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Perspective

Europe's SMR strategy needs a theory of time

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ABSTRACT

In March 2026, the European Commission published its first strategy for small modular reactors (SMRs), envisioning 17–53 GW of SMR capacity by 2050: a substantial scale-up for a technology with no commercial unit operating outside Russia and China. Whether this pace of deployment is ambitious and realistic, and what it would take to achieve it, cannot be judged from the Strategy's internal assumptions alone. This Perspective therefore takes the 'outside view', assessing planned timelines against historical reference cases of comparable technological scale-up. The announced project pipeline could credibly deliver 1–3 GW across about a dozen projects by the mid-2030s. Whether deployment can then scale to the Strategy's ambitions is best assessed against Europe's two rapid, heavily supported scale-ups of complex technologies, conventional nuclear after 1965 and offshore wind after 2005, which mark the outer edge of what deliberate policy has achieved. In both unit and capacity terms, these precedents indicate a historically grounded ambitious upper bound of roughly 20 GW or 60–70 SMRs by 2050, consistent with IEA and NEA scenarios; 53 GW would require substantially more time or unprecedented acceleration. Even the lower bound will demand sizeable financial support, binding national commitments beyond current energy and climate plans, regulatory capacity for series certification of standardised designs, and a pragmatic balance between speed of deployment and the EU's industrial autonomy. A realistic theory of time that matches ambition to the historical clockspeed of energy transition would strengthen Europe's SMR Strategy.

1. Introduction

In March 2026, the European Commission released a strategy for the development and deployment of small modular reactors (SMRs) in Europe [1]. The Strategy aims to reduce the EU's dependence on energy imports and secure its leadership in low-carbon energy technologies. This marks a substantial and contested reorientation: although nuclear power has contributed to EU energy supply for decades, new nuclear construction has been largely absent from the EU-level energy strategy, reflecting persistent disagreements among Member States over the role of nuclear power in a clean energy future. The Strategy envisions first SMRs commissioned in the early 2030s and 17–53 GW of SMR capacity by 2050, which could make up to 40% of all new nuclear capacity in Europe [2]. The Strategy builds on considerable momentum across Member States (Fig. 1, Table S1), yet at present, no commercial SMR operates outside Russia and China and there is not a single SMR under construction in Europe [3].

These capacity ranges originate from scenarios developed in 2023 by the European SMR pre-Partnership, an industry-Commission platform that preceded the European Industrial Alliance on SMRs [4]. Their wide range reflects a large spread in scenario assumptions, stemming from uncertainties and complexity common for new technologies, especially in cases where these are driven by deliberate state policies. In the past, plans and forecasts for new technologies tended to both over- and under-estimate deployment timelines, as was the case for conventional nuclear [5], hydrogen [6], CCS [7], earlier SMRs [8] and solar power [9]. In part, this occurs because planners tend to focus on factors they can control while overlooking or discounting external factors such as supply chains, infrastructure, public and political support, energy markets, and regulatory institutions. Such constraints can be resolved or opportunities leveraged by concerted policy effort, but ultimately they manifest as delay or acceleration, making the pace of deployment their common and observable measure. What, then, is a realistically achievable timeline of SMR deployment and how does it compare with the upper and lower bounds of the industry-led scenarios used in the Strategy?

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To address such questions, technology diffusion scholars increasingly use the 'outside view' [10–12], named in contrast to the 'inside' view of industrial and state planners. The 'outside view' evaluates the viability of planned timelines, as well as their costs and risks, against reference cases drawn from similar developments in the past. For SMRs, such reference cases can be found in Europe's own history of rapid and deliberate upscaling of new energy technologies. In the 1970s, Western Europe expanded large light-water reactors in response to oil supply shocks and rapid increase of electricity demand [13]. More recently, wind and solar power scaled dramatically [14]. These episodes, representing the fastest rates of energy transitions in major economies globally [15], offer an empirical basis for a 'theory of time' for SMR deployment: a realistic estimate of when large-scale growth can begin and how far it can plausibly reach by 2050, given that the fastest historical precedents mark the upper limit of what is achievable under ambitious policies [16].

