce the emissions in the transport sector. The transport sector will be the largest source of emissions in 2040 under the E[R] scenario, with a 38% share of CO_2 generation.

The ADV. E[R] scenario will decarbonize the power and transport sectors, whereas the industry and building sectors will remain responsible for 1 million tons of CO_2 each by 2040, mainly due to gas-based process heat and power generation. The greatest annual CO_2 emissions under the ADV. E[R] scenario will come from the power and transport sectors, with around 55 million tonnes each by 2030. Between 2020 and 2030, the ADV. E[R] scenario will reduce energy-related CO_2 emissions by 778 million tonnes of CO_2, whereas E[R] will save cumulative carbon emissions equivalent to 478 million tons.

The full decarbonization of all sectors seems possible by 2040, with increased import shares of renewable electricity and fuels from neighbouring countries. At the time of writing (Nov 2019), Italy imported 100% of its coal and over 90% of the oil and gas required to supply the country's energy demand—representing an energy import share of around 76.5% (based on primary energy). Compared with the REFERENCE scenario, both Energy [R]evolution scenarios will continuously reduce energy imports. By 2050, the energy import share – mainly from bio – and synthetic fuels - is estimated to be around 27 to 30%, less than half of the current energy import share of 76.5% (2018).

Figure 23: Development of CO_2 emissions by sector under the Energy [R]evolution scenarios
('Savings = reduction compared with the REFERENCE scenario)



3.7 COST ANALYSIS: LONG-TERM ENERGY SCENARIO

FUTURE COSTS OF ELECTRICITY GENERATION

The costs provided in this section include all the construction costs for new power plants, the average standard operation and maintenance costs for each technology, and fuel costs. The infrastructure costs for possibly required additional coal or LNG capacities or grid expansion are not included because they are beyond the scope of this research.

Figure 24 shows the introduction of renewable technologies without carbon costs. Under the REFERENCE scenario, power generation costs will remain at around €0.06 per kWh over the entire modelling period. By 2030, the average generation costs across all technologies will be €0.053 per kWh and by 2050, €0.061 per kWh. The E[R] scenario will lead to slightly lower average generation costs of €0.049 per kWh (2030) and €0.054 per kWh by 2050. The most favourable results in 2050 will be under the ADV. E[R] scenario, in which the shares of solar photovoltaic and wind power will be high, with significantly lower requirements for fuel and lower capital costs for installation. However, due to the rapid increase in the new renewable capacities during the first decade, average generation costs will increase to €0.071 per kWh between 2020 and 2030 but decrease thereafter. By 2040, the ADV. E[R] scenario will have the lowest average generation costs.

Because the uncertainty in the assumed fossil fuel prices increases with time, especially for the REF scenario (which has 42.5% fuel-based generation in 2030), the costs of storage and grid integration are not considered in this calculation (see further discussion of storage in Chapter 4). Under the REF scenario, the growth in demand and increasing fossil fuel prices will result in an increase in total electricity supply costs from €19 billion per year in 2015 to €20 billion in 2030 compared with €21 billion under E[R] and €24 billion under ADV. E[R]. The E[R] scenario has the highest electricity supply cost in 2050, due to the highest electricity demand and comparable high fuel costs for bio-energy.

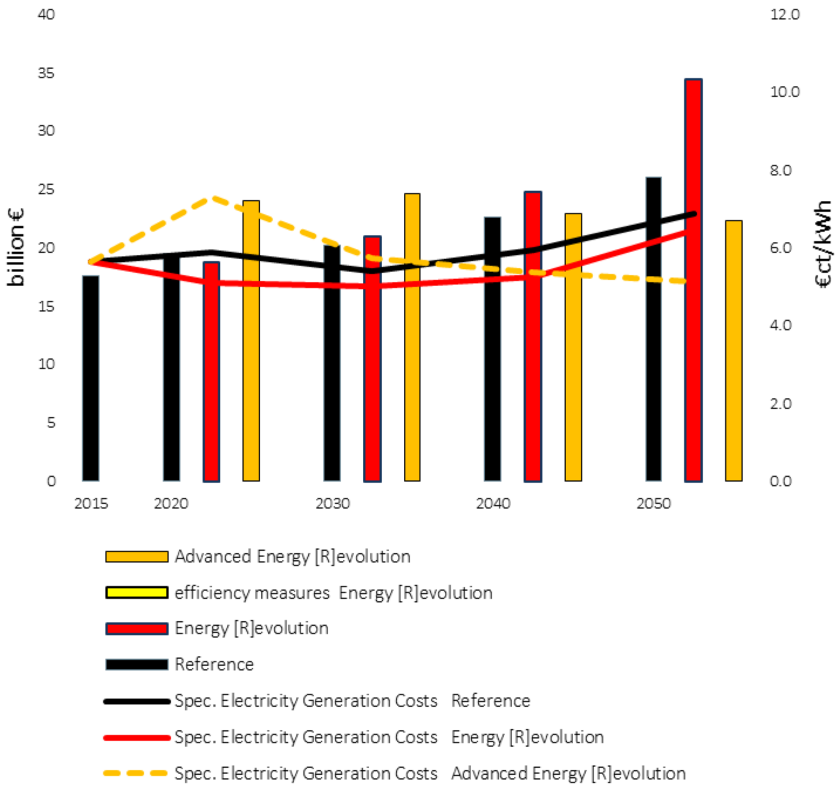


Figure 24: Development of total electricity supply costs and specific electricity generation costs in the scenarios—with no carbon costs

Figure 25 shows that both RENEWABLE scenarios will become more favourable in terms of CO_2 emissions, with an assumed carbon price of €30 per ton of CO_2 in 2030, gradually increasing to €50 per ton of CO_2 in 2050. Both alternative scenarios will be more cost competitive in terms of the average generation costs than the REF scenario. In 2040, the E[R] and ADV. E[R] scenarios will generate electricity for €0.054 per kWh and €0.052 per kWh, respectively, compared with €0.068 per kWh in the fossil-fuel-dominated scenario.

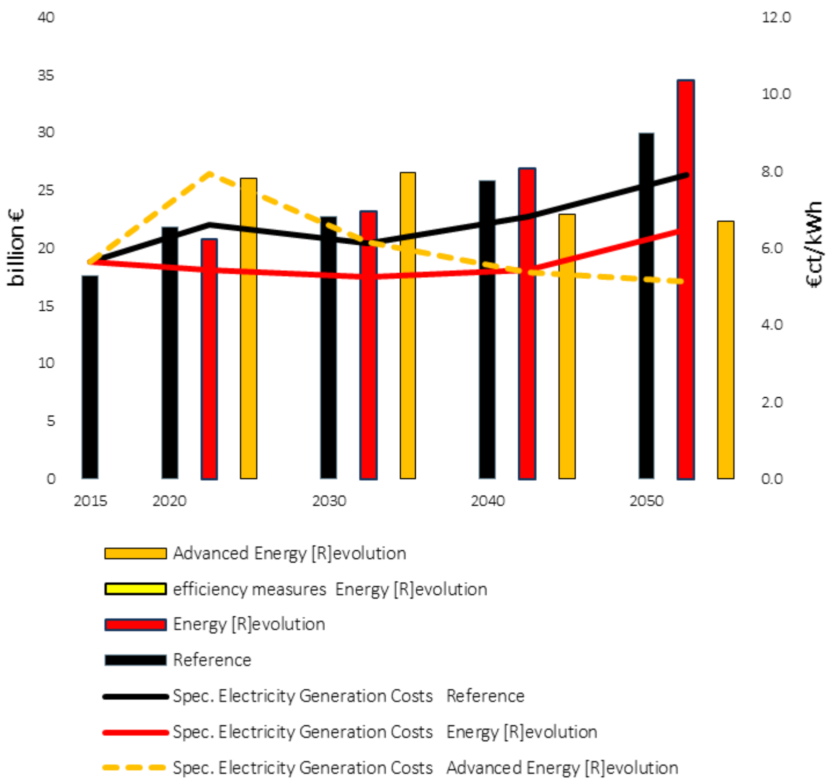
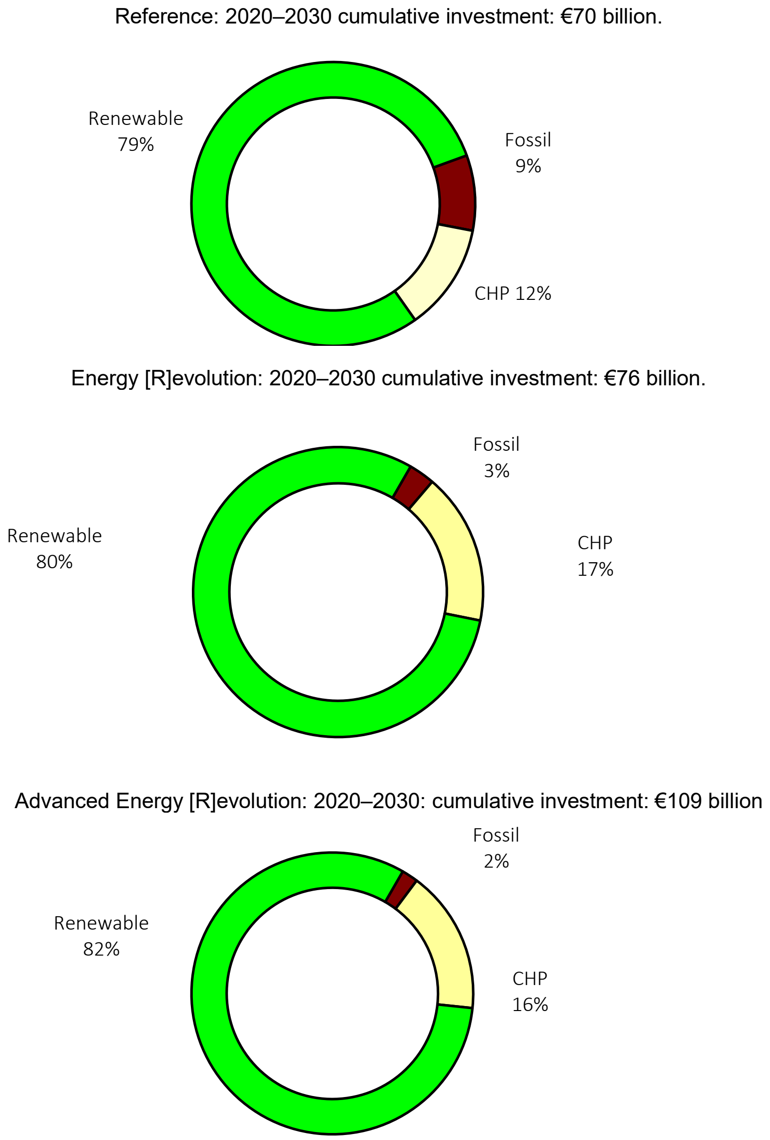


Figure 25: Development of total electricity supply costs and specific electricity generation costs in the scenarios—including carbon costs

FUTURE INVESTMENTS IN THE POWER SECTOR

Around €76 billion will be required in investment between 2020 and 2030 for the E[R] scenario to become a reality—approximately €6 billion more than in the REFERENCE scenario. The Advanced Energy [R]evolution scenario will require €109billion. The additional annual investment in the ADV. E[R] scenario between 2020 and 2030 will be €39 billion more than in the REF scenario and €33 billion more than in the E[R] scenario. Under the REF scenario, the levels of investment in fossil fuel power plants will sum to almost 10%, whereas approximately 79% will be invested in renewable energies until 2050. However, under the E[R] scenario, Italy will shift 80% of its entire investment towards renewables, with 3% towards fossil-fuelled power plants, between 2020 and 2030—a third of the fossil fuel investment shares in the REF scenario. The ADV. E[R] scenario will direct 82% of all new investments into renewable electricity generation between 2020 and 2030.

Figure 26: Cumulative investment in power generation under the three scenarios in 2020–2030



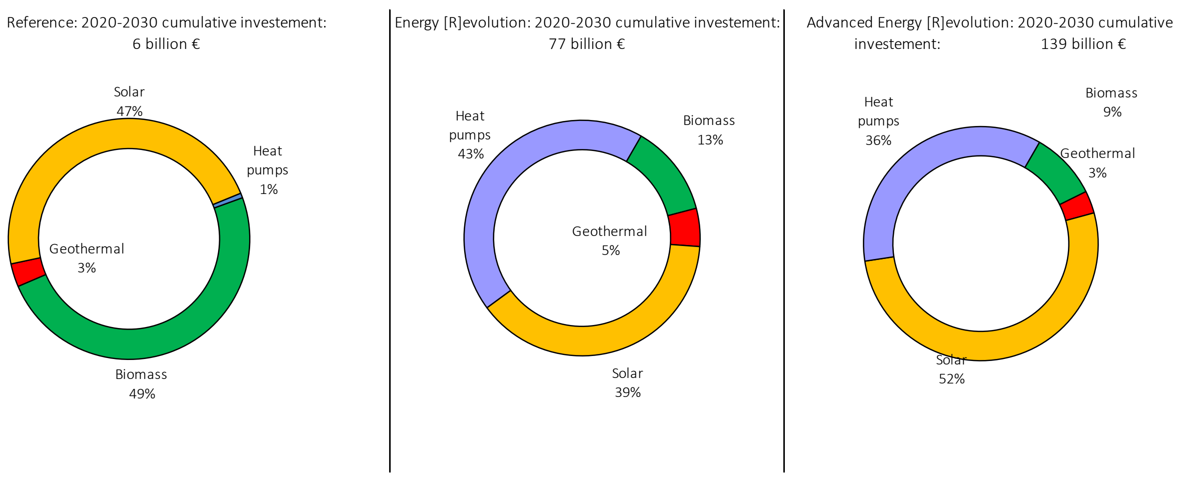
In the long term, until 2050, the fuel cost savings in the E[R] scenario will reach a total of €204 billion up to 2050, or €6.8 billion per year. Therefore, the total fuel cost savings will cover the total additional investments compared with the REF scenario. The fuel cost savings in the ADV. E[R] scenario will be even higher and sum to €275 billion, or €9 billion per year. Renewable energy sources will then go on to produce electricity without any further fuel costs beyond 2050, whereas the costs for coal and gas will continue to be a burden on national economies.

3.8 FUTURE INVESTMENTS IN THE HEATING SECTOR

Similarly, in the heating sector, both RENEWABLES scenarios will require a major revision of current investment strategies in heating technologies. In particular, solar thermal and geothermal heat pump technologies will require enormous increases in installations if their potentials are to be tapped for the—mainly industrial—heating sector. The use of biomass, especially for industrial heat demand, will be substantial in the ADV. E[R] scenario.

