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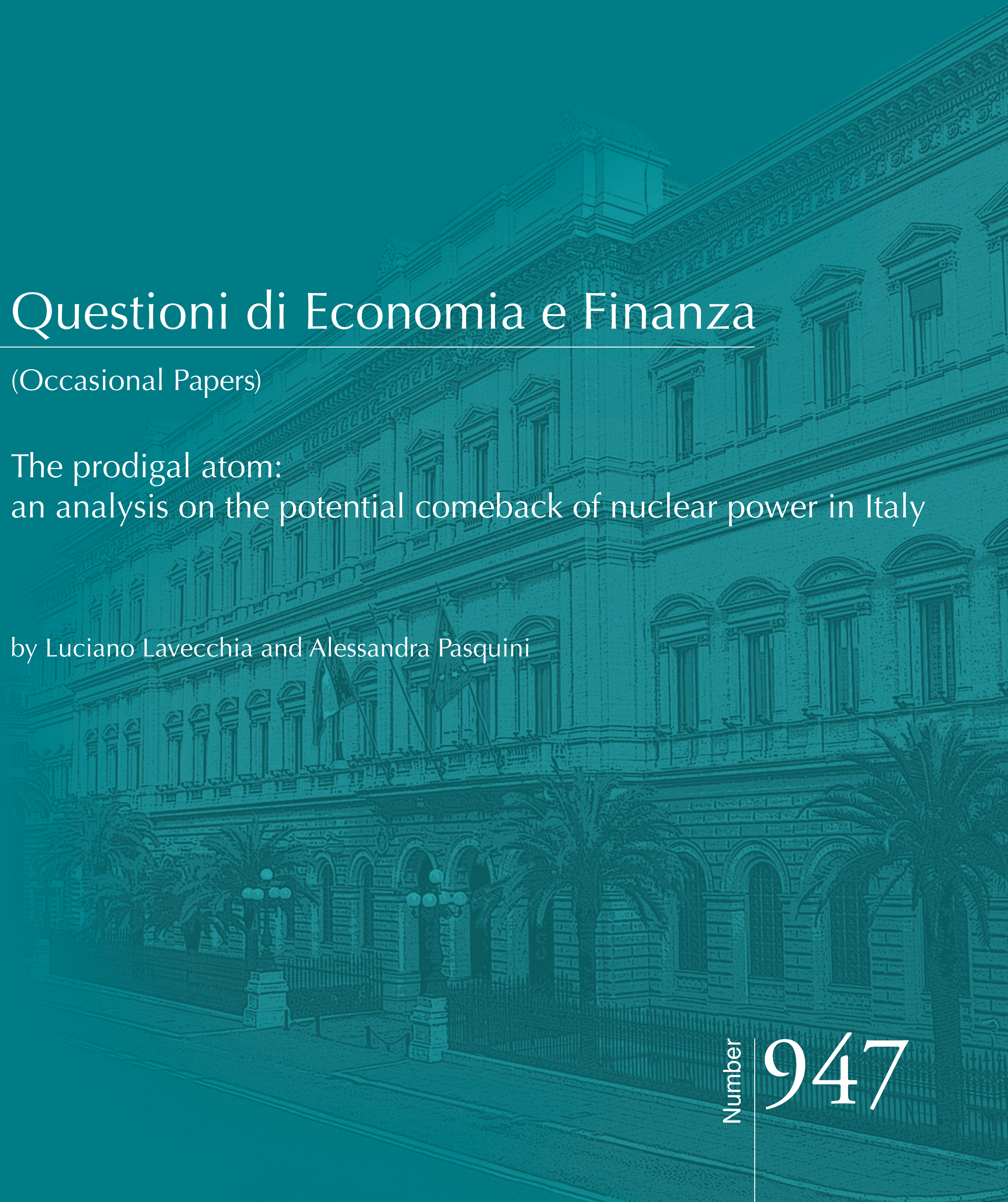

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Number 947 – June 2025

ISSN 1972-6643 (online)