Here, we argue that historical precedents of conventional nuclear and offshore wind point to an ambitious upper bound of roughly 20 GW of SMRs by 2050, just over the lower end of the Strategy's envisaged range. At the same time, 53 GW appears out of reach until at least 2060, unless deployment can accelerate beyond historical rates without the larger unit sizes that drove past nuclear build-outs. The EU has both the motivation and the capacity to deploy SMRs at a meaningful scale, but doing so would require durable policy and financial commitment, coordinated regulatory reform, and a pragmatic balance between speed of deployment and industrial autonomy: relying on the non-European designs closest to deployment for speed, while continuing to develop advanced EU designs, which are generally at earlier stages, to strengthen long-term industrial capability.

2. How fast can SMRs scale in europe?

Whether the Strategy's 2050 ambition and envisaged capacity range are feasible depends on two questions: when the upscaling starts and how fast it runs. The projections underpinning the Strategy anticipate around 3 GW total installed capacity by 2035 under the Current Projection scenario, rising to 17 GW by 2050, and around 7 GW by 2035 under the Boosted Deployment scenario, rising to 53 GW by 2050 [2] (Note S1).

The near-term deployment trajectory reflects an inescapable constraint: the upscaling of SMRs cannot begin before their first-of-a-kind (FOAK) units are licensed and constructed. Although EU and non-EU designs are roughly evenly represented in current plans, those closest to deployment are light-water reactor (LWR) designs from the United States and the United Kingdom, namely GE Hitachi's BWRX-300, NuScale's VOYGR and the Rolls-Royce SMR (Fig. 1, Table S1). By contrast, most EU-based designs are advanced modular reactors (AMRs) using non-water-cooled technologies that remain further from licensing and operation. As a result, at least half of SMR projects planned across ten EU countries by the mid-2030s are likely to originate from outside the EU (Fig. 1, Table S1). This pattern matches the Strategy's own approach, which confines cooperation to partner countries while seeking to avoid new import dependencies [1]; Russian and Chinese designs, the only SMRs in commercial operation, are outside this logic. At the same time, reliance on non-EU designs is in tension with the Strategy's other objective of securing Europe's industrial competitiveness in nuclear technology. Nevertheless, altogether, these projects could reach 1–3 GW by the mid-2030s, approximately matching the Current Projection scenario and providing a base for future upscaling.

However, the history of SMR development suggests that announced milestones should be treated with caution [17]. NuScale Power, for over a decade a global frontrunner, saw its anchor project cancelled in late 2023, after failing to secure a sufficient customer base. Romania's NuScale project, the EU's firmest SMR commitment, was recently postponed from 2030 to 2033. Additionally, NUWARD, France's flagship SMR, underwent a major redesign that delayed its projected FOAK