Renewable heating technologies are extremely variable, from unglazed solar collectors to very sophisticated enhanced geothermal and solar systems. The investment volumes in *renewable heat generation* in all three scenarios will differ significantly: in the REF scenario will require €6 billion, the E[R] €77 billion, and the ADV. E[R] scenario €139 billion between 2020 and 2030. Whereas the REF scenario will continue to rely on fossil-fuel-generated heat, both Energy [R]evolution scenarios will require a significant increase in renewable heat generation capacity. The ADV. E[R] scenario will also phase out fossil-based co-generation, which explains its higher investment costs, even compared with the E[R] scenario.
Bis hier!!!
In the long term, until 2050, cost projections can only be quantitative estimates. The E[R] scenario will require around €280 billion in total to be invested in renewable heating technologies up to 2050 (including investments in replacements after the economic lifetimes of the plants), or approximately €8 billion per year. The ADV. E[R] scenario assumes an equally ambitious expansion of renewable technologies but in a shorter time frame and with higher shares of bio-energy and synthetic fuels replacing fossil gas and an accelerated trajectory for solar thermal heating. It will therefore require a higher average investment of around €9 billion per year leading to a total investment of €332 billion in heating generation between 2015 and 2050.

Figure 27: Cumulative Investment in *renewable* heat generation under the three scenarios in 2020–2030



3.9 INVESTMENT AND FUEL COST SAVINGS IN THE POWER SECTOR

Under the E[R] scenario, the additional investments between 2020 and 2030 are estimated to be €3.9 billion, and compared with the REF scenario, the fuel cost savings will add up to €31.8 billion. Thus, the overall savings will add up to over €28 billion, or €2.8 billion annually. Even under the assumption that there will be large uncertainties in both future investment costs for power generation equipment and the development of fossil fuel prices, it seems certain that the overall cost balance will be economically beneficial under the E[R] scenario.

Table 31: Cumulative investment costs for electricity generation and fuel cost savings under the Energy [R]evolution scenario

CUMULATIVE INVESTMENT COSTS Difference: REFERENCE minus Energy [R]evolution		2020–2030	2020–2030 average per year	2031–2040	2041–2050	2020-2050	2020–2050 average per year
Conventional (fossil)	billion €	3.8	0.4	1.3	−5.6	−10.7	0.4
Renewables (incl. CHP)	billion €	−7.7	−0.8	−40.3	−68.9	−116.9	−3.9
Total	**billion €**	**−3.9**	**−0.4**	**−39.0**	**−63.3**	**−106.2**	**−3.6**
CUMULATIVE FUEL COST SAVINGS							
Cumulative savings Energy [R]evolution versus REFERENCE							
Fuel oil	billion €	7.6	0.8	7.	7.1	22.2	0.7
Gas	billion €	23.7	2.4	53.9	103.9	181.6	6.1
Hard coal	billion €	0.5	0.1	−0.3	0.0	0.2	0.0
Lignite	billion €	0.0	0.0	0.0	0.0	−0.1	0.0
Total	**billion €**	**31.9**	**3.2**	**61.0**	**111.1**	**203.9**	**6.8**

Under the ADV. E[R] scenario, the additional investment between 2020 and 2030 is estimated to be around €38.5 billion compared with the REF scenario. The fuel cost savings will add up to €36.5 billion. Thus, the fuel cost savings cannot re-finance entirely, but only to over 90%. Between 2030 and the end of the modelling period, both Energy [R]evolution scenarios will lead to fuel cost savings that will more than compensate for the investment costs for renewable power generation.

Table 32: Accumulated investment costs for electricity generation and fuel cost savings under the Advanced Energy [R]evolution scenario

CUMULATIVE INVESTMENT COSTS Difference: REFERENCE minus Adv. Energy [R]evolution		2020–2030	2020–2030 average per year	2031–2040	2041–2050	2020–2050	2020–2050 average per year
Conventional (fossil)	billion €	4.0	0.4	10.0	6.8	20.8	0.7
Renewables (incl. CHP)	billion €	−41.0	−4.1	−47.7	−41.6	−130.3	−4.3
Total	**billion €**	**−37.0**	**−3.7**	**−37.7**	**−34.7**	**−109.5**	**−3.6**
CUMULATIVE FUEL COST SAVINGS							
Cumulative savings Adv. Energy [R]evolution versus REFERENCE							
Fuel oil	billion €	9.7	1.0	9.5	9.6	28.9	1.0
Gas	billion €	26.7	2.7	85.2	134.2	246.1	8.2
Hard coal	billion €	0.1	0.0	0.3	0.0	0.4	0.0
Lignite	billion €	0.0	0.0	0.0	0.0	-0.1	0.0
Total	**billion €**	**36.5**	**3.6**	**95.0**	**143.9**	**275.4**	**9.2**

4 ITALY: POWER SECTOR ANALYSIS

In this chapter, we summarize the results of the hourly simulations of the long-term scenarios (Chapter 3). The [R]E 24/7 model calculates the demand and supply by cluster. The electricity market in Italy is in dynamic development and has been fully liberalized according to the requirement of the European Union (EU). This analysis is based on various consultations with stakeholders in the Italian powers sector, including the Italian grid operator TERNA. It takes the key points of the Integrated National Energy and Climate Plan as a central foundation for the development of both Energy [R]evolution scenarios and takes it further in terms of the deployment of renewable and sustainable local resources. The new scenarios aim to avoid the use of limited and unsustainable resources, such as coal, oil, and gas, as much as possible. We also simulated the REFERENCE (REF) scenario with the [R]E24/7 model (see section 1.3) and used measured load curves for all six market zones from 2015 and 2016, which have been provided by TERNA, and used for future load curve calculation for 2020, 2030, 2040, and 2050 (see 1.4). Furthermore, we compared our results for future projected loads with other published analyses such as STATISTA (2019)[50].

4.1 ITALY: DEVELOPMENT OF POWER PLANT CAPACITIES

Italy's current plans for future development of its power capacities (PNIEC 2018)[10] would lead to a high dependence on gas. In 2015, Italy was the 4th largest importer of gas worldwide, whereas only 11% of the demand was produced domestically (ENI 2019)[51]. The total installed capacity for gas power plants (including co-generation) remains around 60 GW throughout the entire modelling period under the REFERENCE scenario.

The capacity for solar photovoltaic and onshore wind will increase under all three scenarios. However, the solar photovoltaic market will vary significantly. While the annual average market until 2025 will range around 650 MW per year under the REFERENCE scenario, E[R] will require an annual installation of 1,100 MW and the ADV. E[R] scenario just over 9,000 MW—similar to Italy's highest annual photovoltaic market volume of 9,000 MW during the year 2011. Furthermore, Italy will increase its geothermal capacity as projected by the Italian geothermal Industry. Offshore wind and concentrated solar power will add to the diverse renewable power generation mix in Italy after 2025.

Table 33: Italy—Average annual changes in installed power plant capacity

Power Generation: average annual change of installed capacity [GW/a]	2015–2025			2026–2035			2036–2050		
	REF	E[R]	ADV. E[R]	REF	E[R]	ADV. E[R]	REF	E[R]	ADV. E[R]
Hard coal	-0.946	-0.923	-0.335	0.000	0.000	0.000	0.000	0.000	0.000
Lignite	-0.016	-0.015	-0.017	0.000	0.000	0.000	0.000	0.000	0.000
Gas	0.093	-1.381	-2.258	-0.056	-1.503	-4.200	-0.276	-3.004	-1.088
Oil/Diesel	-0.352	-0.928	-1.035	-0.330	-0.234	-0.090	-0.385	-0.077	-0.003
Biomass	-0.117	-0.201	0.389	-0.034	0.435	0.615	0.068	2.778	0.798
Hydro	0.182	0.116	0.208	0.013	0.016	0.026	0.000	0.000	-0.017
Wind (Onshore)	0.683	0.509	0.665	0.355	0.358	0.343	-0.056	0.140	0.134
Wind (Offshore)	0.034	0.039	0.096	0.053	0.040	0.094	0.056	0.334	0.073
Photovoltaic (rooftop)	0.612	1.112	7.160	2.738	4.776	7.751	0.267	3.044	-0.202
Photovoltaic (utility scale)	0.204	0.371	2.387	0.913	1.592	2.584	0.089	1.015	-0.067
Geothermal	0.011	0.013	0.022	0.006	0.014	0.036	0.000	0.077	0.100
Solar thermal power plants	0.019	0.020	0.071	0.047	0.265	0.155	0.006	0.614	0.269
Ocean energy	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Renewable Fuel based Co-Generation	-0.004	-0.138	0.505	-0.036	0.284	0.536	-0.001	2.437	0.690

[50] Statista 2019, Forecasted electricity peak demand in Italy in selected years from 2025 to 2050, viewed 17th November 2019, https://www.statista.com/statistics/920730/electricity-peak-demand-forecasts-in-italy/

[51] ENI 2019, ENI sis Italy's largest gas provider (Ente Nazionale Idrocarburi = "State Hydrocarbons Authority"), taken from ENI marketing and PR website, viewed 18th November 2019, http://www.eniscuola.net/en/2016/05/18/the-demand-for-natural-gas-in-italy/

The annual installation rates for solar photovoltaic installations must remain at around 6 GW between 2025 and 2035 in the E[R] scenario and 9 GW in the ADV. E[R] scenario. By 2035, the installation rates for concentrated solar power must reach 250–500 MW in both Energy [R]evolution scenarios. Solar photovoltaics is the key renewable energy technology for Italy, but diversity is required to keep the storage demand low and the security of supply high. All renewable power technologies, concentrated solar power plants, geothermal power, and on- and offshore wind are important for the successful decarbonization of Italy's power sector.

4.2 ITALY: UTILIZATION OF POWER GENERATION CAPACITIES

The division of Italy into six sub-regions reflects the current structure of the domestic power market. It is assumed that the sub-regions will be interconnected according to the regional peak load over time. The resulting net transmission capacities are provided in section 4.4.

Table 34: Italy—Installed photovoltaic and wind capacities by region in the E[R] scenario (2030)

Energy [R]evolution 2030	C Nord	C Sud	Nord	Sud	Sardegna	Sicilia
	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]
Photovoltaic (rooftop)	6,110	7,402	21,850	5,944	1,557	2,250
Photovoltaic (utility scale)	1,528	1,851	5,462	1,486	389	563
Onshore wind	1,305	2,610	2,610	6,526	1,305	1,305
Offshore wind	50	73	657	43	43	80

Table 35: Italy—Installed photovoltaic and wind capacities by region in the ADV. [R]E scenario (2030)

Adv. Energy [R]evolution 2030	C Nord	C Sud	Nord	Sud	Sardegna	Sicilia
	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]
Photovoltaic (rooftop)	13,202	15,994	47,211	12,843	3,364	4,862
Photovoltaic (utility scale)	3,300	3,999	11,803	3,211	841	1,216
Onshore wind	1,416	2,832	2,832	7,079	1,416	1,416
Offshore wind	208	328	2,859	192	178	363

Table 33 and Table 34 show the installed capacities for solar photovoltaics and wind for the E[R] scenario in 2030 and for the more ambitious ADV. E[R] scenario in 2050, respectively. The distributions are based on the regional solar and wind potentials and the regional demands, and aim to generate electricity where the demand is located. Whereas solar photovoltaic power generation is modular and can be installed close to the consumer or even integrated into buildings, onshore wind must be kept at a distance from settlements. Therefore, onshore wind must be clustered into wind farms with double digit megawatt capacities, on average. Offshore wind is not a decentralized renewable energy technology and must be installed in a range of several hundred megawatts to a gigawatt. Therefore, the largest part of the offshore wind capacity in Italy is located in south-east Italy in our model calculations. The distribution of concentrated solar power plants will be based on the available solar resources and therefore will be located more in the southern part of Italy.

Both Energy [R]evolution scenarios aim for an even distribution of variable power plant capacities across all regions of Italy by distributing the utility-scale solar photovoltaic and onshore wind power generation facilities accordingly. However, coastal regions have a significantly higher share of variable wind resources than regions further inland and mountain ranges. By 2030, variable power generation will reach 25%–30% in all regions, whereas the proportions of dispatchable renewables—bio-energy and hydro power—will vary significantly, from 70% in the northern Alps region to only 26% in Sardegna.

The significant regional differences in the power system shares—the ratio between dispatchable and non-dispatchable variable power generation—will require a combination of increased interconnection, storage facilities, and demand-side management incentives. Over time, the proportion of variable power generation will increase (Table 35) under all scenarios. The regions with large utility-scale solar power plants and offshore wind capacities will have the highest shares of variable power generation in the grid, and will require greater interconnection with neighbouring regions than those with smaller shares of variable electricity.

Table 36: **Italy—Power system shares by technology group**

Power Generation Structure in percentage of annual supply [GWh/a]		REFERENCE			Energy [R]evolution			Adv. Energy [R]evolution		
Italy		Variable Renewables	Dispatch Renewables	Dispatch Fossil	Variable Renewables	Dispatch Renewables	Dispatch Fossil	Variable Renewables	Dispatch Renewables	Dispatch Fossil
C Nord	2015	9%	58%	32%						
	2030	29%	39%	31%	31%	48%	21%	45%	39%	16%
	2050	32%	39%	30%	45%	55%	0%	50%	50%	0%
C Sud	2015	19%	40%	41%						
	2030	34%	35%	31%	35%	41%	25%	46%	30%	24%
	2050	34%	34%	33%	44%	55%	1%	49%	51%	0%
Nord	2015	9%	86%	5%						
	2030	25%	70%	5%	26%	70%	3%	40%	57%	3%
	2050	25%	66%	9%	41%	59%	0%	43%	57%	0%
Sud	2015	27%	25%	48%						
	2030	55%	24%	21%	54%	31%	15%	63%	23%	13%
	2050	51%	25%	24%	53%	47%	0%	62%	38%	0%
Sardegna	2015	39%	42%	19%						
	2030	70%	21%	9%	68%	26%	6%	78%	18%	4%
	2050	76%	18%	6%	66%	34%	0%	78%	22%	0%
Sicilia	2015	35%	51%	14%						
	2030	36%	41%	23%	36%	46%	18%	48%	35%	17%
	2050	39%	40%	21%	49%	51%	0%	53%	47%	0%
Average	2015	17%	38%	20%						
	2030	31%	29%	15%	31%	33%	11%	40%	25%	10%
	2050	32%	28%	15%	37%	38%	0%	42%	33%	0%

Table 36 shows the system-relevant technical characteristics of the various generation types. Future power systems must be structured according to the generation characteristics of each technology in order to maximize their synergy. Power utilities can encourage sector coupling—between industry, transport, and heating—in order to utilize various demand-side management possibilities and to maximize the cross-benefits. The integration of large shares of variable power generation will require a more flexible market framework. Those power plants requiring high capacity factors because of their technical limitations regarding flexibility ("base load power plants") might not be desirable to future power system operators. Therefore, capacity factors will become more of a technical characteristic than an economic necessity. Flexibility is a commodity that increases in value over time.