Designed by the Printing and Publishing Division of the Bank of Italy

THE PRODIGAL ATOM:
AN ANALYSIS ON THE POTENTIAL COMEBACK OF NUCLEAR POWER IN ITALY

by Luciano Lavecchia* and Alessandra Pasquini*

Abstract

The debate over a possible reintroduction of nuclear power into the national energy mix has recently reopened. This paper revisits the study by Faiella and Lavecchia (2012) to assess its potential consequences in reducing electricity prices, energy dependence, and greenhouse gas emissions, while also offering additional elements for evaluation and reflection in light of developments over recent years. The analysis shows that, given the structure of the electricity market and electricity bills in Italy, with the current energy mix, reintroducing nuclear power would not significantly affect price levels. Rather, it could reduce price volatility, thereby helping stabilize electricity expenditure for subscribers to long-term contracts. As regards energy dependence, the reduction in hydrocarbon imports would be offset by increased imports of technology and fuel for nuclear generation, which are currently concentrated in countries that are geopolitically not closely aligned with Italy. By contrast, the contribution of a nuclear revival to reducing greenhouse gas emissions could potentially be substantial. Another important element emerging from the analysis concerns the uncertainties associated with the technologies selected, most of which are not yet commercially available. These uncertainties suggest the need for a cautious approach that also prepares and promotes alternative strategies.

JEL Classification: Q42, Q53, Q54.

Keywords: nuclear power, Italy, SMR, decarbonization.

DOI: 10.32057/0.QEF.2025.947EN

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1. Introduction[1]

Building on the contribution by Faiella and Lavecchia (2012), this paper aims to assess the consequences of reintroducing nuclear energy into the national energy mix in terms of electricity price reductions, energy dependence, and greenhouse gas emissions. It also provides new elements for evaluation and reflection, particularly in light of recent developments in technology and energy markets.

At the end of 2023, there were 410 operational nuclear reactors worldwide across 30 countries. Nuclear power was the world's second-largest low-greenhouse-gas source of electricity after hydropower (and the leading source in Europe), accounting for 9 percent of total electricity generation and 4.2 percent of installed capacity (down respectively by 18 and 62 percent compared with the 1990s; US Energy Information Administration - EIA, 2025). By comparison, renewable energy sources as a whole accounted for 30.9 percent of electricity generation against 42.2 percent of installed capacity; these shares declined to 16.3 and 28.8 percent, respectively, when considering only modern renewables (i.e., excluding hydropower).

Operational reactors are concentrated mainly in the United States and the European Union. France holds the world record in terms of the share of domestic electricity generated[2] from nuclear fission, amounting to 65 percent in 2023, followed by Slovakia (60 percent) and Ukraine (50 percent). The share falls to just under 20 percent in Russia and the United States, and below 10 percent in China. The average age of North American and European reactors is significantly higher than that of reactors in emerging economies, where most units currently under construction are concentrated (predominantly based on Chinese or Russian technologies). Over recent decades, investment in these technologies has declined sharply. Although this trend has been widespread, it has been more pronounced in Europe and North America. As a result, most reactors currently operating in Europe stem from major investments made in response to the oil shocks of the 1970s and 1980s, particularly in France under the so-called "Plan Messmer[3]."

The sharp decline in investment in these technologies over recent decades (particularly in Europe and North America) is the result of several political and economic-financial factors. From a political standpoint, the accidents at Three Mile Island (1979), Chernobyl (1986), and Fukushima (2011) led to a shift in public perceptions of safety. In some cases, it resulted in the abandonment of nuclear technology – notably in Italy following the 1987 referendum and in Germany between 2011 and 2023. It also resulted in stricter safety requirements for the construction of new plants, the upgrading of existing

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[1] We thank Federico Barbiellini Amidei, Enrico Bernardini, Raffaello Bronzini, Carlo Stagnaro, Stefano Clò, Ivan Faiella, Maura Francese, Francesca Lotti, Roberto Torrini, and Patrizio Pagano for their useful comments and suggestions. The views expressed and any remaining errors are solely the responsibility of the authors and do not necessarily reflect those of the institution to which they belong. This version was translated from Italian into English in June 2026. We intentionally kept revisions to a minimum, making only those necessary to reflect developments in the legislative process and technological advances.