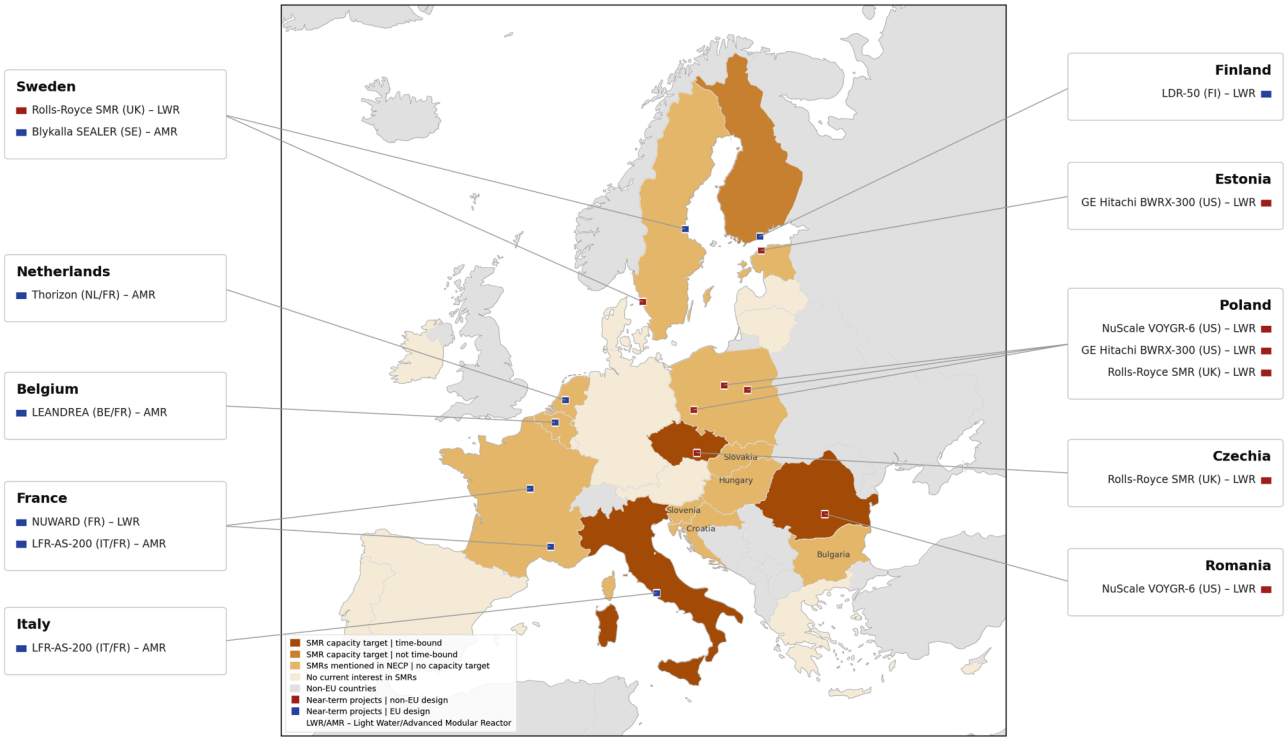


Fig. 1. European Union countries with interest in SMRs and announced SMR projects planned for completion by 2035.
Fifteen EU Member States mention SMRs in their National Energy and Climate Plans, but only Romania, Czechia, and Italy have set time-bound capacity targets. Of the 14 near-term projects announced across 10 countries, half rely on non-EU designs, mostly conventional light-water reactors (red squares). EU designs (blue squares) are generally advanced modular reactors at earlier stages of development. For detail and source of data see Table S1.

deployment from 2030 to 2035. Such contingencies suggest that even the 3 GW envisaged under the Current Projection scenario for 2035 may prove difficult to achieve, while the 7 GW envisaged under the Boosted Deployment scenario is likely out of reach. A similar conclusion emerges from the Nuclear Energy Agency's (NEA) most recent global projections [18]. Under the Current Trends scenario, reflecting policies already in place, the entire OECD SMR pipeline delivers only about 1 GW by 2040.

Even if the near-term pipeline materialises on schedule, the key question is whether deployment can scale from around 1–3 GW across about a dozen projects in the mid-2030s to the 17–53 GW envisioned for 2050. Nearly all of these near-term projects rely on conventional LWR designs, whereas the Strategy's longer-term ambitions also depend on AMRs. Two historical reference cases provide a benchmark: conventional nuclear, which had nine reactors operating in France, Italy, Belgium and Sweden in 1965, and offshore wind, which had around a dozen farms in operation in 2005 across the EU (excluding the UK). Both starting points align approximately with 2035 on the SMR timeline, and the 20 years that followed (1965–1985 for nuclear and 2005–2025 for wind) map onto the 2035–2055 window for SMRs. In unit terms, the two trajectories are similar: both reached 50–70 units by year 15 and close to 90 by year 20 (Fig. 2a). Installed capacity, however, diverged sharply in favour of nuclear (Fig. 2b), reflecting its larger unit size. This convergence between technologies whose median unit size differs threefold (880 MW against 288 MW, Note S1) indicates that the pace of deployment is constrained by the number of projects that can be sited, licensed, financed and built in parallel, not by the size or modularity of individual projects as asserted in the literature [19]. Though offshore wind turbines were mass-produced (about 3600 turbines across 75 farms in 2005–2025, Note S1), wind farms were still built no faster than conventional reactors, and the same constraint is likely to apply to SMRs.

Assuming 300 MW per unit, the upper capacity limit in the IAEA definition of SMRs, the Strategy's lower bound of 17 GW requires 57 reactors, comfortably within this historical envelope, whereas the upper bound of 53 GW requires 177, well beyond it (Fig. 2a). Neither historical analogue reaches 53 GW within the first 20 years of the comparison period, which would place the Strategy's upper bound no earlier than the late 2050s or early 2060s, even under these favourable benchmarks. Moreover, the historical rates of capacity addition were achieved with substantially larger units: 400–500 MW for recent offshore farms and ~880 MW for conventional nuclear reactors (Fig. 2, Note S1).