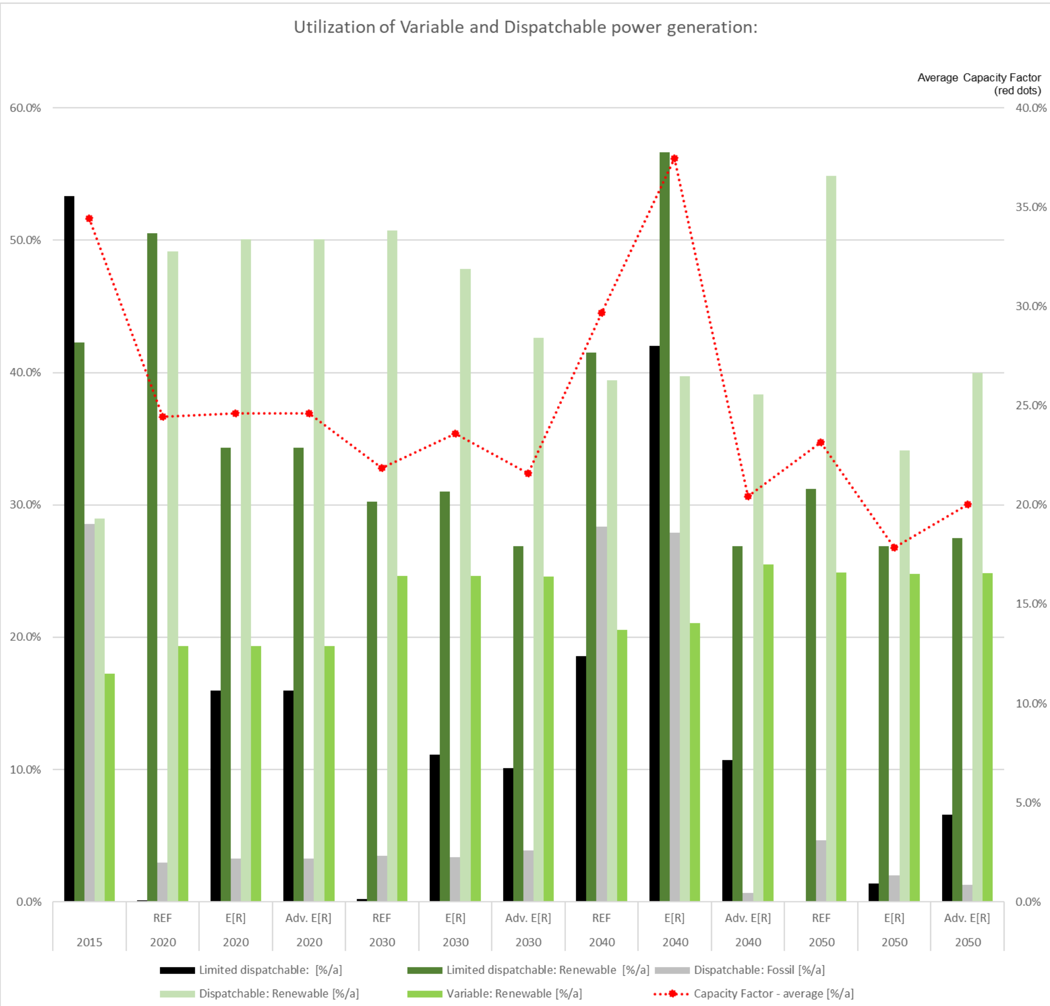
Table 37: Italy—System-relevant generation types

Generation type	Fuel	Technology
Limited dispatchable	fossil, uranium	coal, brown coal/lignite, (incl. co-generation)
	renewable	hydro power, bio energy and synthetic fuels, geothermal, concentrated solar power (incl. co-generation)
Dispatchable	fossil	gas, oil, diesel (incl. co-generation)
		storage systems: batteries, pumped hydro power plants, hydrogen- and synthetic-fuelled power and co-generation plants
	renewable	bio energy, hydro, hydrogen- and synthetic-fuelled power and co-generation plants
Variable	renewable	solar photovoltaic, onshore and offshore wind

Italy's average capacity factors for the entire power plant fleet will decrease from currently around 35% over the entire modelling period to 20%–25% (red dotted line, Figure 28).

The capacity factor for gas power plants will operate on high capacity factors throughout all scenarios—although with significantly different installed capacities. During the uptake phase of variable renewables around 2030–2040, gas- and bio-energy-based generation will play a vital role in the security of supply and in fast-reacting dispatch power plants. Gas power plants will reach their peak capacity in 2020, and gradually be phased out by 2050 in the E[R] scenario and by 2040 in the ADV. E[R] scenario. However, the mid-term (2035) gas capacity will be 46 GW under E[R] and 41 GW under ADV. E[R]. In both scenarios, high capacity factors can be maintained to achieve low average generation costs.

Figure 28: Italy—Utilization of variable and dispatchable power generation



4.3 ITALY: DEVELOPMENT OF LOAD, GENERATION, AND RESIDUAL LOAD

Table 37 shows the actual load of Italy's power market region in 2015. The data were provided by the Italian grid operator TERNA. They show that northern Italy requires about half the country's electricity demand and has also more than half the overall peak load. The average load in this region represents 55% of the value for the whole of Italy.

Table 38: Italy—Load, generation, and residual load in 2015 (TERNA)

Real load – measured by TERNA in 2015	Annual demand [MWh/a]	Max Load [MW]	Min Load [MW]	Average Load [MW]
C Nord	33,457,614	6,400	1,248	3,819
C SUD	48,553,674	9,386	1,750	5,543
Nord	176,458,278	34,543	9,327	20,144
Sud	29,843,302	5,332	1,673	3,407
Sardegna	9,098,917	1,523	702	1,039
Sicilia	18,854,940	3,295	1,198	2,152
Italy	316,959,112	60,236	18,588	36,183

Table 38 shows that Italy's average load is predicted to increase over the next decade by approximately 15% under the REFERENCE and Energy [R]evolution scenario, and by 22% under the Adv. Energy [R]evolution scenario. The E[R] scenario will have the highest peak load by 2050, as a result of the increased electrification of the heating and transport sectors, while the energy efficiency targets are similar to those under the REREFENCE scenario. The ADV. E[R] scenario has a more stringent electrification strategy, especially in the transport sector, due to an earlier phase-out target for fossil fuels, and a more ambitious energy efficiency strategy. In comparison, the load under ADV. E[R] will be only 10% higher than in the REF scenario in 2050, despite an electrification rate of 75% for road and rail transport vehicles.

Table 39: Italy—Projection of load, generation, and residual load until 2050

Italy: Development of load and generation		REF				Energy [R]evolution				Adv. Energy [R]evolution			
		Max. Demand	Max. Generation	Max. Residual Load	Peak load increase	Max Demand	Max Generation	Max Residual Load	Peak load increase	Max Demand	Max Generation	Max Residual Load	Peak load increase
Italy		[GW/h]	[GW/h]	[GW/h]	[%]	[GW/h]	[GW/h]	[GW/h]	[%]	[GW/h]	[GW/h]	[GW/h]	[%]
C Nord	2020	6.6	10.4	0.4	100%	6.6	8.9	0.4	100%	6.6	8.9	0.4	100%
	2030	7.2	8.5	2.3	108%	7.1	8.0	2.8	108%	7.5	13.1	2.8	113%
	2050	7.3	8.4	4.0	110%	10.2	18.4	7.5	154%	8.0	16.4	6.5	122%
C Sud	2020	8.5	8.7	0.9	100%	8.4	8.6	0.9	100%	8.4	8.6	0.9	100%
	2030	9.8	10.1	2.4	116%	9.8	10.1	2.9	117%	10.5	15.6	3.5	125%
	2050	10.6	10.8	2.3	125%	14.5	22.2	9.7	173%	11.9	19.7	8.8	141%
Nord	2020	23.1	23.6	1.9	100%	23.0	23.5	1.9	100%	23.0	23.5	1.9	100%
	2030	27.2	27.9	1.7	118%	27.2	28.2	3.4	118%	28.7	44.6	10.0	125%
	2050	30.5	31.1	1.2	132%	41.3	64.6	28.1	179%	33.5	56.5	26.4	146%
Sud	2020	6.2	6.3	0.5	100%	6.1	6.3	0.5	100%	6.1	6.3	0.5	100%
	2030	7.3	12.3	2.7	118%	7.3	12.9	2.7	118%	7.6	17.0	3.1	124%
	2050	8.0	13.5	5.1	130%	10.9	30.9	4.9	177%	8.8	24.4	4.4	143%
Sardegna	2020	1.6	5.1	0.5	100%	1.6	4.2	0.5	100%	1.6	4.2	0.5	100%
	2030	1.8	4.1	1.0	114%	1.8	3.9	0.9	115%	1.9	4.3	1.1	120%
	2050	1.8	3.8	1.2	111%	2.5	7.9	1.3	158%	2.0	6.0	1.0	123%
Sicilia	2020	2.8	7.3	0.7	100%	2.7	8.0	0.7	100%	2.7	8.2	0.7	100%
	2030	3.1	8.8	1.6	114%	3.1	8.0	1.5	114%	3.4	7.3	1.7	124%
	2050	3.2	8.7	2.1	114%	4.5	11.5	1.2	163%	3.6	8.7	1.5	133%
Italy	2020	51.3	61.4	7.5	100%	51.0	59.5	7.5	100%	51.0	59.7	7.5	100%
	2030	56.4	71.7	14.1	114%	56.4	71.2	14.1	115%	59.7	101.9	22.2	122%
	2050	61.4	76.3	52.9	120%	83.8	155.6	52.9	167%	67.9	131.7	48.6	135%

Although there are significant regional differences, under E[R], three regions will almost double their loads between 2020 and 2050: C Sud, Nord, and Sicilia. The calculated peak loads under the REFERENCE and Advanced Energy [R]evolution scenarios will be almost identical throughout the entire modelling period and across all regions. This is an indication of the need to introduce energy efficiency in parallel with the implementation of electric mobility to limit the required investment in the upgrade of Italy's power grid infrastructure. However, under any scenario and independent of the type of power generation, Italy's power grid must by expanded over the next two decades, because increased electric mobility will require additional capacity in the power grid to accommodate the higher charging loads for vehicles. However, the locations of transmission grids will be dependent on the form of generation because the locations of generation and demand centres may differ for decentralized and centralized power generation. The REF scenario will lead to a significant concentration of generation capacity close to gas pipelines and LNG terminals for imported gas.

4.4 ITALY: DEVELOPMENT OF INTER-REGIONAL EXCHANGE OF CAPACITY

The increasing electricity load in all regions, shown in Table 38, will require an increase in the transmission and distribution networks in Italy. This analysis assumes that those network upgrades will be implemented as the demand increases. Because it is a technical requirement, Italy must increase its grid capacity proportionally to the increasing demand. This technical requirement to expand the grid capacity as demand increases is largely independent of the type of power generation.

The inter-regional exchange of capacity is a function of load development and generation capacity in all six regions. The [R]E 24/7 model distributes generation capacity according to the regional load and the conditions for power generation. The locations of gas power plants are fixed and the installation of new capacities will depend on the possibility of fuel supply. Renewable power generation is more modular and can be distributed according to the load in the first place. However, as the share of renewable electricity increases, and the space available for utility-scale solar and onshore wind generation facilities and the availability and quality of local resources (such as solar radiation and/or wind speed) decrease, power might be generated further from its point of consumption. This will require more transmission capacity to exchange generation capacities between the six regions of Italy analysed here.

In our analysis, an increase in the necessary inter-regional exchange of capacity, in addition to the increase in grid capacity within the regions as demand increases, will start between 2030 and 2040. This will be particularly true of those regions with a high population density, high demand, and lower generation potential, such as C Nord, Sardegna and Sicilia. The main generation hub for renewable power in our analysis will the northern (Nord) region followed by the southern Italy (Sud). Both regions have significant solar and wind resources, which will require significant increases in transmission capacity.

However, another option will be to increase dedicated *energy communities*, which will increase storage as part of their local energy plan, reducing the transmission required, but increasing the overall storage capacity. Whether increased storage or increased transmission with future storage costs is more economic is beyond the scope of this study and requires further research.

The current actual interconnection capacities between the six analysed regions were not available, so the modelling results are based on the assumptions described earlier. Furthermore, the transfer capacities for the REF (Figure 29) and both alternative scenarios (Figure 30 and Figure 31) are only estimates because capacities can be reduced by demand-side management measures, increased storage capacities, and variations in the actual distribution of power generation. The net transfer capacity in the REF scenario in 2050 will follow the same pattern as that in the two alternative scenarios, whereas the 2040 values will differ. The modelling results indicate that interconnections must be built earlier in the alternative scenarios. The large solar capacities in the south (Sud) and the concentration of dispatchable renewables in the north (Nord) will require transmission capacities in the demand centres of Italy.

Limitations

Calculated loads are not optimised in the regard to local storage, self-consumption of decentralised producer of solar photovoltaic electricity and demand side management. Thus, calculated loads may be well below the actual values. Furthermore, the calculated export load from *SUD* is a cumulative value and will have to be distributed across the two neighbouring regions.

Figure 29: Italy—Maximum inter-regional exchange capacities, additional to the required grid capacity expansion in response to load increase, under the REFERENCE scenario

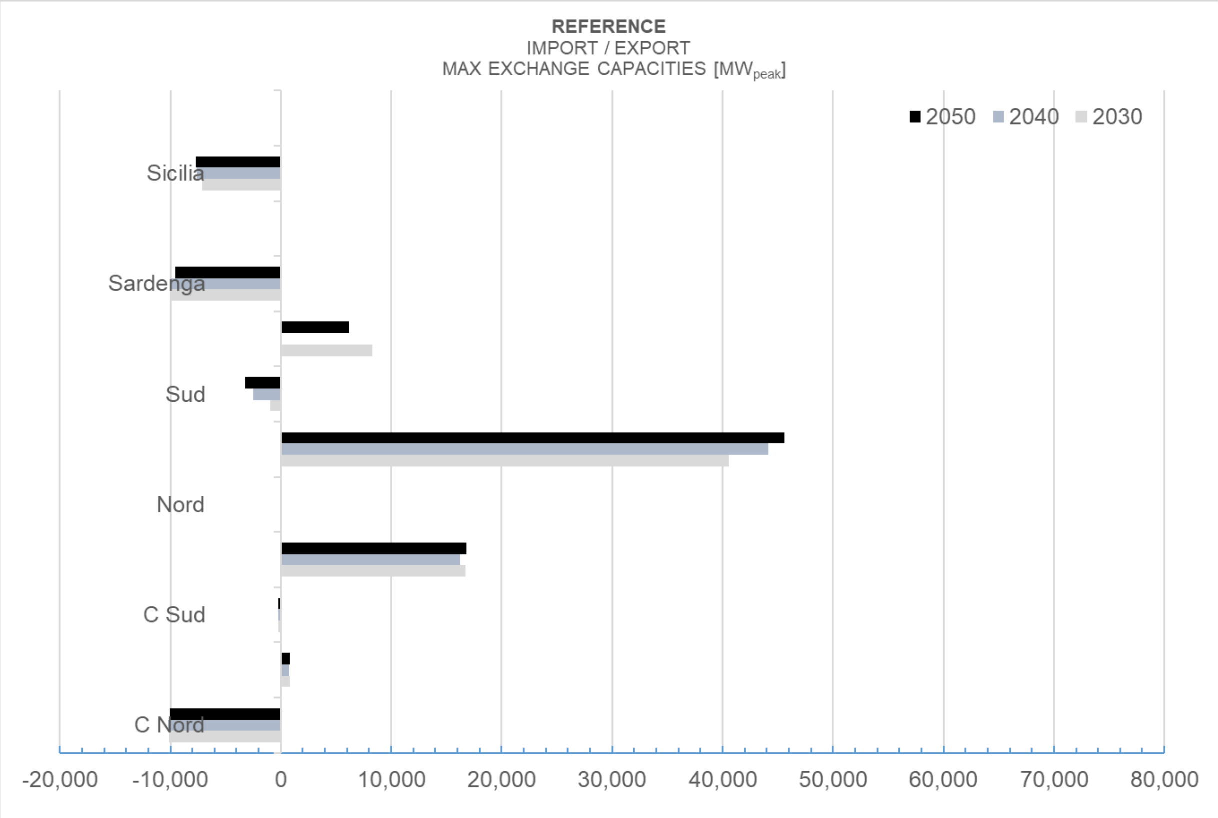


Figure 30: Italy—Maximum inter-regional exchange capacities, additional to the required grid capacity expansion in response to load increase, under the Energy [R]evolution scenario

