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# The Strategic Role of Nuclear Power in building Europe's Future Energy Infrastructure

**Giorgio Locatelli, Benito Mignacca, Giacomo Dei, Paolo Trucco, Marco Ricotti**

## 2 Executive summary

Europe is entering a decisive decade for its energy transition. The imperatives of deep decarbonization and energy security are entwined with industrial competitiveness, social cohesion, and geopolitical stability. Policymakers face the task of supporting an energy system that clean, affordable, resilient and legitimate in the eyes of citizens, shaping Europe's energy landscape for generations. Yet, many appraisal frameworks and procurement processes continue to rely on narrow economic criteria, undervaluing long-term benefits, underestimating delivery risks, and overlooking public legitimacy.

This policy brief, grounded on three years of research under the auspices of ECOSENS WP3, proposes a novel, comprehensive and pragmatic framework supporting the appraisal of future nuclear energy infrastructure with three interlocking priorities. First, a nuclear programme is a long-term investment; therefore, it must be appraised using criteria that reflect intergenerational value. Second, a country's readiness to deliver nuclear energy infrastructure must be treated as central, focusing on evaluating its governance capacity, institutional stability, and supply chain maturity. Last, circular economy principles must be considered from the beginning, emphasizing life-extension strategies and component reuse opportunities, which can deliver high environmental and economic returns.

Nuclear power should be considered within this broader framework as a strategic option, not as an ideological battleground. In fact, it is not a solution for all member states, nor appropriate in every circumstance. But for those countries with the institutional, financial and social capacity to deploy it, nuclear provides unique system value: it serves as a low-carbon baseload generation source that stabilises grids with high renewable penetration, supports industrial ecosystems, and contributes to strategic autonomy. The path forward, therefore, is about making context-specific, evidence-based choices. That implies evaluating three tracks: extending and modernising existing fleets where safe and economical;

enabling selective large-scale new builds, particularly in countries with strong delivery capacity; and planning small modular reactors in settings where modularity, flexibility and shorter lead times add value.

This brief presents a clear, evidence-based guide supporting evaluation and decisions about nuclear infrastructure. Indeed, if Europe acts with clarity and courage, it can build resilient, low-carbon, and publicly legitimate infrastructure. If it delays or relies on traditional narrow metrics (e.g., the Net Present Value method, and the Levelised Cost of Electricity), it risks an underpowered and fragile transition that undermines prosperity and public trust. The decisions taken in the next five years will determine Europe's energy trajectory for decades.

# 3 The Challenge of Current Appraisal and Planning

Europe's energy transition is hampered, among other things, by outdated appraisal and planning frameworks that fail to capture the full spectrum of benefits, risks, and societal factors relevant to large-scale infrastructure (Boardman et al., 2018; Locatelli et al., 2023). Most public appraisals still rely on levelized cost of electricity (LCOE) and Net Present Value (NPV) methods that treat infrastructure as a short-term commercial investment using high discount rates rather than a multi-decade societal asset (Weitzman, 2001). As a result, projects with high upfront capital costs but durable long-term benefits, such as nuclear power plants or waste repositories, appear, in some cases, unattractive (Arrow et al., 2014).

The limitations of these approaches are evident when examined through the lens of nuclear power. A new GW-scale nuclear plant may require €10-15 billion in upfront investment, but it provides stable, zero-carbon electricity for forty to sixty years. It preserves industrial skills, provides reliable baseload power that complements variable renewables, and contributes to energy sovereignty by reducing reliance on imported gas (Hecht, 1998). However, when appraised using a commercial discount rate, much of this value disappears (Arrow et al., 2014). Furthermore, small changes in discount rates can swing nuclear projects from uneconomic to clearly beneficial. This reveals that the issue can be, in some cases, not the intrinsic economics of nuclear but the appraisal lens.