Neither conventional nuclear nor offshore wind is a perfect analogy for SMRs. Conventional nuclear shares core technological elements and was scaled up under the oil embargoes of the 1970s, comparable to the geopolitical turbulence of the 2020s. However, it expanded against rapidly growing electricity demand in regulated markets, where it was virtually the only substitute for imported fuels and enjoyed consistent political support. By contrast, SMRs would have to compete with (or complement) wind, solar and large nuclear reactors in liberalised markets under uncertain demand growth and political contestation. Offshore wind is sometimes invoked by EU nuclear stakeholders as a more relevant model for EU-wide ambition [4]: it developed in liberalised markets, built on an established onshore industry as its technological predecessor, and has unit sizes closer to those of SMRs (median 288 MW for farms built in 2005–2025, Note S1) as well as a modular, iterative deployment logic. Yet, taken together, these reference cases of heavily supported scale-ups converge on an upper-bound benchmark for assessing the Strategy's ambitions: about 20 GW by 2050, enough for the 17 GW floor but well short of the 53 GW ambition. Whether SMRs can improve on this record is an open question. Factory-built modules may enable serial production and learning, but whether these advantages can offset diseconomies of scale and reduce costs per kilowatt remains uncertain [20,21]. The Strategy itself notes that this business model 'has yet to be proven in practice' [1], and each project must still pass through siting, licensing, financing, construction and grid connection. Nor are large reactors, which the Commission expects to deliver most of Europe's new nuclear capacity [2], an unconstrained alternative: recent European projects have run many years behind schedule with substantial cost escalation [17], and the prospects for deploying both large and small reactors in liberalised markets have been questioned [22].

Our reference-case-based estimate aligns closely with the IEA's scenario range of 15–30 GW of SMRs in the EU [23], which likewise encompasses the Strategy's lower bound but falls well short of its upper ambition. Global scenario projections point the same way. Under the NEA's Current Trends scenario, worldwide SMR capacity reaches only 30 GW by 2050, whereas 53 GW in the EU would require the assumptions of the Transformative scenario: full delivery of announced national programmes and factory-scale SMR mass manufacturing, lifting global SMR capacity to 150 GW by 2050 [18].

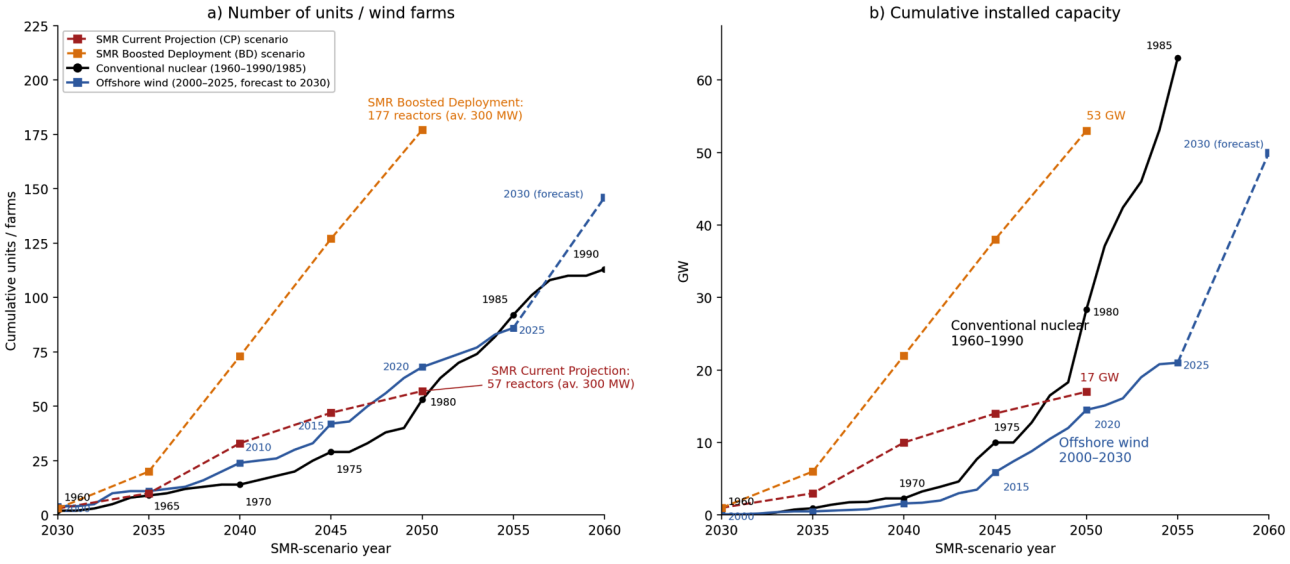


Fig. 2. Comparative deployment of SMRs, conventional nuclear and offshore wind.
(a) Cumulative reactor/offshore wind farms. **(b)** Cumulative installed capacity in GW. Horizontal axes shifted to align 1965 for conventional nuclear, 2005 for offshore wind and 2035 for SMRs, when approximately 10 reactors / offshore wind farms were or are expected to be in commercial operation. Dashed blue lines extend offshore wind to 2030 with forecast values. Dashed red and orange lines show the SMR Strategy's Boosted Deployment and Current Projection scenarios. Sources of data: see Note S1.