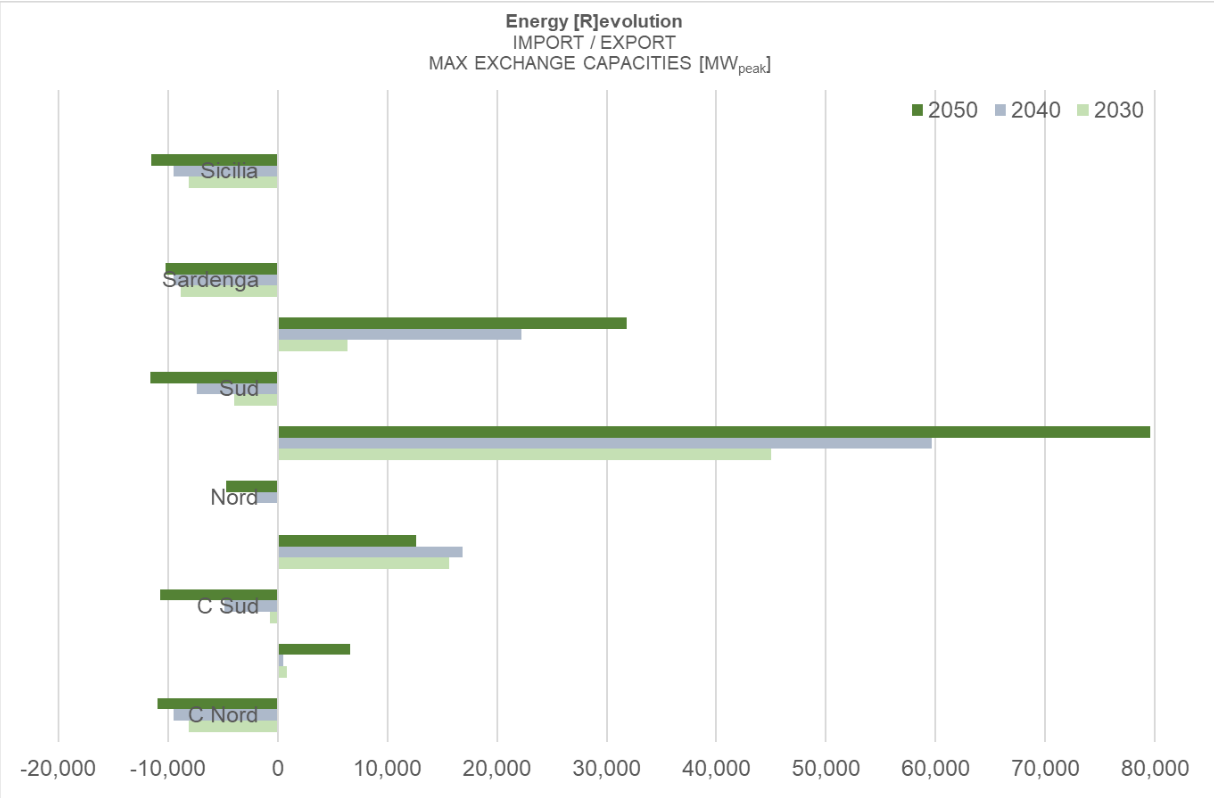


Figure 31: Italy—Maximum inter-regional exchange capacities, additional to the required grid capacity expansion in response to load increase, under the Adv. Energy [R]evolution scenario

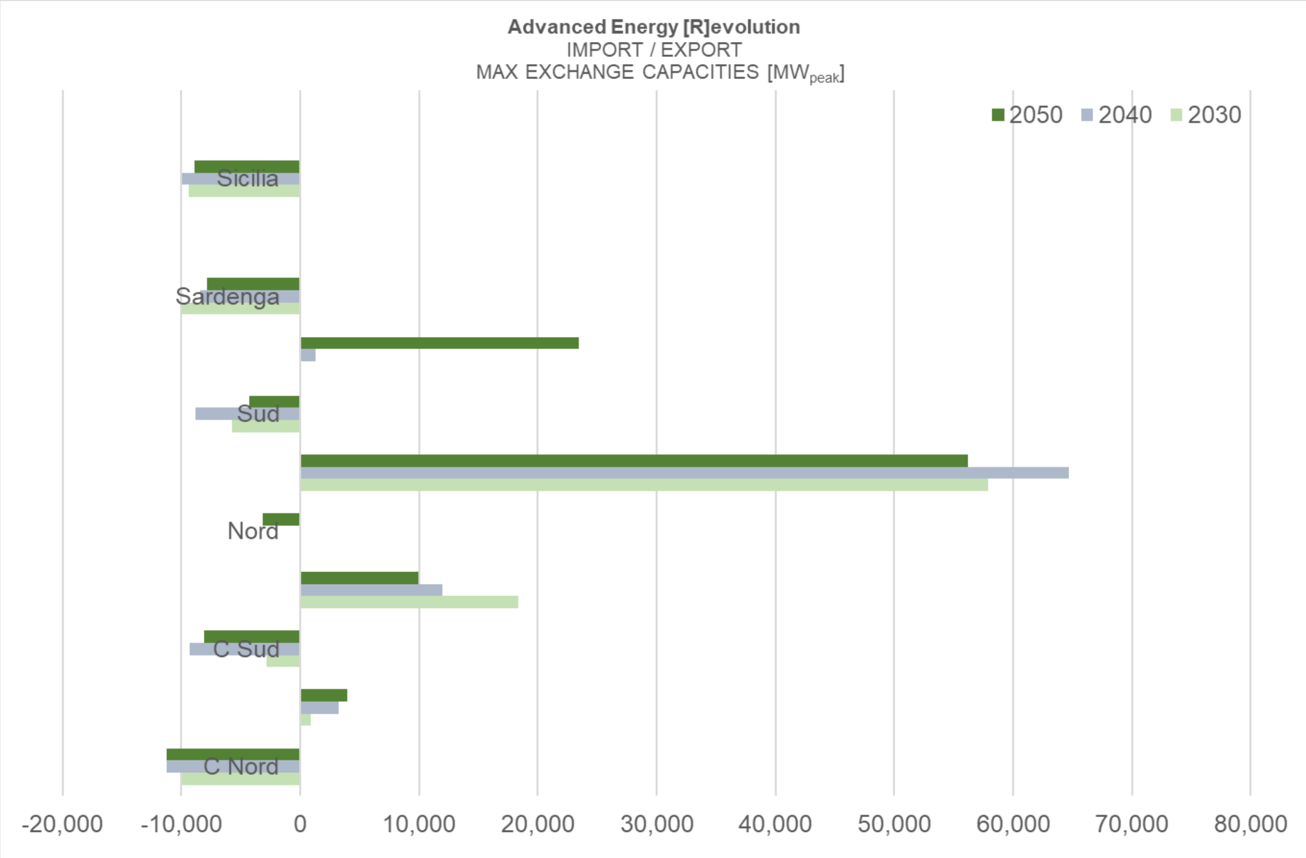
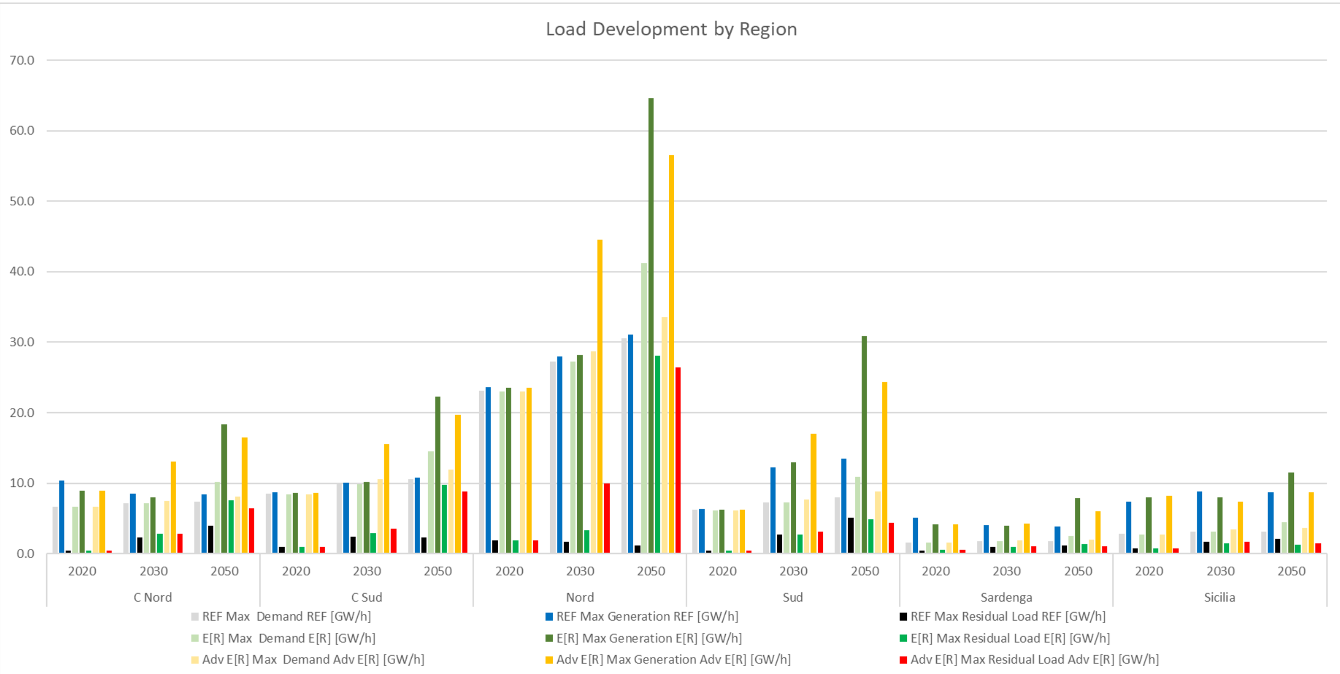


Figure 32: Peak load and maximum generation development by region, in GW



The high-power demand in northern Italy (see Table 37) reflects the significant industrial infrastructure around Milano and the river Po region. The NORD region will continue to dominate the Italian electricity market under all scenarios. However, the southern region will grow substantially as well. Both Energy [R]evolution scenarios have greater differences between peak generation and peak demand throughout the years, which is a consequence of power generation from variable sources. The development of the peak loads, peak demands, and maximum residual loads (the difference between demand and supply) for Italy's six sub-regions is shown in Figure 32.

Peak load and peak generation events do not appear at the same time, so the values cannot be simply added. Moreover, the peak loads can vary across all regions and appear at different times. Therefore, to sum all the regional peak loads will only provide an indication of the peak load for the whole country. The maximum residual load[52] shows the maximum undersupply in a region and indicates the maximum load imported into that region. This event can only be several hours long, so the interconnection capacity might not be as high as the maximum residual load indicates. Optimizing the interconnection for all regions was beyond the scope of this analysis. To guarantee the security of supply, the residual load of a region must be supplied by the following options:

- imports from other regions through interconnections;
- charged storage facilities providing additional load;
- available back-up capacities, such as gas peaking plants;
- load and demand-side management.

In practice, security of supply will be achieved with a combination of several measures and will require the in-depth analysis of regional technical possibilities, e.g., whether or not a cable connection is possible.

4.5 STORAGE REQUIREMENTS

The quantity of storage required is largely dependent on the storage costs, grid expansion possibilities, and the generation mix itself. In terms of grid expansion, the geographic situation greatly influences the construction costs; crossing mountains, rivers, or swamps is significantly more expensive than crossing flat lands (Wendong 2016)[53]. Furthermore, the length of the permission process and whether people will be displaced by grid expansions may make storage economically preferable to grid expansion, even though the current transmission costs are lower per megawatt-hour than storage costs. Cebulla et al. (2018)[54] reported that "in general terms, photovoltaic-dominated grids directly correlate to high storage requirements, in both power capacity and energy capacity. Conversely, wind-dominated scenarios require significantly lower storage power and energy capacities, if grid expansion is unlimited or cheap". They also found, in an analysis of 400 scenarios for Europe and the USA, that once the share of variable renewables exceeds 40% of the total generation, the increase in electrical energy storage power capacity is about 1–2 GW for each percentage of variable renewable power generation in wind-dominated scenarios and 4–9 GW in solar-photovoltaic-dominated scenarios.

In the E[R] scenario, the share of variable generation will exceed 30% by 2030 in all but one region (Nord), whereas the ADV. E[R] scenario will reach 40% variable power generation in all regions by 2030. Table 40 shows the storage and dispatch requirements to avoid curtailment under both the RENEWABLE and REFERENCE scenarios. The table identifies the capacity (= storage volume) in gigawatt hours per year (GWh/a) and the required annual through-put capacity of the storage system. It also shows the installed capacity required to avoid curtailment, in terms of the load in gigawatts (GW). These results are consistent with the findings of Cebulla et al., with 60 GW storage required in E[R] by 2050 and 62 GW in ADV. E[R]. However, there is no "hard number" for storage requirements because they are dependent upon the available dispatch capacity (e.g., from [bio-]gas power plants) and the possibility of demand-side management. The economic optimal storage capacity, in terms of both the overall storage volume and the installed capacity, is also a function of the storage costs, the wind and solar generation costs, and the power system requirements.

Over the past decade, the cost of batteries, especially lithium batteries, has declined significantly. However, solar photovoltaic costs have also declined significantly. Storage is economic when the cost per kilowatt-hour is equal to or lower than the cost of generation. Therefore, if storage costs are high, curtailment could be economic. However, there are various reasons for curtailment, including transmission constraints, system balancing, or economic reasons (NREL 2014)[55]. The California Independent System

[52] Residual load is the load remaining after local generation within the analysed region is exhausted. There could be a shortage of load supply due to the operation and maintenance of a coal power plant or reduced output from wind and solar power plants.