Delivery risk is another blind spot. Large infrastructure projects frequently suffer cost overruns and delays, but these are not solely the result of technological challenges (Lehtonen et al., 2022). Indeed, political instability, shifting regulatory regimes, fragmented governance, and underdeveloped supply chains often play a relevant role (Bijker et al., 1989). The countries studied in the ECOSENS WP3 confirm this reality (Dei et al., 2025b). Romania, despite limited financial resources, made steady progress because of consistent political support and centralised delivery structures (Dei et al., 2025c). Spain and Belgium, by

contrast, saw nuclear trajectories falter due to policy reversals and public opposition, regardless of technical potential (Dei et al., 2025c). Italy's long-standing moratorium illustrates how political decisions can shut down options entirely (Dei et al., 2025c). These cases show that governance capacity and political continuity are decisive determinants of infrastructure success, yet current appraisals rarely quantify them.

Circular economy considerations are similarly marginalized. Too often, policy discussions reduce circularity to end-of-life recycling (Dei et al., 2025a). However, in complex assets like nuclear plants, great environmental benefit can also come from other circular economy strategies, such as extending operational life or reusing components (Mignacca et al., 2020; Mignacca and Locatelli, 2021). Regulatory frameworks and financing models do not always reward such measures (Mignacca et al., 2020; Sainati et al., 2019).

Finally, public legitimacy remains inadequately addressed. Infrastructure projects succeed only when communities (locally and nationally) grant their consent. This consent is not automatic; it must be earned through transparency, oversight, and tangible benefits (Miller et al., 2013). Public opposition has stalled or cancelled numerous projects across Europe, from nuclear reactors to wind farms (Barthe and and Mays, 2001). Yet social acceptance is still treated as an afterthought rather than a central variable. The result is fragile projects vulnerable to political shifts and community backlash.

These deficiencies are not minor technicalities. They shape the entire trajectory of Europe's energy system. Unless appraisal and planning frameworks are improved, Europe will continue to underinvest in resilience, misallocate resources, and erode public trust. A new approach is needed, one that values long-term benefits, prioritises delivery capacity, embeds circularity, and foregrounds legitimacy.

# 4 A New Framework for Appraisal and Decision Making

The ECOSENS WP3 developed a practical diagnostic tool for evaluating national readiness and the feasibility of nuclear development based on the System of Provision (SoP) approach (Bayliss and Fine, 2020; Dei et al., 2025d, 2023). The SoP approach fosters a systemic understanding of how nuclear technologies are embedded in broader structures of production, governance, and meaning-making. The SoP lens foregrounds political support, social legitimacy, industrial capabilities, and cultural narratives as co-constitutive dimensions of energy systems (Fine, 2002).

The investigation of several European nuclear energy systems through the lens of the SoP led to the creation of the SoP-based model (Dei et al., 2025a). Through its five analytical dimensions, socio-economic, political, technological, socio-cultural, and environmental, the model captures the interdependencies and

feedback loops that determine the feasibility and desirability of nuclear pathways. These dimensions provide a granular, multi-level understanding of readiness conditions, illuminating why certain contexts facilitate nuclear expansion while others resist it despite having similar technical infrastructure.

Through the definition of determinants, preconditions, enablers and barriers related to each of the five dimensions, the model allows for a differentiated analysis that moves beyond binary framings of "pro-nuclear" versus "anti-nuclear" countries (Dei et al., 2025a). It supports a continuum-based assessment that reflects the complexity and contingency of real-world decision-making. The following Table 1 presents the determinants, preconditions, enablers and barriers included in the SoP-based model.

| Determinants | Preconditions | Enablers | Barriers |
|---|---|---|---|
| **SOCIO-ECONOMIC** | | | |
| Human Resources | Availability of human capital (technical expertise) | High-Quality Technical Universities (FR) / Public and Private investments in Education (DE, FR) / Creation of Employment Opportunities (UK) | Shortage of skilled professionals (UK) |
| Public Financial Resources | Long-term availability of high capital from public finances | Country GDP sufficient to generate (DE, UK, IT, FR) / Tax Revenue for public financing (DE, UK, IT, FR) / Government willing to support nuclear technologies through subsidies (DE, UK, FR) | Low electricity price (DE) / High cost of capital (UK) |
| Lenders and Private Investors support | Ensure bankability and willingness to invest | Public-private partnerships (DE) / Consortium (FR) / Energy-intensive industry willing to co-finance nuclear technologies (FR). | Liberalisation of the electricity market increasing investors risk-averse attitude (DE, UK) |
| Nuclear supply chain | Existing capabilities on nuclear technologies within the country / Existence of nuclear military industry | Willingness of the domestic industry to develop capabilities and invest on nuclear technologies / Access to industrial capabilities outside the country (UK, IT) / Connection with other countries that have a robust nuclear supply chain (UK, IT) | Major actors in nuclear energy sector withdrawing from the nuclear market (DE) |