3. From long-term vision to near-term action

The Strategy sets out actions intended to support SMR deployment, including industrial coordination, investment, supply-chain development and regulatory cooperation [1]. Whether these measures can deliver the Strategy's 17–53 GW ambition will depend on three enabling conditions: durable financial support, credible national commitments, and regulatory capacity. The first is the most immediate. SMRs are currently more expensive (LCOE ~€112/MWh [23]) than both EU wholesale electricity prices (~€90/MWh) and renewables (Note S1). Levelised cost, however, understates the picture on both sides: it ignores the time-specific value of electricity [24]. As firm, dispatchable generation, SMRs could earn a value premium (a value factor at or above one) by producing when renewable output is low and prices are high, whereas the market value of wind and solar falls as their share of the system grows (Note S1). Even after accounting for this premium, a cost gap remains. But like every low-carbon technology scaled in the EU, from offshore wind to large nuclear, SMRs will require public support to reach the Strategy's ambitions; the question is not whether support is needed but on what scale and for how long. Between 2012 and 2023, EU governments provided over €35 billion in subsidies for offshore wind to grow by roughly 17 GW (Note S1). Reaching the Strategy's comparable lower bound of 17 GW could require even larger financial support, as nuclear generates roughly twice as much subsidised electricity per gigawatt of installed capacity. The Strategy's only quantified deployment instrument, a possible €200 million InvestEU top-up until 2028 shared across light-water SMRs, advanced modular reactors, microreactors and fusion [1], is directed at initial commercial units; the operating support that carried offshore wind to scale is not yet addressed. In practice, securing such support may be harder because fiscal resources are already stretched across renewables, large nuclear, hydrogen, and CCS. Mechanisms that worked for offshore wind, such as contracts for difference, joint cross-border procurement, and long-term power purchase agreements with industrial consumers, offer viable routes.

The second condition concerns the credibility of national commitments. Although 15 EU countries consider SMR deployment in their National Energy and Climate Plans (NECPs), only Romania, Czechia, and Italy have time-bound capacity targets, while Finland has a target without a deployment timeline (Fig. 1, Table S1). The three NECP targets add up to roughly 1.3 GW by 2035, less than half of the Strategy's Current Projection scenario for that year. A similar gap between EU-level aspiration and firm national commitments undermines the achievement of EU-level targets for onshore wind [25,26]. Closing this gap would require more countries setting SMR targets and those with concrete projects translating them into national commitments aligned with the EU Strategy.

The third condition is regulatory readiness. Nuclear energy requires detailed, technology-specific legal frameworks covering licensing, permitting, financing, operation, and the fuel cycle. These frameworks remain deeply uneven across the EU. This unevenness is consistent with the comparatively low market readiness scores of European SMR designs for licensing and siting, which emerge as the weakest dimensions across the development pipeline [27]. Several frontrunners have introduced significant reforms (Table S1): Sweden has adopted new siting rules and a dedicated state aid framework for nuclear, Finland is reforming its Nuclear Energy Act to accommodate SMRs, and France streamlined permitting through its 2023–2024 nuclear acceleration law. Most Member States still rely on legacy frameworks poorly suited to SMRs, designed for bespoke licensing of one-off large reactors rather than series certification of standardised modules, and for water-cooled technology rather than lead-cooled and molten-salt reactors. The Strategy's response, an 'SMR coalition' of interested Member States aligning or mutually recognising licensing decisions, supported by a Commission grant scheme for joint safety assessments (Action 8), relies on voluntary coordination and does not itself establish a route to series certification [1]. Several countries must also build nuclear regulatory capacity from scratch, or from a low base, in parallel with SMR licensing, financing and construction. This is a demanding coordination challenge.