[53] Wendong (2016), Wei, Wendong et al. Regional study on investment for transmission infrastructure in China based on the State Grid data,10.1007/s11707-016-0581-4, Frontiers of Earth Science, June 2016

[54] Cebulla et. al. (2018), How much electrical energy storage do we need? A synthesis for the U.S., Europe, and Germany, Journal of Cleaner Production, February 2018, https://www.researchgate.net/publication/322911171_How_much_electrical_energy_storage_do_we_need_A_synthesis_for_the_US_Europe_and_Germany/link/5a782bb50f7e9b41dbd26c20/download

[55] Wind and Solar Energy Curtailment: Experience and Practices in the United States; Lori Bird, Jaquelin Cochran, and Xi Wang, National Renewable Energy Laboratory (NREL), March 2014, https://www.nrel.gov/docs/fy14osti/60983.pdf

Operator (CISO)[56] defines economic curtailment during times of oversupply as a market-based decision. “During times of oversupply, the bulk energy market first competitively selects the lowest cost power resources. Renewable resources can “bid” into the market in a way to reduce production when prices begin to fall. This is a normal and healthy market outcome. Then, self-scheduled cuts are triggered and prioritized using operational and tariff considerations. Economic curtailments and self-scheduled cuts are considered “market-based”.

In this analysis, we assume that a curtailment rate of 5% with regard to the annual generation (in GWh/a) for solar photovoltaics and onshore and offshore wind will be economically viable by 2030. By 2050, we assume an “economic curtailment rate” of 10%. However, economic curtailment rates are dependent on the available grid capacities and can vary significantly, even within Italy. Curtailment will be economic when the power generated from a wind turbine or photovoltaic power plant exceeds the demand for only a few hours per day and this event occurs rarely across the year. Therefore, grid expansion will not be justifiable. Table 39 shows the storage required to avoid curtailment, or in other words, the entire surplus generation at any given time, by region and under all three scenarios.

Table 40: Italy—Storage requirements to avoid curtailment

Storage requirement to avoid curtailment		REF		Energy [R]evolution		Advanced Energy [R]evolution	
		Required storage to avoid curtailment (Overproduction)	Required storage capacity to avoid curtailment	Required storage to avoid curtailment (overproduction)	Required storage capacity to avoid curtailment	Required storage to avoid curtailment (Overproduction)	Required storage capacity to avoid curtailment
Italy		[GWh/a	[GW/a]	[GWh/a]	[GW/a]	[GWh/a]	[GW/a]
C Nord	2020	0	0	0	0	0	0
	2030	71	2	188	2	4,334	7
	2050	207	2	7,137	10	7,552	9
C Sud	2020	0	0	0	0	0	0
	2030	53	2	95	2	3,694	7
	2050	38	2	3,416	8	5,078	9
Nord	2020	0	0	0	0	0	0
	2030	14	1	135	3	12,055	20
	2050	3	1	11,909	24	15,265	25
Sud	2020	41	1	54	1	54	1
	2030	1,833	6	1,732	6	6,293	10
	2050	1,256	6	5,977	12	7,480	12
Sardegna	2020	78	0	87	0	87	0
	2030	890	1	801	1	2,212	3
	2050	1,152	2	2,940	3	3,449	3
Sicilia	2020	53	1	66	1	66	1
	2030	108	1	144	1	1,523	3
	2050	182	1	2,074	4	2,458	4
Total	2020	172	3	207	3	207	3
	2030	2969	14	3096	16	30110	49
	2050	2838	13	33451	60	41282	62

The REFERENCE scenario will require only minor storage capacity, mainly on the islands and the southern region where wind power generation is currently concentrated, although it is within the economic curtailment range. The high variable renewable generation level, combined with the high demand, in northern Italy will lead to substantial storage requirements in 2030 and 2050 under the ADV. E[R] scenario. In contrast, the E[R] scenario will lead to only minor oversupply situations by 2030, mainly in the NORD and SUD regions by 2030, again within the curtailment range, and the storage demand will be

[56] Impacts of renewable energy on grid operations, factsheet, https://www.caiso.com/Documents/CurtailmentFastFacts.pdf

significantly lower than in the ADV. E[R] scenario. However, by 2050, temporary oversupply will occur in almost all regions, which will increase storage demand. Both Energy [R]evolution scenarios will require a total storage capacity in the range of 60 GW to avoid curtailment. The storage requirements have been assessed based on the assumptions that all the regions will have established interconnection capacities as indicated in section 4.3 and that the economic curtailment rates are fully exhausted.

Table 41: Italy—Estimated electricity storage requirements for both Energy [R]evolution scenarios

Storage and H_2 Dispatch		Energy [R]evolution		Adv. Energy [R]evolution	
		Total storage throughput	Storage capacity (1)	Total storage throughput	Storage capacity (1)
Italy		[GWh/yr]	[GW]	[GWh/yr]	[GW]
C Nord	2020	0	0	0	0
	2030	373	0	3551	3
	2050	7672	6	8609	7
C Sud	2020	0	0	0	0
	2030	191	0	4256	4
	2050	6515	5	9060	8
Nord	2020	0	0	0	0
	2030	270	0	10730	9
	2050	21132	18	24533	20
Sud	2020	67	0	67	0
	2030	1800	2	4177	3
	2050	7041	6	8700	7
Sardegna	2020	171	0	171	0
	2030	1227	1	2393	2
	2050	2064	2	2960	2
Sicilia	2020	129	0	129	0
	2030	282	0	2475	2
	2050	3657	3	4296	4
Total	**2020**	367	0	367	0
	2030	4143	3	27581	23
	2050	48080	40	58159	48

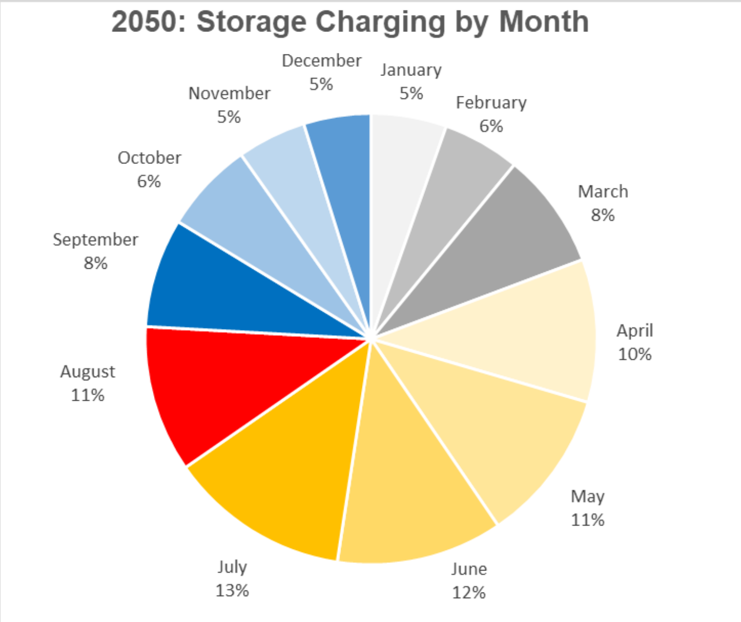
(1) Calculated with an average capacity factor of 1,200 hours per year

Whereas Table 39 shows the theoretical storage demand required to avoid curtailment, Table 40 gives an overview of the estimated installed storage capacity requirements for both Energy [R]evolution scenarios. The majority of storage facilities will be required in northern Italy, although the capacity is lower than indicated in Table 40 because production peaks have been curtailed. For the whole of Italy, the required storage capacity in 2050 will be 33% below the capacity required to avoid curtailment in the E[R], and 23% below the capacity required under the ADV. E[R] scenario. However, there are significant regional differences. The requirement for utility-scale storage will occur between 2025 and 2030. The storage demand will vary significantly and will be a function of the regional distribution of variable power generation and the extent to which the regions can exchange load via interconnections.

The estimates provided for the storage requirements also presuppose that variable renewables will be first in the dispatch order, ahead all other types of power generation. Priority dispatch is the economic basis for investment in utility-scale solar photovoltaic and wind projects. The curtailment rates or storage rates will be significantly higher with the priority dispatch of other types of power. This case has not been calculated because it would involve a lack of investment in solar and wind in the first place. With decreasing storage costs, as projected by Bloomberg (2019)[57], interconnections might become less economically favourable than batteries. This would increase even further the economic advantage of decentralized solar photovoltaics close to the electricity demand over centralized gas power plants.

The storage estimations provided in Table 40 are technology neutral and includes - besides lithium batteries - also flow-batteries or any kind of thermal storage options (e.g. molten salt).
Figure 33 shows the need for seasonal storage: 65% of the storage demand are required during the sunnier periods April to September, while only 35% are required during the autumn and winter period.

Figure 33: Storage demand by month



However, an expansion of the electricity network as the demand increases is unavoidable under any scenario, to reduce the storage requirements and increase the load transfer options for Italy as a result of increased electric mobility.

4.6 SUMMARY: POWER SECTOR ANALYSIS FOR ITALY

Both Energy [R]evolution scenarios prioritize the use of Italy's renewable energy resources to reduce its dependence on energy importation and to utilize local resources. Italy will increase its power demand under each power generation scenario as a result of the implementation of electric mobility, which is currently at a low level. Therefore, power grids must expand and power generation must increase as the load increases, under both a conventional power generation pathway and a renewable-power-dominated pathway.

However, renewable-energy-dominated power generation requires a different infrastructural design than a fossil-power-dominated future. To harvest Italy's vast solar resources, the power grid must be able to transport large loads from the south to the demand centres, whereas decentralized power will shoulder a significant part of the residential sector demand. Utility-scale solar power will require medium-voltage-level transmission lines to the load centres of Italy.

In 2050, the majority of dispatch power will come from bio-energy and synthetic fuels and—within technical limitations—from geothermal and solar thermal power plants, which may be operated with heat storage after 2030. Italy has abundant renewable energy resources, which could supply, with the currently available technologies, all the renewable electricity required. However, more research is required to assess how high levels of electric mobility can be integrated into demand and generation management and a country-wide storage concept.

[57] Bloomberg (2019), A Behind the Scenes Take on Lithium-ion Battery Prices, Logan Goldi-Scot, BloombergNEF, March 5 2019, https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

5 EMPLOYMENT ANALYSIS

5.1 METHODOLOGY: EMPLOYMENT ANALYSIS

The methodology outlined in this section has two dimensions: total employment in the energy sector and occupational breakdown. The methodology used to analyse the total employment in the energy sector was first developed in 2009 for the Greenpeace Energy [R]evolution study (see Rutovitz et al., 2015; Rutovitz and Atherton, 2009). This methodology has been updated for a global energy scenario project by UTS-ISF, in partnership with the German Aerospace Centre (DLR), Institute for Engineering Thermodynamics, and Department of Systems Analysis and Technology Assessment (STB), with funding by the Leonardo DiCaprio Foundation (Teske, 2019) and the German Greenpeace Foundation (Greenpeace Umweltstiftung).

This study projects the total employment in the energy sector under three scenarios: the Energy [R]evolution, Adv. Energy [R]evolution, and REFERENCE scenarios. Employment is projected for Italy under each scenario from 2015 until 2050. The calculations are based on a series of employment multipliers and the projections for energy use and capacity. Only direct employment is included—jobs in construction, manufacturing, operations and maintenance, fuel supply associated with electricity generation, and direct heat provision. An overview of the total employment methodology is given in Figure 34.

Figure 34: Total employment calculation: methodological overview

Manufacturing (for local use)	=	MW installed per year in region	x	Manufacturing employment factor	X	Regional job multiplier for year	x	% local manufacturing
Manufacturing (for export)	=	MW exported per year	x	Manufacturing employment factor	X	Regional job multiplier for year		
Construction	=	MW installed per year	x	Construction employment factor	X	Regional job multiplier for year		
Operation and maintenance	=	Cumulative capacity	x	O&M employment factor	X	Regional job multiplier for year		
Fuel supply (coal, gas and biomass)	=	Primary energy demand plus exports	x	Fuel employment factor (always regional for coal)	X	Regional job multiplier for year	x	% of local production
Heat supply	=	MW installed per year	x	Employment factor for heat	X	Regional job multiplier for year		

Jobs in region	=	Manufacturing	+	Construction	+	Operation and maintenance (O&M)	+	Fuel	+	Heat

Employment factors at 2020, 2030, or 2050	=	2015 employment factor	x	Technology decline factor $^{[\text{number of years after 2015}]}$

The main inputs for the quantitative employment calculations are outlined below.

5.1.1 For each scenario (REF, E[R], and ADV. E[R]):

- the electrical and heating capacity that will be installed each year for each technology;
- the primary energy demand for coal, gas, and biomass fuels in the electricity and heating sectors;
- the amount of electricity generated per year from oil, and diesel.

5.1.2 For each technology:

- 'employment factors', or the number of jobs per unit of capacity, separated into manufacturing, construction, operation, and maintenance, and per unit of primary energy for fuel supply;
- for the 2020, 2030, and 2050 calculations, a 'decline factor' for each technology, which reduces the employment factor by a certain percentage per year. This reflects the fact that employment per unit will decrease as technology efficiencies improve.

The figures for the increase in electrical capacity and energy use for each scenario are multiplied by the employment factors for each of the technologies, and then adjusted for the regional labour intensity and the proportion of fuel or manufacturing that occurs locally.

A range of data sources were used for the model inputs, including the International Energy Agency, US Energy Information Administration, BP Statistical Review of World Energy, US National Renewable Energy Laboratory, International Labour Organization, World Bank, industry associations, national statistics, company reports, academic literature, and the UTS-ISF's own research.

These calculations only consider direct employment; for example, the construction team required to build a new wind farm. They do not include indirect employment; for example, the extra services provided in a town to accommodate the construction team.

The calculations do not include jobs in energy efficiency because this is beyond the scope of this research. The large number of assumptions required to make these calculations means that the employment numbers are only estimates, especially for regions for which few data exist. However, within the limits of data availability, the figures presented are representative of employment levels under the given scenarios.

5.1.3 Employment factors

Employment factors were used to calculate the number of jobs required per unit of electrical or heating capacity, or per unit of fuel. The employment factors differ depending on whether they involve manufacturing, construction, operation and maintenance, or fuel supply. Information about these factors usually comes from OECD countries because they are where most data are collected, although local data were used wherever possible. The employment factor for OECD Europe was used for Italy in our calculations, as shown in Table 41.

Table 42: Summary of employment factors

	Construction/ installation	Manufacturing	Operations & maintenance	Fuel—Primary energy demand
	Job years/ MW	Job years/ MW	Jobs/MW	
Coal	11.4	5.1	0.14	Regional
Gas	1.8	2.9	0.14	Regional
Biomass	14.0	2.9	1.5	2.5 Jobs/PJ
Hydro, large	7.5	3.9	0.2	
Hydro, small	15.8	11.1	4.9	
Wind onshore	3.0	3.4	0.3	
Wind offshore	6.5	13.6	0.15	
Photovoltaic	3.2	1.5	0.7	
Geothermal	6.8	3.9	0.4	
Solar thermal	8.9	4.0	0.7	
Ocean	10.3	10.3	0.6	
Geothermal—heat	6.9 jobs/MW (construction and manufacturing)			
Solar—heat	8.4 jobs/MW (construction and manufacturing)			
Combined heat and power	CHP technologies use the factor for the technology, i.e., coal, gas, biomass, geothermal, etc., increased by a factor of 1.5 for operations & maintenance only.			