[2] In addition to producing electricity, nuclear power is often used to produce thermal energy for civil and industrial uses: over 70 reactors are currently used to produce both forms of energy (cogeneration).

[3] On March 6, 1974, French Prime Minister Pierre Messmer announced a plan to reduce France's dependence on oil (which at the time was used for electricity generation). The ambitious plan envisaged the construction of around 80 reactors by 1985 and 170 by 2000. In practice, 58 reactors were built over a 30-year period, based on an original Westinghouse design modified by the French company Framatome, with increasing power ratings over time: 900 MW (34 reactors, CP0, CP1, and CP2 models); 1,300 MW (20 reactors, P4 and P'4 models); and 1,450 MW (4 N4 reactors). France is currently developing a new generation of reactors, the EPR/EPR2, with a capacity of 1,650 MW; four units have already been completed (two in China, one in Finland, and one in France), while two more are under construction in the UK (Hinkley Point C) and another two are in the planning stage (Sizewell C, UK).

ones, and waste management, including in the medium and long term. This, in turn, led to increased costs and longer construction and design times for new facilities (Lovering et al., 2016; Haas et al., 2019). These factors are particularly relevant in the nuclear sector, which is characterized by a very high share of fixed construction costs, while variable costs (especially fuel costs) are relatively limited. Nuclear power therefore requires the investment of large amounts of capital whose return remains uncertain until the completion of the (typically lengthy) construction phase and plant commissioning. Growing political uncertainty surrounding these technologies has further increased the cost of capital, discouraging investment.

Moreover, the liberalization of the electricity market in Europe led to the fragmentation of vertically integrated public monopolies into a plurality of private operators. This resulted in a market model that improved system efficiency and resilience. However, the new private operators tend to favor technologies with lower capital intensity and much shorter construction times. This further slowed investment in nuclear technology.

Contrary to the decline observed over the previous decades, recent years have nevertheless seen a recovery in investment, which exceeded USD 65 billion in 2023 (up from USD 40 billion in 2018), compared with USD 480 billion invested in solar photovoltaics alone. Of total nuclear investment, USD 42 billion was devoted to the construction of new reactors, while the remainder was allocated to maintenance and lifetime extensions of existing plants (IEA, 2024)[4]. According to the International Energy Agency - IEA (2025), nuclear power generation is expected to reach a record high in 2025, driven by the restart of Japanese reactors shut down after the Fukushima Daiichi accident, the completion of maintenance work at several French plants, and the commissioning of new facilities in China, India, and Korea (62 reactors are currently under construction, which would add 64.4 GW to the world's total installed nuclear capacity of 377 GW). In Europe, two units are under construction[5], and another two are in the planning stage[6], although all have experienced numerous delays and cost overruns (Figure 1). Two recently grid-connected units are also noteworthy (Olkiluoto in Finland and Flamanville in France)[7].

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[4] Many plants in the United States and France were deemed sufficiently safe to obtain authorization to extend their operating life from the originally planned 30/40 years by an additional 20 years, subject to major maintenance works. Overall, 64 reactors in 13 countries, with a combined capacity of 65 GW, equal to 15 percent of the global total, had obtained operating lifetime extensions worldwide (IEA, 2025).

[5] These are in the United Kingdom (Hinkley Point C-1 and C-2). A third unit has recently be completed and is currently loading fuel. It is the fourth unit of the Mochovce plant, located in the Slovak Republic (Mochovce) with a capacity of 440 MWe, based on the Soviet VVER V-213 design developed between the 1970s and 1980s. Construction of the plant began in 1987 and was suspended between 1992 and 2009.