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| Ability to undertake major projects | Strong project management infrastructure and expertise | Positive track record in large-scale infrastructure projects (DE, FR) / Effective government intervention (FR) | Negative track record in large-scale infrastructure projects (Cost overruns / Public opposition / Delays) (UK, IT) |
| **POLITICAL** | | | |
| Political Support | Guarantee of long-term political support on nuclear investment decisions | Political consensus on the role of nuclear technologies (UK, FR) / Political structure that minimizes parliamentary interference in energy decisions (UK, FR) | Parties' coalitions opposing nuclear (DE) / Influence of political interests on energy policy (Politicization) (DE, IT) |
| Political stability | Stable political environment (general, not directly related to nuclear) | Powerful and effective governmental institutions (UK, FR) | Frequent changes in leadership and government (DE) |
| Governmental leadership | Active and centralized involvement of the government over energy decisions | Direct control of the key actors (FR)/ Unified decision-making body (UK, FR) | Weak government control (DE, IT)/ Decision-making process inefficiencies (IT) |
| Commitment to energy independence and security | Existence of a strategic energy plan | Long-term energy self-sufficiency planning (DE, UK, FR) / High imports dependence (DE, UK, IT, FR | |
| Long-term planning | Long term commitment to nuclear technologies (e.g., do not plan for a single reactor, but for a program of power plants) | Centralised decision-making (FR) | Privatization (DE, UK) |
| Liberalized market | Well-functioning market mechanisms and regulatory frameworks that ensure fair competition among energy providers | Corporate investment and innovation drive, allowing for competitive pricing and technology advancement | Market volatility and corporate interests prioritise short-term profits over long-term national energy security or safety (DE, UK) |
| Centralised Governance | Strong state institutions capable of long-term planning and effective coordination | Centralised capabilities under a single entity (FR) | |
| **TECHNOLOGICAL** | | | |

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|---|---|---|---|
| Radioactive Waste | Existence of a national waste repository in the country/ Long-term agreements on waste management with other countries/ Existence of a radioactive waste management program and of a national radioactive waste organisation | To have a nuclear industry with competencies in managing radioactive waste (FR) | Social opposition to the waste repository (IT) / Poor waste management (IT) |
| Electricity Demand | High electricity demand. Scale is not adequate: should have a neutral connotation | Electricity demand growth (DE, UK, IT, FR)/ Electricity export market available (FR) | Demand for energy coming from renewables (DE) |
| Standardisation of design | Commitment to a single nuclear technology/design | Centralised decision-making (i.e., single utility) (FR) | Diversification (IT, UK) |
| Siting | Localised consumption centres | Efficient construction methods and well-established regulatory framework (FR) | |
| R&D on nuclear technologies | High investment in R&D projects with low TRL | Excellent technical universities (FR)/ Research centres (DE) | |
| Grid capacity | To have a reliable electricity grid | Grid centralised under the same utility (DE, FR) | Aging infrastructure (UK) |
| Primary energy sources | Scarcity of primary energy sources (e.g., coal, oil, methane, Hydro, wind) | Volatility price and uncertainty of alternatives (DE, UK, IT, FR) | Sunk costs and pathway dependency on long-term assets and investments for the supply of other energy sources (e.g., pipelines) (DE) |
| **SOCIO-CULTURAL** | | | |
| Media Support | Dominant narrative favourable to nuclear technologies. | Transparent government communication (UK, FR) | Misinformation (IT) |
| Siting | Communities willing to host nuclear infrastructure | Job Opportunities in depressed areas (FR) | Local community opposition (UK, IT) |
| Citizens Support | High public acceptance of nuclear power (on average, considering different types of infrastructure) | Public trust in government actions (FR)/ Reframing of the technology (UK FR) | Anti-nuclear movements (DE) |