5.1.4 COAL FUEL SUPPLY

The employment factors for coal are particularly important at the regional level, because employment per ton varies significantly across world regions and because coal plays a significant role in energy production in many countries. The calculation of coal and gas employment per petajoule (PJ) is based on data from national statistics and company reports, combined with production figures from the BP Statistical Review of World Energy 2018 (BP-SR 2018) or other sources. Data were collected for as many major coal-producing countries as possible, and coverage was obtained for 90% of the world coal production.

Table 43: Employment factors used for coal fuel supply (mining and associated jobs)

	Employment factor Jobs per PJ	Tonnes per person per year (coal equivalent)
World average	36.2	943
OECD Europe	36.2	942

5.1.5 REGIONAL ADJUSTMENTS

The employment factors used in this model for energy technologies other than coal mining were usually for OECD regions, which are typically wealthier than other regions. A regional multiplier was applied to make the jobs per MW more realistic for other parts of the world. In developing countries, there are generally more jobs per unit of electricity because those countries have more labour-intensive practices. The multipliers change over the study period, consistent with the projections for GDP per worker. This reflects the fact that as prosperity increases, labour intensity tends to fall. The multipliers are shown in Table 43.

Table 44: Regional multipliers used for the quantitative calculation of employment

	2015	2020	2030	2040	2050
OECD (North America, Europe, Pacific)	1.0	1.0	1.0	1.0	1.0
Latin America	3.4	3.4	3.4	3.1	2.8
Africa	5.7	5.7	5.5	5.2	4.8
Middle East	1.4	1.5	1.4	1.4	1.2
Eastern Europe/Eurasia	2.4	2.4	2.2	2.0	1.8
India	7.0	5.5	3.7	2.7	2.2
Developing Asia	6.1	5.2	4.1	3.5	3.1
China	2.6	2.2	1.6	1.3	1.2

Source: Derived from ILO (2013) Key Indicators of the Labour Market, eighth edition software, with growth in GDP per capita derived from IEA World Energy Outlook 2018 and World Bank data.

For this analysis, the regional factors and multipliers for Europe were used for Italy because no local data were available.

5.2 RESULTS: EMPLOYMENT ANALYSIS

Employment development has been calculated based on the methodology described and the results for the long-term energy scenario documented in Chapter 3. The figures represent quantitative estimates and have been compared with the current workforces in Italy when information was available. The employment data for the base year has been taken from MISE (2018)[58].

Table 44 shows the projected development of employment in the energy sector in Italy. Under the REF scenario, while employment in the gas sector will remain at over 20,000 jobs, employment in the renewables sector will increase. The total number of jobs in the energy sector will decrease slightly from the current 88,200 jobs to 85,000 jobs by 2025 and increase thereafter as a result of increased renewable energy deployment, to 98,000 by 2030.

Table 45: Italy—Development of employment in the energy sector

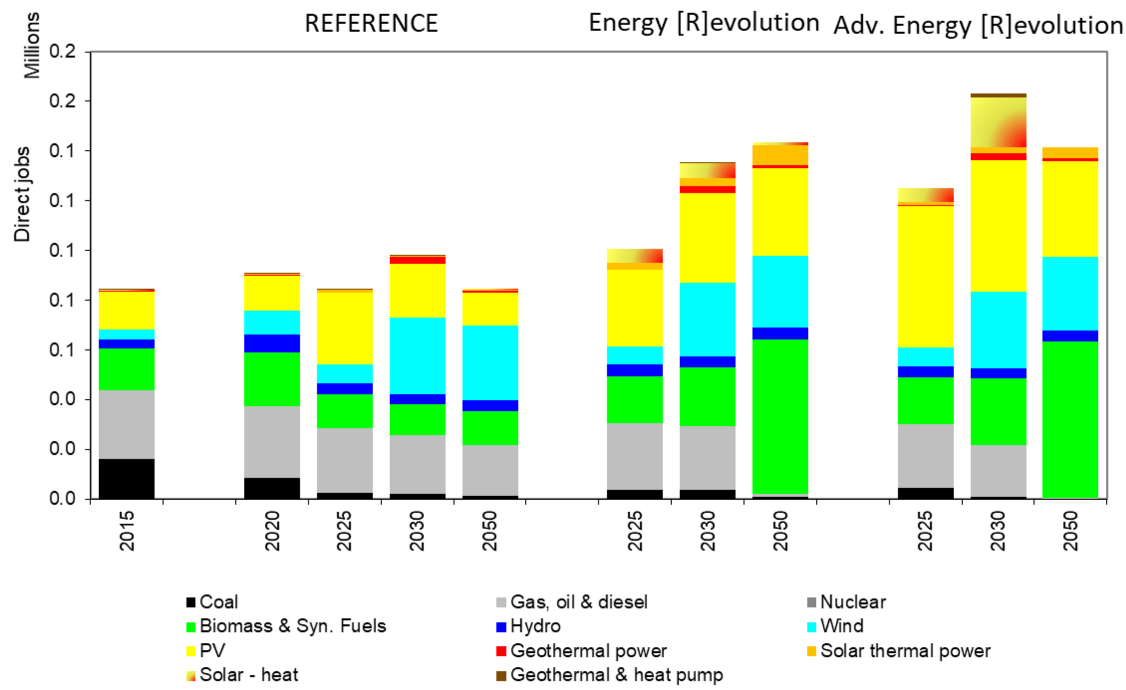
Italy: Development of Employment under Three Scenarios										
		REFERENCE			Energy [R]evolution			Adv. Energy [R]evolution		
Thousand jobs	2015	2025	2030	2050	2025	2030	2050	2025	2030	2050
Coal	16	3	2	1	4	4	1	4	1	0
Gas, oil, & diesel	28	26	23	20	27	26	1	26	21	0
Renewable	44	56	73	63	70	106	141	95	141	141
Total jobs	88	85	98	84	101	135	144	125	163	141
Construction and installation	5	14	15	13	20	30	19	29	25	25
Manufacturing	5	8	15	14	10	22	17	15	21	20
Operations and maintenance	53	46	53	45	49	61	103	53	79	94
Fuel supply (domestic)	25	17	15	12	21	22	3	22	16	2
Coal and gas export	-	-	-	-	-	-	-	-	-	-
Solar and geothermal heat	0.3	0.4	0.4	0.2	6	6	1	6	21	1
Total jobs (thousands)	88	85	98	84	101	135	144	125	163	141

[58] MISE 2018, MINISTERO DELLO SVILUPPO ECONOMICO, DIREZIONE GENERALE PER LA SICUREZZA DELL'APPROVVIGIONAMENTO E LE INFRASTRUTTURE ENERGETICHE, :LA SITUAZIONE ENERGETICA NAZIONALENEL 2018, GIUGNO 2019, https://www.federesco.org/images/Situazione%20energetica%20nazionale.pdf

Figure 34 shows the changes in job numbers under all scenarios for each technology between 2015 and 2050. Jobs in the REF scenario will be at current levels by 2050. However, both alternative energy pathways will lead to stronger growth in the renewable sector, significantly overcompensating for the losses in the gas industry. The E[R] scenario will increase overall employment in the energy sector from 88,200 today to 101,000 by 2025, and further increase it to around 135,000 jobs by 2030. Only 22% of the jobs in 2030 will be in the fossil fuel industry, whereas the remaining 78% will be in the renewables industry.

Our analysis shows higher renewable energy employment developments under the ADV. E[R] scenario: the overall number of jobs in 2025 will be 24,000 higher than under the E[R] scenario. As the development of renewables accelerates under the ADV. E[R] scenario, the construction rates will decrease after 2030, so that by 2050, there will be around 3,000 fewer jobs than under the E[R] scenario, but still approximately 57,000 more than under the REF scenario.

Figure 35: Total employment in Italy's energy sector in 2025, 2030, and 2050



6 APPENDIX

Italy

Reference

Electricity generation [TWh/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
Power plants	**186**	**206**	**158**	**209**	**250**	**265**	**276**
- Hard coal (& non-renewable waste)	43	34		0	0	0	0
- Lignite	1	0		0	0	0	0
- Gas	38	53		65	59	56	53
of which from H2	0	0		0	0	0	0
- Oil	4	3		3	3	3	3
- Diesel	0	0		0	0	0	0
- Nuclear	0	0		0	0	0	0
- Biomass (& renewable waste)	10	19		18	17	19	21
- Hydro	46	46		49	49	49	49
- Wind	15	18		32	39	43	46
of which wind offshore	0	0		1	2	3	5
- PV	23	27		34	73	85	93
- Geothermal	6	6		7	7	7	7
- Solar thermal power plants	0	0		1	2	2	2
- Ocean energy	0	0		0	0	0	0
Combined heat and power plants	**96**	**96**	**74**	**96**	**91**	**85**	**80**
- Hard coal (& non-renewable waste)	2	3		2	1	0	0
- Lignite	0	0		0	0	0	0
- Gas	75	76		78	77	75	72
of which from H2	0	0		0	0	0	0
- Oil	9	9		7	5	2	1
- Biomass (& renewable waste)	10	9		9	8	8	7
- Geothermal	0	0		0	0	0	0
- Hydrogen	0	0		0	0	0	0
CHP by producer							
- Main activity producers	78	78		78	74	70	65
- Autoproducers	18	18		18	17	16	15
Total generation	**282**	**302**	**232**	**305**	**341**	**350**	**356**
- Fossil	173	178		156	145	137	130
- Hard coal (& non-renewable waste)	45	37		2	1	0	0
- Lignite	1	0		0	0	0	0
- Gas	113	129		143	136	131	125
- Oil	13	12		10	8	6	4
- Diesel	0	0		0	0	0	0
- Nuclear	0	0		0	0	0	0
- Hydrogen	0	0		0	0	0	0
- of which renewable H2	0	0		0	0	0	0
- Renewables (w/o renewable hydrogen)	109	124		149	196	213	227
- Hydro	46	46		49	49	49	49
- Wind	15	18		32	39	43	46
- PV	23	27		34	73	85	93
- Biomass (& renewable waste)	19	28		27	26	27	28
- Geothermal	6	6		7	7	7	7
- Solar thermal power plants	0	0		1	2	2	2
- Ocean energy	0	0		0	0	0	0
Distribution losses	20	21		21	22	23	24
Own consumption electricity	21	21		21	22	23	23
Electricity for hydrogen production	0	0		0	0	0	0
Electricity for synfuel production	0	0		0	0	0	0
Final energy consumption (electricity)	287	294		304	309	329	343
Variable RES (PV, Wind, Ocean)	38	44		66	112	128	139
Share of variable RES	13%	15%		21%	33%	36%	39%
RES share (domestic generation)	39%	41%		49%	57%	61%	64%

Transport - Final Energy [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020	2025	2030	2040	2050
road	**1,402**	**1,516**	**1,099**	**1,490**	**1,435**	**1,412**	**1,315**
- fossil fuels	1,320	1,411		1,373	1,291	1,228	1,087
- biofuels	44	52		57	67	85	96
- synfuels	0	0		0	0	0	0
- natural gas	38	39		38	44	52	53
- hydrogen	0	0		0	0	0	0
- electricity	0	13		22	33	47	79
rail	**40**	**40**	**29**	**41**	**41**	**43**	**45**
- fossil fuels	1	10		9	9	9	8
- biofuels	0	0		0	0	0	0
- synfuels	0	0		0	0	0	0
- electricity	39	30		32	32	34	37
navigation	**39**	**41**	**30**	**40**	**40**	**40**	**40**
- fossil fuels	39	41		40	40	40	40
- biofuels	0	0		0	0	0	0
- synfuels	0	0		0	0	0	0
aviation	**29**	**26**	**19**	**26**	**26**	**27**	**29**
- fossil fuels	29	26		26	26	27	29
- biofuels	0	0		0	0	0	0
- synfuels	0	0		0	0	0	0
total (incl. pipelines)	**1,518**	**1,631**	**1,182**	**1,605**	**1,549**	**1,528**	**1,435**
- fossil fuels	1,389	1,488		1,449	1,366	1,303	1,164
- biofuels (incl. biogas)	44	52		57	67	85	96
- synfuels	0	0		0	0	0	0
- natural gas	46	47		46	51	59	59
- hydrogen	0	0		0	0	0	0
- electricity	39	43		54	65	81	116
total RES	59	70		83	104	135	170
RES share	4%	5%		5%	7%	9%	11%

Heat supply and air conditioning [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020	2025	2030	2040	2050
District heating plants	**43**	**79**	**59**	**101**	**123**	**142**	**136**
- Fossil fuels	0	0		0	0	0	0
- Biomass	34	63		80	98	112	108
- Solar collectors	0	0		0	0	0	0
- Geothermal	9	17		21	26	30	28
Heat from CHP 1)	**257**	**224**	**168**	**223**	**209**	**194**	**181**
- Fossil fuels	168	171		163	155	142	133
- Biomass	89	53		60	54	51	48
- Geothermal	0	0		0	0	0	0
- Hydrogen	0	0		0	0	0	0
Direct heating	**1,766**	**1,885**	**1,414**	**1,954**	**1,872**	**1,915**	**1,799**
- Fossil fuels	1,437	1,522		1,592	1,512	1,558	1,477
- Biomass	214	219		213	210	199	213
- Solar collectors	8	9		10	11	12	13
- Geothermal	0	0		0	0	0	0
- Heat pumps 2)	7	7		7	7	7	8
- Electric direct heating	100	128		131	132	139	89
- Hydrogen	0	0		0	0	0	0
Total heat supply3)	**2,065**	**2,189**	**1,641**	**2,277**	**2,204**	**2,251**	**2,116**
- Fossil fuels	1,605	1,693		1,755	1,667	1,700	1,609
- Biomass	336	334		353	361	363	369
- Solar collectors	8	9		10	11	12	13
- Geothermal	9	17		21	26	30	28
- Heat pumps 2)	7	7		7	7	7	8
- Electric direct heating	100	128		131	132	139	89
- Hydrogen	0	0		0	0	0	0
RES share (including RES electricity)	19%	19%		20%	21%	22%	22%
electricity consumption heat pumps (TWh/a)	0.0	0.0		0.1	0.1	0.2	0.3

Installed Capacity [GW]	2015	2020		2025	2030	2040	2050
Total generation	**131**	**137**		**136**	**164**	**164**	**165**
- Fossil	79	81		69	67	63	61
- Hard coal (& non-renewable waste)	8	7		0	0	0	0
- Lignite	0	0		0	0	0	0
- Gas (w/o H2)	61	61		61	61	59	58
- Oil	10	13		7	6	4	3
- Diesel	0	0		0	0	0	0
- Nuclear	0	0		0	0	0	0
- Hydrogen (fuel cells, gas power plants,	0	0		0	0	0	0
- Renewables	52	56		67	96	101	105
- Hydro	19	19		20	20	20	20
- Wind	9	10		15	17	18	18
of which wind offshore	0	0		0	0	1	1
- PV	19	22		25	52	56	59
- Biomass (& renewable waste)	3.9	4.634		4.885	5.005	5.156	5.5
- Geothermal	1	1		1	1	1	1
- Solar thermal power plants	0	0		0	1	1	1
- Ocean energy	0	0		0	0	0	0
Variable RES (PV, Wind, Ocean)	28	32		40	69	74	77
Share of variable RES	21%	23%		30%	42%	45%	47%
RES share (domestic generation)	40%	41%		49%	59%	62%	63%