[6] Sizewell C, in the United Kingdom. The project envisages two 1.7 GWe EPR reactors (Sizewell C-1 and C-2) at an estimated cost of GBP 40 billion, lower than Hinkley Point C-1 and C-2 because it is expected to benefit from learning economies generated by previous construction projects. The plants are expected to be built by the French company EDF, although discussions with the Government are ongoing regarding cost sharing.

[7] Olkiluoto, Flamanville, and Hinkley Point are all EDF projects based on the proprietary GEN III+ European Pressurized Reactor (EPR) design, with a capacity of 1.6 GWe. All these projects have suffered major delays and cost overruns. In particular, construction of the third Olkiluoto unit, the first reactor built in Europe after 15 years of inactivity, began on May 12, 2005, and concluded with grid connection on March 12, 2022, almost 13 years later than originally scheduled (December 2009), while costs increased from approximately EUR 3 billion to EUR 11 billion. Similarly, the third unit at Flamanville (the first nuclear construction project in France after 25 years), also an EDF project based on the EPR design, began construction on December 3, 2007, and was finally completed with grid connection on December 21, 2024, with a 12-year delay and costs nearly quadrupling (from EUR 3.3 billion to EUR 13.2 billion). Hinkley Point C-1 and C-2 is a joint venture project between EDF and China General Nuclear Power Group (CGN) which, after building two EPR reactors in China (Taishan 1 and 2), won the contract to build two 1.6 GWe EPR reactors at the Hinkley Point site in the United Kingdom. Construction of unit C-1 began on December 11, 2018, and that of unit C-2 on December 12, 2019. Delivery was initially expected after 115 months (early 2026/2027), but has recently been revised to 2029/2030; meanwhile, estimated costs have nearly tripled

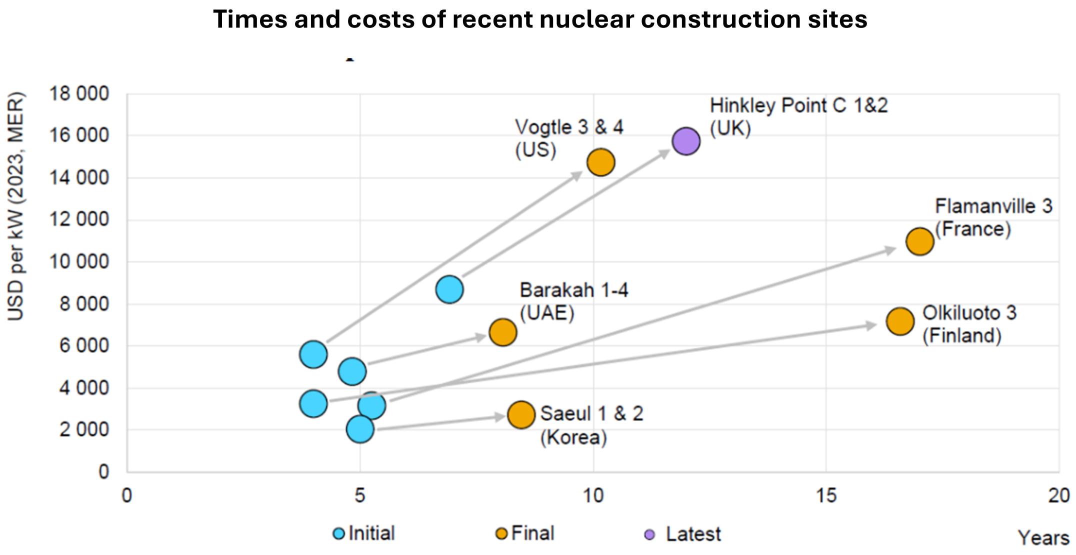
Times and costs of recent nuclear construction sites

Fig.1: Capital costs and projected and actual construction times for a series of recently built nuclear power plants. Source: IEA (2025).