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| Public awareness | Public knowledge on nuclear energy (awareness of pros and cons) | Educational campaigns (UK, FR) | Low interest in the topic (DE, IT) |
| **ENVIRONMENTAL** | | | |
| Environmental Sentiment | Positive nuclear environmental sentiment (e.g., no anti-nuclear environmental movements) | Environmental reframing from the government (UK) | Environmental protest (DE) |
| Siting | Presence of suitable nuclear sites in the national territory (e.g., water availability, geological conditions) | Availability of water and lowly populated areas (DE, UK, FR) | |
| Circular Economy planning for reuse | Suitable dimensions of modules and components for transportation and inspection / Monitoring of modules and components' conditions | Early consideration of CE principles / Government support / Design standardisation of modules, components and interfaces | Modules and components contamination / Political pressure / Inappropriate regulatory framework |
| Circular Economy planning for life extension | Suitable technology for life extension | Stable electricity market prices / Adequate maintenance during operations / Direct involvement of the State (e.g., subsidies and contractual agreements) | Frequent safety standards changes |

*Table 1: The SoP-based model*

The application of the model to Italy, Romania, Belgium, and Spain during the ECOSENS project also showed its comparative utility (Dei et al., 2025c). For policymakers, the SoP-based model provides a structured framework to identify intervention points, design targeted strategies, and anticipate challenges. It highlights that successful nuclear programs are not solely the result of technical capacity or financial capital, but depend crucially on institutional coordination, political coherence, and societal engagement (Finon and and Staropoli, 2001; Sovacool and Valentine, 2012). By mapping barriers and enablers, the model can inform priority-setting for investment and reform, whether that means building institutional trust, securing long-term financing, strengthening regulatory frameworks, or launching educational campaigns to increase public awareness. It also allows for adaptive policymaking: the model can be periodically updated to reflect changes in political leadership, technological innovation, or societal values, making it suitable for dynamic and long-term planning. Moreover, by zooming in on the social discount rate, this research offers an innovative method to align economic evaluation with intergenerational equity and societal values (Boardman et al., 2018; Weitzman, 2001). It allows for the recalibration of policy timelines and investment rationales in line with the long-term nature of nuclear infrastructure.

# 5 Nuclear's Role in Europe's Energy Mix

Within this framework, nuclear power emerges as a strategic option to be deployed selectively. Its advantages are clear: low-carbon, reliable, long-duration generation that stabilises systems with high renewable penetration; preservation of industrial and technological capabilities; and contribution to energy sovereignty (Finon and and Staropoli, 2001). Its challenges are equally clear: high capital costs, long construction times, and political sensitivity. The correct approach is neither blanket endorsement nor blanket rejection but pragmatic, context-specific deployment.

For countries with existing fleets, an immediate priority can be life-extension. Extending reactors' lifetime by one or two decades delivers some of the fastest decarbonization gains available. It avoids the emissions associated with premature closure and replacement by fossil generation. It preserves skilled workforces and industrial supply chains. It reduces waste by maximising the value extracted from existing assets. With appropriate safety upgrades and regulatory oversight, life extension is often the most cost-effective path forward. New mechanisms, such as contracts for difference or power purchase agreements, can ensure economic viability in liberalised markets. For other countries, selective new large-scale builds may be justified. These projects should be pursued only where governance capacity, financial frameworks, and public support are robust. In such contexts, new reactors provide durable, low-carbon power and anchor national industrial ecosystems. But risks must be managed carefully. Projects should use standardised designs to reduce complexity, centralised delivery agencies to avoid fragmentation, and transparent financing models to allocate risk appropriately (Mignacca et al., 2025b). Waste management and decommissioning provisions should be established and funded before plants begin operation (Abadie, 2020).