Final Energy Demand [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
Total (incl. non-Energy use)	4,970	5,135	3,925	5,287	5,177	5,285	5,260
Total Energy use 1)	4,694	4,815	3,604	4,889	4,743	4,756	4,631
Transport	**1,523**	**1,540**	**1,116**	**1,522**	**1,476**	**1,454**	**1,422**
- Oil products	1,389	1,396		1,362	1,295	1,232	1,172
- Natural gas	46	48		50	53	58	61
- Biofuels	49	52		58	67	86	95
- Synfuels	0	0		0	0	0	0
- Electricity	39	43		52	61	78	95
RES electricity	15	18		26	35	47	60
- Hydrogen	0	0		0	0	0	0
RES share Transport	4%	5%		5%	7%	9%	11%
Industry	**1,045**	**1,078**	**819**	**1,162**	**1,234**	**1,270**	**1,324**
- Electricity	406	401		411	416	437	448
RES electricity	157	164		201	239	266	285
- Public district heat	100	116		128	135	135	121
RES district heat	2	3		4	5	7	9
- Hard coal & lignite	40	58		56	48	32	32
- Oil products	128	116		117	111	72	38
- Gas	355	364		422	489	541	603
- Solar	0	1		1	1	1	1
- Biomass	16	21		27	34	53	79
- Geothermal	0	0		0	0	0	1
- Hydrogen	0	0		0	0	0	0
RES share Industry	17%	18%		20%	23%	26%	28%
Other Sectors	**2,126**	**2,198**	**1,669**	**2,205**	**2,033**	**2,032**	**1,884**
- Electricity	590	614		630	634	668	686
RES electricity	228	252		308	365	407	436
- Public district heat	48	48		51	53	59	62
RES district heat	9	9		9	11	10	11
- Hard coal & lignite	0	0		0	0	0	0
- Oil products	217	252		262	233	250	257
- Gas	989	1,000		991	852	837	689
- Solar	8	8		9	9	11	12
- Biomass	269	271		258	246	202	174
- Geothermal	5	5		5	5	5	5
- Hydrogen	0	0		0	0	0	0
RES share Other Sectors	24%	25%		27%	31%	31%	34%
Total RES	758	804		905	1,016	1,096	1,168
RES share	16%	17%		19%	21%	23%	25%
Non energy use	**277**	**320**	**320**	**398**	**434**	**529**	**629**
- Oil	250	288		358	388	471	565
- Gas	24	28		36	40	51	63
- Coal	3	4		4	6	7	0

Energy-Releated CO2 Emissions [Million tons/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
Condensation power plants	51	48		26	24	23	21
- Hard coal (& non-renewable waste)	34	27		0	0	0	0
- Lignite	1	0		0	0	0	0
- Gas	13	19		23	21	20	18
- Oil + Diesel	3	3		3	3	3	3
Combined heat and power plants	73	73		73	68	62	57
- Hard coal (& non-renewable waste)	3	4		3	1	0	0
- Lignite	0	0		0	0	0	0
- Gas	55	56		58	57	55	53
- Oil	15	14		13	10	6	3
CO2 emissions power and CHP plants	124	122		99	92	84	78
- Hard coal (& non-renewable waste)	36	30		3	1	0	0
- Lignite	1	0		0	0	0	0
- Gas	68	75		81	78	76	72
- Oil + Diesel	19	16		15	12	8	6
CO2 intensity (g/kWh)	0	0		0	0	0	0
without credit for CHP heat	0	0		0	0	0	0
- CO2 intensity fossil electr. generation	720	682		638	632	617	601
- CO2 intensity total electr. generation	441	402		326	268	241	219
CO2 emissions by sector	**348**	**360**	**278**	**341**	**321**	**309**	**290**
- % of 1990 emissions (Mill t)	80%	83%		79%	74%	71%	67%
- Industry 1)	41	43	32	46	48	45	46
- Other sectors 1)	73	76	58	76	66	67	59
- Transport	107	107	78	105	100	96	91
- Power generation 2)	108	105	81	82	77	72	68
- Other conversion 3)	19	29	29	32	30	29	26
Population (Mill.)	61	60		60	59	58	56
CO2 emissions per capita (t/capita)	6	6		6	5	5	5

Primary Energy Demand [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020	2025	2030	2040	2050
Total	**6,466**	**6,981**	**5,226**	**7,043**	**6,967**	**7,014**	**6,638**
- Fossil	5,434	5,770		5,719	5,453	5,415	5,006
- Hard coal	505	455		159	138	112	103
- Lignite	8	0		0	0	0	0
- Natural gas	2,710	2,997		3,223	3,087	3,141	2,752
- Crude oil	2,211	2,319		2,337	2,229	2,162	2,150
- Nuclear	0	0		0	0	0	0
- Renewables	1,032	1,211		1,324	1,513	1,598	1,632
- Hydro	164	164		177	177	177	177
- Wind	53	64		114	141	156	165
- Solar	91	105		134	280	324	358
- Biomass (& renewable waste)	608	756		762	772	798	795
- Geothermal	116	122		138	143	143	136
- Ocean energy	0	0		0	0	0	0
- of which non-energy use	277	320		398	434	529	629
Total RES	1,096	1,260		1,397	1,536	1,652	1,709
RES share	16%	17%		19%	22%	23%	25%

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Energy [R]evolution

Electricity generation [TWh/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
Power plants	186	**206**	**158**	196	243	321	418
- Hard coal (& non-renewable waste)	43	34		0	0	0	0
- Lignite	1	0		0	0	0	0
- Gas	38	53		49	42	27	0
of which from H2	0	0		0	0	0	0
- Oil	4	3		0	0	1	1
- Diesel	0	0		0	0	0	0
- Nuclear	0	0		0	0	0	0
- Biomass (& renewable waste)	10	19		20	24	31	46
- Hydro	46	46		49	50	50	50
- Wind	15	18		29	36	42	61
of which wind offshore	0	0		1	2	4	18
- PV	23	27		41	79	139	207
- Geothermal	6	6		7	7	9	13
- Solar thermal power plants	0	0		1	5	23	40
- Ocean energy	0	0		0	0	0	0
Combined heat and power plants	96	**96**	**74**	96	91	85	80
- Hard coal (& non-renewable waste)	2	3		3	4	0	0
- Lignite	0	0		0	0	0	0
- Gas	75	76		74	64	53	6
of which from H2	0	0		0	0	0	0
- Oil	9	9		4	2	0	0
- Biomass (& renewable waste)	10	9		15	21	32	75
- Geothermal	0	0		0	0	0	0
- Hydrogen	0	0		0	0	0	0
		0					
CHP by producer		0					
- Main activity producers	78	78		78	74	70	65
- Autoproducers	18	18		18	17	16	15
Total generation	282	**302**	**232**	292	334	406	499
- Fossil	173	178		130	113	82	8
- Hard coal (& non-renewable waste)	45	37		3	4	1	0
- Lignite	1	0		0	0	0	0
- Gas	113	129		123	106	80	6
- Oil	13	12		4	2	1	1
- Diesel	0	0		0	0	0	0
- Nuclear	0	0		0	0	0	0
- Hydrogen	0	0		0	0	0	0
- of which renewable H2	0	0		0	0	0	0
- Renewables (w/o renewable hydrogen)	109	124		162	221	325	491
- Hydro	46	46		49	50	50	50
- Wind	15	18		29	36	42	61
- PV	23	27		41	79	139	207
- Biomass (& renewable waste)	19	28		36	45	63	121
- Geothermal	6	6		7	7	9	13
- Solar thermal power plants	0	0		1	5	23	40
- Ocean energy	0	0		0	0	0	0
Distribution losses	20	21		21	22	28	35
Own consumption electricity	21	21		17	15	12	10
Electricity for hydrogen production	0	0		0	0	0	0
Electricity for synfuel production	0	0		0	0	0	0
Final energy consumption (electricity)	287	294		294	312	390	490
Variable RES (PV, Wind, Ocean)	38	44		70	115	181	268
Share of variable RES	13%	15%		24%	35%	45%	54%
RES share (domestic generation)	39%	41%		55%	66%	80%	98%

Transport - Final Energy [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
road	1,419	**1,516**	**1,099**	1,355	1,264	1,045	595
- fossil fuels	1,386	1,411		1,275	1,087	700	0
- biofuels	0	52		16	89	111	118
- synfuels	0	0		0	0	0	0
- natural gas	34	39		31	24	20	0
- hydrogen	0	0		0	0	0	0
- electricity	0	13		34	65	213	477
rail	40	**40**	**29**	42	46	59	77
- fossil fuels	1	10		6	5	1	0
- biofuels	0	0		0	0	0	0
- synfuels	0	0		0	0	0	0
- electricity	39	30		36	42	58	77
navigation	39	**41**	**30**	48	54	69	91
- fossil fuels	39	41		46	48	41	0
- biofuels	0	0		1	5	28	91
- synfuels	0	0		0	0	0	0
		0					
aviation	29	**26**	**19**	26	26	27	29
- fossil fuels	29	26		26	24	18	0
- biofuels	0	0		1	1	9	29
- synfuels	0	0		0	0	0	0
total (incl. pipelines)	1,546	**1,631**	**1,182**	1,488	1,406	1,215	805
- fossil fuels	1,455	1,488		1,353	1,164	761	0
- biofuels (incl. biogas)	0	52		18	95	147	237
- synfuels	0	0		0	0	0	0
- natural gas	43	47		40	32	28	7
- hydrogen	0	0		0	0	0	0
- electricity	39	43		69	107	271	553
total RES	15	70		56	166	364	782
RES share	4%	5%		4%	12%	30%	100%
		0	0		304		

Heat supply and air conditioning [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
District heating plants	43	**79**	**59**	73	80	89	63
- Fossil fuels	0	0		0	0	0	0
- Biomass	34	63		53	56	52	34
- Solar collectors	0	0		4	6	18	16
- Geothermal	9	17		16	18	20	14
Heat from CHP 1)	257	**224**	**168**	250	253	257	247
- Fossil fuels	257	171	0	134	106	33	0
- Biomass	0	53	0	116	147	224	247
- Geothermal	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0
Direct heating	1,766	**1,885**	**1,414**	1,729	1,652	1,682	1,603
- Fossil fuels	1,437	1,522	0	1,240	1,027	529	4
- Biomass	214	219	0	235	248	342	531
- Solar collectors	8	9	0	74	146	388	504
- Geothermal	0	0	0	0	0	0	0
- Heat pumps 2)	7	7	0	74	118	282	390
- Electric direct heating	100	128	0	105	114	140	174
- Hydrogen	0	0	0	0	0	0	0
Total heat supply3)	2,065	**2,189**	**1,641**	2,052	1,985	2,028	1,913
- Fossil fuels	1,694	1,693	0	1,375	1,133	563	4
- Biomass	247	334	0	404	451	618	811
- Solar collectors	8	9	0	78	152	406	519
- Geothermal	9	17	0	16	18	20	14
- Heat pumps 2)	7	7	0	74	118	282	390
- Electric direct heating 2)	100	128	0	105	114	140	174
- Hydrogen	0	0	0	0	0	0	0
RES share (including RES electricity)	15%	19%	0%	31%	41%	71%	100%
electricity consumption heat pumps (TWh/a)	0.0	0.0	0.0	3.8	10.2	26.4	39.1

Installed Capacity [GW]	2015	2020		2025	2030	2040	2050
		0					
Total generation	131	**137**		125	152	182	211
- Fossil	79	81		53	48	33	3
- Hard coal (& non-renewable waste)	8	7		1	1	0	0
- Lignite	0	0		0	0	0	0
- Gas (w/o H2)	61	61		50	46	32	2
- Oil	10	13		3	1	1	1
- Diesel	0	0		0	0	0	0
- Nuclear	0	0		0	0	0	0
- Hydrogen (fuel cells, gas power plants,	0	0		0	0	0	0
- Renewables	52	56		72	104	149	208
- Hydro	19	19		20	21	21	21
- Wind	9	10		14	16	17	22
of which wind offshore	0	0		0	0	1	5
- PV	19	22		31	56	92	130
- Biomass (& renewable waste)	3.9	4.634		6.550	8.186	11.697	23.3
- Geothermal	1	1		1	1	1	2
- Solar thermal power plants	0	0		0	1	6	10
- Ocean energy	0	0		0	0	0	0
		0					
Variable RES (PV, Wind, Ocean)	28	32		44	73	110	153
Share of variable RES	21%	23%		35%	48%	60%	72%
		0					
RES share (domestic generation)	40%	41%		58%	68%	82%	99%

Final Energy Demand [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
Total (incl. non-energy use)	4,949	5,135	3,925	4,748	4,557	4,361	3,814
Total energy use 1)	4,673	4,815	3,604	4,548	4,365	4,178	3,638
Transport	1,519	**1,540**	**1,116**	1,525	1,445	1,247	797
- Oil products	1,389	1,396	0	1,399	1,212	802	0
- Natural gas	41	48	0	39	31	27	6
- Biofuels	49	52	0	18	95	147	237
- Synfuels	0	0	0	0	0	0	0
- Electricity	39	43	0	69	107	271	553
RES electricity	15	18	0	39	71	217	545
- Hydrogen	0	0	0	0	0	0	0
RES share Transport	4%	5%	0%	4%	12%	30%	100%
Industry	1,028	**1,078**	**819**	1,014	1,071	1,096	1,140
- Electricity	406	401		375	394	427	450
RES electricity	157	164		208	261	341	443
- Public district heat	100	116		118	128	133	141
RES district heat	2	3		11	33	90	141
- Hard coal & lignite	40	58		41	44	22	4
- Oil products	111	116		82	44	9	0
- Gas	355	364		357	330	165	0
- Solar	0	1		14	37	114	161
- Biomass	16	21		17	68	155	278
- Geothermal	0	0		10	26	70	106
- Hydrogen	0	0		0	0	0	0
RES share Industry	17%	18%		26%	40%	70%	99%
Other Sectors	2,126	**2,198**	**1,669**	2,010	1,848	1,835	1,701
- Electricity	590	614		615	624	705	761
RES electricity	228	252		341	413	563	750
- Public district heat	48	48		46	41	41	39
RES district heat	9	9		17	20	38	53
- Hard coal & lignite	0	0		1	0	0	0
- Oil products	217	252		205	185	83	17
- Gas	989	1,000		744	569	314	0
- Solar	8	8		61	109	274	343
- Biomass	269	271		296	262	282	354
- Geothermal	5	5		43	59	137	187
- Hydrogen	0	0		0	0	0	0
RES share Other Sectors	24%	25%		38%	47%	71%	99%
Total RES	757	804		1,080	1,460	2,441	3,614
RES share	16%	17%		24%	33%	58%	99%
		0					
Non energy use	277	320		199	192	183	175
- Oil	250	288		180	173	164	158
- Gas	24	28		17	17	16	15
- Coal	3	4		2	2	2	2