Globally, the IEA forecasts a further increase in investments in the coming years. According to the baseline scenario[8] presented in the World Energy Outlook 2024, these investments are expected to increase from $65 billion to $70 billion annually between 2023 and 2030. Eighty percent would go to finance large-scale reactors, 10 percent to new modular technologies (Small Modular Reactors - SMRs; see the box "Selected Technologies: SMRs and AMRs"), and the remainder to extend the useful life of existing plants. However, under the "Net Zero Emissions by 2050" scenario, in which the goal of zero emissions by 2050 would be achieved, nuclear investments would more than double, reaching $155

(from GBP 18 billion in 2015 to around GBP 47 billion in 2024). The project uses a Contract for Difference (CfD) scheme between EDF-CGN and the UK Government (with a strike price of GBP 92.5 per MWh for 35 years indexed to inflation, meaning that by 2024 the guaranteed price had risen to GBP 123.9/MWh, equivalent to EUR 146/MWh). Under a CfD, the plant developer receives the difference between the strike price and the wholesale electricity price whenever the latter is lower. Conversely, if the wholesale price exceeds the strike price, the developer pays the difference to the Treasury (link). Furthermore, in February 2022, the French Government announced a plan—still not yet launched—to build several nuclear reactors based on a revised version of the Evolutionary Power Reactor (EPR), now known as the EPR2. The project envisages the construction of six EPR2 reactors (1.6 GWe installed capacity) across three existing plants (see action NUC.3, French Government, 2024). Estimated construction costs amount to EUR 52 billion (EUR 8.7 billion per reactor), corresponding to a generation cost between EUR 40 and EUR 100 per MWh depending on the assumed cost of capital (from 1 to 7%; see fiche). The project also envisages the assessment of a further eight reactors (action NUC.4), for a total capacity of 13 GW. More recently, cost estimates for the first tranche were revised upward (from EUR 52 billion to EUR 67 billion; see SFEN), and the French Court of Auditors criticized the delays and low profitability of EDF's most recent completed or ongoing projects. The Court also recommended proceeding with the final investment decision on the new EPR2 program only after clarifying its financing arrangements and completing the detailed plant design. Furthermore, the French Court of Auditors recommended that international projects should generate revenues for the EPR2 program rather than delay its implementation.

[8] In this scenario (the "Stated Policies Scenario"), the IEA assumes that policies and actions undertaken by the private sector will remain unchanged. In another, more optimistic scenario ("Net Zero Emissions by 2050"), it assumes that the energy sector will achieve its goal of zero emissions by 2050.

billion in 2030 (IEA, 2025). For this scenario to materialize, however, the IEA and the OECD's Nuclear Energy Agency (NEA) list a series of conditions that would have to occur[9].

Against this backdrop of renewed investment in nuclear technologies, the Italian government has demonstrated its willingness to reopen the debate regarding the possible reintroduction of this energy source in Italy, particularly with a focus on new small modular reactors and nuclear fusion. This paper, after examining the Italian historical context within which such a reintroduction would be considered (section 2) and the government's recent proposal (section 3), analyzes the potential advantages and the feasibility of a return to nuclear energy production in Italy (section 4). Finally, without claiming to be exhaustive, this paper addresses some of its potential critical issues (section 5). Thirteen years ago, Faiella and Lavecchia (2012) pointed out that a return to nuclear power offered advantages in terms of reducing price volatility rather than price levels, an uncertain outcome in terms of energy security, and undoubted benefits in terms of reducing greenhouse gas (GHG) emissions; however, at the cost of other environmental impacts. The updated analysis largely confirms the findings of previous studies. The main difference is a stronger case for nuclear energy from the perspective of energy security, which has become a central concern following the events of 2021–2023, the increasing instability of the geopolitical landscape, and the urgent need to reduce Europe's dependence on Russian oil and natural gas. Another significant difference compared to the past is the government's orientation towards new technologies which, if they reach an adequate level of maturity, could allow overcoming some of the obstacles that characterize traditional plants.

2. A Brief History of Nuclear Power in Italy

In the 1950s, nuclear power began to establish itself internationally as the technology that would revolutionize the field of electricity generation. In Europe, the European Atomic Energy Community (Euratom) Research and Training Programme was created during those years under the Euratom Treaty signed in Rome on March 25, 1957. The purpose of this programme, which still underpins most nuclear energy initiatives carried out at the EU level, was and remains the promotion of research and cooperation among European countries in the field of nuclear science and technology, including the establishment of uniform safety standards for the production and management of radioactive waste[10].