SMR and advanced designs represent a third track. Their modularity and potential for shorter construction times make them attractive for certain contexts, such as smaller grids, industrial clusters, or regions where public acceptance of large reactors is low. However, SMRs remain at an early commercial stage (Mignacca et al., 2025c). They should be pursued as pilot projects, with strict cost reporting and transparent evaluation. EU-level coordination on licensing could accelerate deployment and reduce duplication. Over time, successful pilots could be scaled.

In all tracks, circular economy principles must be considered and embedded, planning for life-extension strategies and reuse opportunities from the beginning (Mignacca et al., 2025a). Financing models should reward such measures, and regulators should adapt licensing frameworks to recognise them.

# 6 Policy recommendations

A credible European strategy for energy infrastructure cannot be built on generic calls for innovation or investment. It must be rooted in measurable criteria that allow projects to be assessed on their true value to society, while also reflecting the lessons of real-world experience. This was part of the scope of WP3 in the ECOSENS project. Informed by the studies conducted as part of WP3, our policy recommendations have four pillars.

**The first pillar is delivery readiness.**

Projects should not proceed to procurement without passing an institutional capacity audit covering political stability, regulatory predictability, supply chain maturity, and governance clarity. The contrast between France and some other countries illustrates the stakes, with France's historical success in deploying a standardised fleet relying on centralised delivery under EDF with strong state backing. Recent experience in Finland, the USA or the UK has been burdened by fragmented procurement and unstable financing arrangements, driving costs upward (Lehtonen et al., 2022). A readiness test would have flagged such vulnerabilities early, allowing remedial steps, such as a central delivery agency or cross-party compacts, to be mandated before approval. Europe cannot afford to repeat these avoidable mistakes.

**The second pillar is intergenerational value, assessed through social discount rate scenarios.**

Every project with a lifetime beyond two decades should be evaluated using multiple discount rates, including a low SDR that reflects the needs of future generations. This is not theoretical: the difference between private-sector discounting and a public social discount rate has already proven decisive in nuclear project appraisals. Most of the nuclear reactors in operation or planned today would not be there with high-discount assumptions, yet their contribution to decarbonization and security is now indisputable.

**The third pillar is Holistic and Systemic Analysis.**

Adopting holistic frameworks, like the SoP in our case, is crucial. Nuclear energy must be treated as a complex socio-technical system rather than as a standalone technology (Dei et al., 2025a). This ensures that political, socio-cultural, and environmental factors are evaluated alongside the purely economic and technical ones. By considering all interconnected elements, policymakers can develop a robust and effective long-term energy strategy, mitigating risks and building public trust from the outset.

**The fourth pillar is public legitimacy.**

No project can endure without societal consent. Finland's Onkalo repository demonstrates how legitimacy can be built: decades of transparent engagement, independent oversight, and tangible community benefits created trust in one of the most sensitive areas of nuclear policy (Barthe and and Mays, 2001). Germany, conversely, illustrates how mistrust and political contestation can decisively close nuclear options regardless of technical merit. Policy makers must therefore institutionalise independent monitoring bodies, mandate benefit-sharing with host communities, and enforce transparency in safety and environmental reporting. Legitimacy is not optional; it is the foundation of durability (Miller et al., 2013).

# 7 Closing reflections

The ECOSENS project offers valuable country-specific lessons. Europe's energy transition is not merely a technical challenge but a societal project. It requires infrastructure that is durable, resilient, and publicly legitimate. Current appraisal and planning frameworks are insufficient, undervaluing long-term benefits, overlooking governance, and neglecting circularity and public legitimacy. Instead, Europe must adopt a broader, more sophisticated framework rooted in intergenerational value, delivery readiness, and public legitimacy. For policymakers, this means shifting focus from a simple "pro" or "anti" nuclear stance to a nuanced, context-specific approach.. Risks must be managed transparently, and policies must be implemented in a phased, pragmatic roadmap. If Europe adopts these reforms, it can build an energy system that is not only low-carbon but also resilient, affordable and legitimate. If it fails, the transition risks being brittle, costly and contested. The stakes are high, but the path forward is clear. Decisions made in the next five years will shape Europe's energy future for generations.

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