Energy-Releated CO2 Emissions [Million tons/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
		0					
Condensation power plants	51	48		18	16	11	1
- Hard coal (& non-renewable waste)	34	27		0	0	0	0
- Lignite	1	0		0	0	0	0
- Gas	13	19		18	15	10	0
- Oil + Diesel	3	3		0	0	1	1
		0					
		0					
Combined heat and power plants	78	73		71	62	46	4
- Hard coal (& non-renewable waste)	3	4		4	5	0	0
- Lignite	0	0		0	0	0	0
- Gas	55	56		55	48	39	3
- Oil	20	14		13	10	6	1
		0					
CO2 emissions power and CHP plants	129	122		89	78	56	5
- Hard coal (& non-renewable waste)	36	30		4	5	1	0
- Lignite	1	0		0	0	0	0
- Gas	68	75		72	63	49	3
- Oil & diesel	23	16		13	10	7	2
		0					
CO2 intensity (g/kWh)	0	0		0	0	0	0
without credit for CHP heat	0	0		0	0	0	0
- CO2 intensity fossil electr. generation	744	682		686	692	692	692
- CO2 intensity total electr. generation	744	402		686	692	692	692
		0					
CO2 emissions by sector	347	**360**	**278**	302	258	163	7
- % of 1990 emissions (Mill t)	80%	83%	0%	70%	59%	38%	2%
		0	0				
- Industry 1)	41	43	32	39	34	18	3
- Other sectors 1)	73	76	58	58	47	24	1
- Transport	107	107	78	107	93	62	0
- Power generation 2)	108	105	81	70	61	45	1
- Other conversion 3)	19	29	29	28	23	15	1
		0					
Population (Mill.)	61	60		60	59	58	56
CO2 emissions per capita (t/capita)	6	6		5	4	3	0

Primary Energy Demand [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
Total	6,473	**6,981**	**5,226**	6,372	6,180	5,803	4,838
- Fossil	5,438	5,770		4,850	4,148	2,727	292
- Hard coal (& non-renewable waste)	505	455		84	100	30	7
- Lignite	8	0		0	0	0	0
- Natural gas	2,713	2,997		2,722	2,306	1,582	105
- Crude oil	2,211	2,319		2,045	1,741	1,115	180
- Nuclear	0	0		0	0	0	0
- Renewables	1,036	1,211		1,522	2,032	3,075	4,546
- Hydro	164	164		177	178	178	178
- Wind	53	64		104	131	151	221
- Solar	91	105		224	447	971	1,391
- Biomass (& renewable waste)	612	756		806	1,037	1,398	2,229
- Geothermal	116	122		211	238	377	527
- Ocean energy	0	0		0	0	0	0
		0					
- of which non-energy use	277	320		199	192	183	175
		0					
Total RES	1,036	1,260		1,522	2,032	3,075	4,546
RES share	16%	17%		23%	33%	52%	92%

Italy

Advanced Energy [R]evolution

Electricity generation [TWh/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
Power plants	186	**206**	**158**	205	286	343	355
- Hard coal (& non-renewable waste)	43	34		0	0	0	0
- Lignite	1	0		0	0	0	0
- Gas	38	53		43	36	0	0
of which from H2	0	0		0	0	0	0
- Oil	4	3		1	0	0	0
- Diesel	0	0		0	0	0	0
- Nuclear	0	0		0	0	0	0
- Biomass (& renewable waste)	10	19		19	14	43	27
- Hydro	46	46		49	50	49	49
- Wind	15	18		28	36	42	50
of which wind offshore	0	0		2	3	6	8
- PV	23	27		57	141	189	193
- Geothermal	6	6		7	7	10	16
- Solar thermal power plants	0	0		1	2	9	19
- Ocean energy	0	0		0	0	0	0
Combined heat and power plants	96	**96**	**74**	96	91	71	80
- Hard coal (& non-renewable waste)	2	3		7	0	0	0
- Lignite	0	0		0	0	0	0
- Gas	75	76		74	60	0	0
of which from H2	0	0		0	0	0	0
- Oil	9	9		0	0	0	0
- Biomass (& renewable waste)	10	9		15	31	71	80
- Geothermal	0	0		0	0	0	0
- Hydrogen	0	0		0	0	0	0
		0					
CHP by producer		0					
- Main activity producers	78	78		78	74	56	65
- Autoproducers	18	18		18	17	16	15
Total generation	282	**302**	**232**	301	377	414	435
- Fossil	173	178		125	97	0	0
- Hard coal (& non-renewable waste)	45	37		7	0	0	0
- Lignite	1	0		0	0	0	0
- Gas	113	129		117	96	0	0
- Oil	13	12		1	0	0	0
- Diesel	0	0		0	0	0	0
- Nuclear	0	0		0	0	0	0
- Hydrogen	0	0		0	0	0	0
- of which renewable H2	0	0		0	0	0	0
- Renewables (w/o renewable hydrogen)	109	124		175	281	414	434
- Hydro	46	46		49	50	49	49
- Wind	15	18		28	36	42	50
- PV	23	27		57	141	189	193
- Biomass (& renewable waste)	19	28		34	45	114	107
- Geothermal	6	6		7	7	10	16
- Solar thermal power plants	0	0		1	2	9	19
- Ocean energy	0	0		0	0	0	0
Distribution losses	20	21		21	25	28	28
Own consumption electricity	21	21		17	15	12	10
Electricity for hydrogen production	0	0		0	0	0	0
Electricity for synfuel production	0	0		0	0	0	0
Final energy consumption (electricity)	287	294		300	351	402	396
Variable RES (PV, Wind, Ocean)	38	44		85	177	232	243
Share of variable RES	13%	15%		28%	47%	56%	56%
RES share (domestic generation)	39%	41%		58%	74%	100%	100%

Transport - Final Energy [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
road	1,419	**1,516**	**1,099**	1,293	1,012	694	585
- fossil fuels	1,386	1,411		1,166	666	0	0
- biofuels	0	52		16	69	290	169
- synfuels	0	0		0	0	0	0
- natural gas	34	39		31	24	0	0
- hydrogen	0	0		0	0	0	0
- electricity	0	13		80	253	404	416
rail	40	**40**	**29**	40	43	58	77
- fossil fuels	1	10		4	1	0	0
- biofuels	0	0		0	0	0	0
- synfuels	0	0		0	0	0	0
- electricity	39	30		36	42	58	77
navigation	40	**41**	**30**	40	40	40	41
- fossil fuels	40	41		35	27	0	0
- biofuels	0	0		5	13	40	41
- synfuels	0	0		0	0	0	0
		0					
aviation	29	**26**	**19**	26	26	27	29
- fossil fuels	29	26		26	19	0	0
- biofuels	0	0		1	6	27	29
- synfuels	0	0		0	0	0	0
total (incl. pipelines)	1,547	**1,631**	**1,182**	1,416	1,137	834	746
- fossil fuels	1,456	1,488		1,231	713	0	0
- biofuels (incl. biogas)	0	52		21	89	357	239
- synfuels	0	0		0	0	0	0
- natural gas	43	47		40	32	8	7
- hydrogen	0	0		0	0	0	0
- electricity	39	43		115	295	461	493
total RES	15	70		89	308	818	731
RES share	4%	5%		6%	27%	99%	101%
		0	0				

Heat supply and air conditioning [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
District heating plants	43	**79**	**59**	54	66	103	88
- Fossil fuels	0	0		0	0	0	0
- Biomass	34	63		39	46	60	47
- Solar collectors	0	0		3	5	21	22
- Geothermal	9	17		12	14	23	19
Heat from CHP 1)	257	**224**	**168**	239	236	169	169
- Fossil fuels	257	171	0	147	81	27	-36
- Biomass	0	53	0	92	155	142	205
- Geothermal	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0
Direct heating	1,766	**1,885**	**1,414**	1,659	1,552	1,576	1,428
- Fossil fuels	1,437	1,522	0	1,188	619	0	0
- Biomass	214	219	0	233	334	466	295
- Solar collectors	8	9	0	73	325	589	548
- Geothermal	0	0	0	0	17	69	90
- Heat pumps 2)	7	7	0	73	161	333	353
- Electric direct heating	100	128	0	92	95	119	141
- Hydrogen	0	0	0	0	0	0	95
Total heat supply3)	2,065	**2,189**	**1,641**	1,951	1,854	1,849	1,780
- Fossil fuels	1,694	1,693	0	1,336	700	27	-36
- Biomass	247	334	0	364	536	667	546
- Solar collectors	8	9	0	75	330	610	570
- Geothermal	9	17	0	12	32	92	110
- Heat pumps 2)	7	7	0	73	161	333	353
- Electric direct heating	100	128	0	92	95	119	141
- Hydrogen	0	0	0	0	0	0	95
RES share (including RES electricity)	15%	19%	0%	30%	61%	99%	97%
electricity consumption heat pumps (TWh/a)	0.0	0.0	0.0	3.3	8.5	31.4	28.8

Installed Capacity [GW]	2015	2020	2025	2030	2040	2050
		0				
Total generation	131	**137**	132	188	188	189
- Fossil	79	81	49	41	0	0
- Hard coal (& non-renewable waste)	8	7	1	0	0	0
- Lignite	0	0	0	0	0	0
- Gas (w/o H2)	61	61	47	41	0	0
- Oil	10	13	1	0	0	0
- Diesel	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0
- Hydrogen (fuel cells, gas power plants,	0	0	0	0	0	0
- Renewables	52	56	83	147	188	189
- Hydro	19	19	20	21	20	20
- Wind	9	10	13	16	17	19
of which wind offshore	0	0	0	1	1	2
- PV	19	22	42	100	125	122
- Biomass (& renewable waste)	3.9	4.634	6.279	8.353	21.522	20.8
- Geothermal	1	1	1	1	2	3
- Solar thermal power plants	0	0	0	1	2	5
- Ocean energy	0	0	0	0	0	0
		0				
Variable RES (PV, Wind, Ocean)	28	32	56	116	143	141
Share of variable RES	21%	23%	42%	62%	76%	74%
		0				
RES share (domestic generation)	40%	41%	63%	78%	100%	100%

Final Energy Demand [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
Total (incl. non-energy use)	4,949	5,135	3,925	4,558	4,083	3,613	3,238
Total energy use 1)	4,673	4,815	3,604	4,359	3,891	3,430	3,063
Transport	1,519	**1,540**	**1,116**	1,442	1,155	825	738
- Oil products	1,389	1,396	0	1,266	740	0	0
- Natural gas/biogas	41	48	0	39	31	7	6
- Biofuels	49	52	0	21	89	357	239
- Synfuels	0	0	0	0	0	0	0
- Electricity	39	43	0	115	295	461	493
RES electricity	15	18	0	67	219	461	493
- Hydrogen	0	0	0	0	0	0	0
RES share Transport	4%	5%	0%	6%	27%	99%	101%
Industry	1,028	**1,078**	**819**	919	936	902	835
- Electricity	406	401		361	360	368	335
RES electricity	157	164		210	267	368	335
- Public district heat	100	116		103	107	110	104
RES district heat	2	3		9	44	109	101
- Hard coal & lignite	40	58		35	14	0	0
- Oil products	111	116		72	37	0	0
- Gas	355	364		312	206	0	0
- Solar	0	1		12	30	94	59
- Biomass	16	21		15	154	221	218
- Geothermal	0	0		8	28	108	119
- Hydrogen	0	0		0	0	0	0
RES share Industry	17%	18%		28%	56%	100%	100%
Other Sectors	2,126	**2,198**	**1,669**	1,998	1,800	1,704	1,489
- Electricity	590	614		603	608	619	599
RES electricity	228	252		352	452	618	598
- Public district heat	48	48		46	41	41	39
RES district heat	9	9		17	37	62	62
- Hard coal & lignite	0	0		1	9	0	0
- Oil products	217	252		205	183	16	12
- Gas	989	1,000		744	268	0	0
- Solar	8	8		61	295	495	489
- Biomass	269	271		296	291	327	114
- Geothermal	5	5		43	105	205	236
- Hydrogen	0	0		0	0	0	0
RES share Other Sectors	24%	25%		38%	66%	100%	101%
Total RES	759	804		1,112	2,012	3,426	3,080
RES share	16%	17%		26%	52%	100%	101%
		0					
Non energy use	277	320		199	192	183	175
- Oil	250	288		180	173	164	158
- Gas	24	28		17	17	16	15
- Coal	3	4		2	2	2	2

Energy-Related CO2 Emissions [Million tons/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
		0					
Condensation power plants	51	48		17	13	0	0
- Hard coal (& non-renewable waste)	34	27		0	0	0	0
- Lignite	1	0		0	0	0	0
- Gas	13	19		16	13	0	0
- Oil + Diesel	3	3		1	0	0	0
		0					
		0					
Combined heat and power plants	66	73		64	46	0	0
- Hard coal (& non-renewable waste)	3	4		9	0	0	0
- Lignite	0	0		0	0	0	0
- Gas	55	56		55	46	0	0
- Oil	8	14		0	0	0	0
		0					
CO2 emissions power and CHP plants	117	122		80	59	0	0
- Hard coal (& non-renewable waste)	36	30		9	0	0	0
- Lignite	1	0		0	0	0	0
- Gas	68	75		70	59	0	0
- Oil & diesel	11	16		1	0	0	0
		0					
CO2 intensity (g/kWh)	0	0		0	0	0	0
without credit for CHP heat	0	0		0	0	0	0
- CO2 intensity fossil electr. generation	677	682		619	524	4	48
- CO2 intensity total electr. generation	677	402		619	524	4	48
		0					
CO2 emissions by sector	347	**360**	**278**	288	179	3	3
- % of 1990 emissions (Mill t)	80%	83%	0%	66%	41%	1%	1%
		0	0				
- Industry 1)	41	43	32	35	20	1	1
- Other sectors 1)	73	76	58	58	30	1	1
- Transport	107	107	78	97	57	0	0
- Power generation 2)	108	105	81	71	55	0	0
- Other conversion 3)	19	29	29	26	17	0	0
		0					
Population (Mill.)	61	60		60	59	58	56
CO2 emissions per capita (t/capita)	6	6		5	3	0	0

Primary Energy Demand [PJ/a]	2015	Estimation for 2020 EXCLUDING COVID-19 2020	Estimation after COVID-19 -base June 2020 2020	2025	2030	2040	2050
Total	6,473	**6,981**	**5,226**	6,137	5,528	4,650	4,188
- Fossil	5,438	5,770		4,629	2,989	237	219
- Hard coal (& non-renewable waste)	505	455		140	29	5	5
- Lignite	8	0		0	0	0	0
- Natural gas	2,713	2,997		2,631	1,756	53	49
- Crude oil	2,211	2,319		1,858	1,204	177	164
- Nuclear	0	0		0	0	0	0
- Renewables	1,036	1,211		1,507	2,538	4,414	3,969
- Hydro	164	164		177	178	177	177
- Wind	53	64		102	130	152	179
- Solar	91	105		279	840	1,303	1,312
- Biomass (& renewable waste)	612	756		736	1,094	2,267	1,658
- Geothermal	116	122		214	296	515	643
- Ocean energy	0	0		0	0	0	0
		0					
- of which non-energy use	277	320		199	192	183	175
		0					
Total RES	1,036	1,260		1,507	2,538	4,414	3,969
RES share	16%	17%		24%	46%	93%	95%

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