Italy, whose electricity sector in the postwar period had been weakened by the conflict and was hampering economic recovery, was among the first countries to take an active interest in the peaceful use of nuclear energy. At that time, the “threat” of nationalization loomed over the electricity sector, and the new technology was viewed by both public and private firms (or at least by ENI according to Lavista, 2017) as a means of establishing themselves in the sector and emerging as key players, as well as a solution to Italy’s energy problem (Bini and Londero, 2017). This context, together with the absence of a centralized plan, led in the initial phase to a disorderly development of nuclear power, without synergies or economies of scale and within a political environment characterized by considerable uncertainty and the absence of adequate regulation (Bini, 2017; Lavista, 2017). Public and private bodies and firms

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[9] These include: reduced construction times and costs (especially in Europe and North America); increased returns on capital invested in these projects compared to what is envisaged by the current electricity market design; increased incentives and improved communication to build public consensus on nuclear power plants and radioactive waste storage; effective regulation to ensure plant safety, including the creation of an independent regulatory authority (both for safety reasons and to reassure the public); the availability of substantial capital at interest rates that attract potential investors (traditional nuclear power plants require particularly long construction times and costs); the creation of an efficient production chain for the fuel cycle and plant construction; and the existence of an adequately trained workforce.

[10] For a detailed list of initiatives currently undertaken within the Euratom framework, or to which the programme contributes, see Garbil (2020).

competed with one another and used the means at their disposal to slow down their rivals[11]. The outcome was the construction of three different plants based on three different technologies, two American and one British, which entered into operation between 1964 and 1965 and reflected the three competing entities[12]. Despite the limited initial planning, Italy became during those years the world's third-largest producer of nuclear energy in absolute terms (after the United Kingdom and the United States) and the second-largest (after the United Kingdom) in terms of the share of electricity generated, amounting to approximately 4 percent[13].

In 1962, following the nationalization of the electricity sector and the founding of ENEL, the Italian nuclear program underwent a sharp slowdown, as the company found it more convenient to rely on oil-fired thermoelectric plants rather than build new nuclear facilities. Indeed, under the Marshall Plan, Italy's refining capacity had expanded significantly, exceeding domestic demand and turning the country into the "refinery of Europe" (Lombardo, 2000). The refineries built at the time were based on simple technology that produced large quantities of low-quality residual fuel oil (Zorzoli, 2017), which was then made available to ENEL at highly favorable prices. In addition, the discovery of new oil fields in North Africa during those years contributed to a collapse in oil prices (Bini, 2017).

The situation changed with the 1973 oil crisis. In response to rising oil prices and to reduce national energy dependence, in 1975 Carlo Donat-Cattin, then Minister of Industry, decided to include nuclear energy in the first National Energy Plan (PEN). The Plan, originally proposed by ENEL, was ambitious: it envisaged the construction of up to 20 nuclear power plants with a total installed capacity of 13–19 GW electric (GWe) over a period of 8–10 years (the preliminary plan contained no details regarding locations, technologies, or operators involved; Baracca, 2017). However, the funds allocated were insufficient: in 1973 ENEL's endowment fund to cope with the oil crisis amounted to 250 billion lire for a five-year period[14]. The political world was divided over the technology to be adopted, and ENEL entered into agreements with all the major foreign companies (Di Nucci, 2006). Public sentiment had meanwhile become increasingly unfavorable: in previous years (beginning in 1971–72 and escalating sharply in 1973; Spaziante, 1980), local opposition movements against power plants under construction (including non-nuclear facilities) had begun to emerge. By 1977, most plants that should already have been operational had suffered delays or faced obstruction from local administrations. This was also due to the structure of the authorization process, which made it difficult for ENEL to reach agreements with other local authorities[15]. These difficulties were not resolved by the law approved in 1975, which was

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[11] For example, between 1956 and 1957, Felice Ippolito (Secretary General of the National Committee for Nuclear Energy, CNEN) pressured Cortese (then Minister of Industry and Commerce) to reject Edison's request for an exchange-rate guarantee on an Export-Import Bank loan intended to finance the construction of a plant (Bini, 2017).