Underlying these enabling conditions is technological learning, through which repeated deployment could reduce costs and construction times. Historical nuclear experience indicates that such learning depends on standardisation and repeated construction of similar units [28,29]. The Strategy reflects this: it asks the Industrial Alliance and Member States to concentrate support on 'a limited number of the most promising SMR designs' and calls for a fleet approach based on standardised designs (Actions 1 and 3), while also promoting the parallel development of advanced reactors and a supply chain serving 'a broad spectrum of components for different design options', and leaving design selection to industry [1]. With about a dozen designs from EU and non-EU vendors in the current pipeline (Fig. 1, Table S1), this creates a trade-off between concentrating deployment sufficiently to accelerate learning and maintaining the technological diversity intended to strengthen Europe's long-term industrial capability. The United States offers a precedent: two decades of advanced-fission funding spread across many designs, with shifting priorities, brought none to deployment readiness [30].

4. From momentum to lasting commitment

The EU SMR Strategy emerged from the energy-security turn that followed Russia's invasion of Ukraine in 2022, which disrupted European energy markets and mobilised political support for energy diversification [25]. But geopolitical shocks alone cannot sustain the multi-decadal effort required to scale a new technology. The challenge is to convert short-term momentum into durable commitment by locking in the dynamics that drive successful transitions: technological learning, growing demand, socio-economic benefits, and supportive political coalitions. Europe has done this at least twice before. Two decades of rapid nuclear build-out followed the 1970s oil shocks, and three decades of renewable expansion followed the policy reforms of the 1990s. The EU also brings two structural advantages: a common policy framework and electricity market that allow new technologies to scale across a coordinated economy, and diverse national systems that provide fertile ground for early deployment.

Realising these advantages will require navigating three tensions. The first is between speed of deployment and industrial autonomy. Non-European designs dominate the near-term pipeline, and waiting for domestic alternatives could delay upscaling by a decade or more. France's Messmer programme, launched in response to the 1970s oil shocks, offers a precedent: Framatome began by licensing Westinghouse's pressurised water reactor model and progressively domesticated it, building a standardised fleet and a national industry in parallel [13]. A pragmatic path for the EU is to prioritise deployment-ready designs whether from the EU or from partner countries, while securing supply-chain participation and know-how transfer, so that first-wave deployment strengthens rather than undermines Europe's long-term industrial capacity.

The second tension is between EU-level ambition and national-level authority. Nuclear licensing, siting, and financing remain national competences, limiting how quickly the Strategy's ambitions can translate into construction starts. This challenge is compounded by the fact that about half of the Strategy's envisaged SMR capacity is earmarked for heat and hydrogen, not electricity [2]. Since both hydrogen and the electricity used to produce it are envisioned as internationally traded, the regulatory and cross-border coordination challenges multiply. The third tension is social and political. Nuclear power remains contested and SMRs inherit that image problem [2]. Durable deployment will require engaging publics early and honestly about the potential and the limits of the technology.

5. Conclusion

Europe's SMR Strategy sets out a credible direction but a less credible timetable. Historically, no energy technology has scaled from a handful of FOAK units to tens of gigawatts in a single decade, and SMRs are unlikely to be the exception. Treating 17 GW by 2050 as an aspiration instead of a floor, and 53 GW as a long-term ambition instead of an outcome expected by 2050, would align the Strategy with what history shows is realistically achievable. It would also free policy attention for simultaneously securing meaningful growth and EU participation in supply chains through sustained financial commitment, binding national targets, and regulatory capacity for series certification of standardised designs.

A theory of time is neither an excuse for delay nor a prediction of inevitable limits. Rather, it serves as a boundary concept bridging sceptical and optimistic outlooks on SMRs. It recognises the complexity of the task and uses the timescales of past industrial transformations as a realistic yet ambitious anchor for today's efforts. It is a discipline of matching ambition to the clockspeed of industrial reality, and, in doing so, giving SMRs their best chance to contribute meaningfully to Europe's decarbonisation before the century is out.

Declaration of generative AI and AI-assisted technologies

During the preparation of this work the authors used Claude (Anthropic) to improve readability and language, and to generate Python code used to produce the figures from data provided by authors. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Anastasia Pavlenko: Writing – original draft, Writing – review & editing, Visualization, Formal analysis, Conceptualization. **Joel Adam Gordon:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Aleh Cherp:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

Manuscript: "Europe's SMR Strategy Needs a Theory of Time" by Anastasia Pavlenko, Joel Adam Gordon, and Aleh Cherp, submitted as a Perspective to Renewable and Sustainable Energy Transition.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rset.2026.100170.

Data availability

Data will be made available on request.

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