[12] The Garigliano/Sessa Aurunca plant (Energia Nucleare Sud Italia, ENSI project) was financed by the World Bank (the only case to date of a nuclear power plant financed by this institution – World Bank, 2016) and resulted from an agreement between the Società Elettrica Nazionale (SENN) and General Electric (United States), which supplied the BWR technology, with the involvement of IRI and on behalf of the National Committee for Nuclear Energy (CNEN). Construction of the Latina plant was carried out by the Società Italiana Meridionale per l'Energia Atomica (SIMEA), controlled by ENI (with participation by Agip-Nucleare and IRI), using British technology (a graphite gas-cooled reactor) supplied by Nuclear Power Plant. The Trino Vercellese plant was built by SELNI (controlled by Edison) and was based on Westinghouse PWR technology (Curli, 2000).

[13] Source: World Bank, Electricity production from nuclear sources (% of total).

[14] As an example, according to a statement by Arnaldo Maria Angelini (President of ENEL between 1973 and 1979), the investments required to build a 1 GWe nuclear plant exceeded by 300 billion lire those needed to construct thermoelectric plants of equivalent capacity (Padovan, 2024).

[15] While private citizens were mainly concerned about the environmental implications of power plant construction, local administrations opposed them because of the removal of the excise tax on electricity consumption from which they had previously benefited (Spaziante, 2017).

intended to better define and regulate the relationships and timelines of authorization procedures (Spaziante, 1980).

Due to widespread public protests, the agreement between local governments and ENEL for the construction of the Montalto di Castro plant was reached only in 1978, after two years of negotiations involving the national government[16]. Molise opposed the construction of the nuclear plant envisaged under the PEN; Piedmont and Lombardy were unable to reach agreements with municipalities regarding the siting of the planned plants; and for two additional plants envisaged by the PEN, construction sites had not yet been identified (Spaziante, 1980). In 1979, the Three Mile Island accident gave further momentum to anti-nuclear movements (Baracca, 2017) and required a reconsideration of nuclear plant safety criteria, resulting in longer construction times and higher costs (Haas et al., 2019).

Following the second oil crisis of 1979, a new PEN was drafted and published in 1981 (PEN, 1981). Compared with the previous version, the new plan reduced the number of plants envisaged and defined their locations more precisely. In particular, it provided for the construction of two nuclear units at Montalto di Castro and six additional plants in Piedmont, Lombardy, and Puglia, the latter based on Westinghouse pressurized water reactor (PWR) technology, bringing total installed capacity to 12 GW[17]. Six years later, construction of the plants in Piedmont had still not begun, and the exact sites for the plants to build in Lombardy and Puglia regions had not yet been identified (according to data from the International Atomic Energy Agency's Power Reactor Information System - PRIS).

On April 26, 1986, the Chernobyl accident occurred, followed on November 8, 1987, by a referendum on the use of nuclear energy in Italy. The overwhelming victory of the anti-nuclear side marked the end of the Italian nuclear program and led to the closure, over the following three years, of all operating nuclear plants (the Garigliano/Sessa Aurunca plant had already ceased operations in 1982[18]), as well as a five-year moratorium on the construction of new facilities (Moncada, Lo Giudice and Asdrubali, 2010). Internationally, the Chernobyl accident led to a generalized decline in reliance on nuclear power (Makarin et al., mimeo) and in research and development investment (Orsatti, 2024). However, the decision to halt nuclear power generation was taken only in Italy, even though the referendum did not impose any ban on nuclear electricity generation itself, but rather repealed provisions that granted preferential procedures for the construction of new plants (Faiella and Lavecchia, 2012). Other countries instead introduced moratoria on the construction of new plants (for example Spain and Belgium) while fully exploiting the operational life of existing facilities. The decision to halt nuclear power generation in Italy coincided with a period of strong growth in electricity demand and was followed by a rapid increase in electricity imports from abroad (particularly from France, which exported nuclear-generated electricity), as well as by the subsequent replacement of coal and oil with natural gas. Given the cost structure of nuclear electricity generation, characterized by high plant construction costs relative to operating and fuel costs, abandoning nuclear power proved extremely costly for the country. Despite the substantial construction costs incurred before the referendum and decommissioning costs afterward (suffice it to note that between 2008[19] and 2023 decommissioning costs paid still amounted

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[16] In addition to local opposition, construction of the plant was slowed by a lack of expertise: both Ansaldo (to which ENEL had commissioned the project) and ENEL lacked experience in constructing plants of that size, and archaeological remains were also present in the area (Zorzoli, 2017).

[17] In addition to the plants envisaged by the PEN, construction of the CIRENE prototype, based on Italian technology and located in Latina, also began in 1979.

[18] The reactor at the plant had been shut down in 1978 due to a malfunction, and in 1981 ENEL decided not to restart operations because of the high cost of the repairs required and the plant's limited remaining operational life.

[19] For the previous period, a SOGIN document reports EUR 2.1 billion for 2001–2013 (SOGIN, 2014).

to approximately EUR 4.3 billion and were estimated at a further EUR 400 million for subsequent years), the expected benefits from electricity generation were never realized[20].

In 2008, a new plan to revive nuclear energy in Italy was proposed, with the long-term objective of achieving an electricity generation mix composed of 50 percent fossil-fuel sources, one-quarter renewable energy, and one-quarter nuclear power (equivalent to an installed capacity of approximately 13 GWe with annual generation of around 100 TWh). Following an intense political debate, the Berlusconi Government enacted Decree-Law No. 34 of March 31, 2011, which, in Article 5, included provisions for the construction of new nuclear plants. However, the tsunami of March 11, 2011, and the subsequent accident at the Fukushima Daiichi nuclear power plant in Japan reignited public debate and led to a new referendum (held on June 12–13, 2011). The referendum question concerned the "Repeal of the new provisions permitting the production of nuclear electricity within the national territory." The near-plebiscitary victory of the "yes" vote (with turnout reaching 57 percent) brought the new Italian nuclear development program to an end.

3. The Path Identified in the Most Recent Legislative Measures and Official Documents

3.1 The 2024 PNIEC

Achieving the GHG reduction targets set out in the European Green Deal (see Section 4.3 below) requires, among other things, a reconfiguration of the energy mix toward low-carbon sources, alongside greater electrification of energy consumption and increased energy efficiency. EU targets stipulate that by 2030, 32 percent of total final energy consumption should be covered by renewable sources. To this end, the Integrated National Energy and Climate Plan (PNIEC, 2024) envisages for Italy a 39.4 percent share of renewables by 2030, an increase of 14 percentage points compared with 2025. The largest contribution to the growth of these sources is expected to come from the thermal and electricity sectors, the latter foreseeing an increase of almost 70 GW in installed renewable capacity by 2030, compared with 61 GW installed at the end of 2022.

Greater penetration of renewable energy sources (whose generation is inherently intermittent and non-dispatchable) requires significant investments in grids and infrastructure, in addition to the installation of storage systems[21]. Complementing these investments, the 2024 PNIEC envisages the use of dispatchable low-carbon electricity generation sources such as hydropower and nuclear energy. Nuclear power was not included in the previous 2020 version of the PNIEC.

The modalities for reintroducing this energy source are based on the findings of the National Platform for Sustainable Nuclear Energy (PNNS), established in September 2023 at the initiative of the Italian Ministry of Environment and Energy Security (MASE), with the aim of assessing the feasibility of reintroducing nuclear power in Italy[22]. In its final report, the PNNS (2025) suggests a gradual process

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[20] Until January 1, 2023, the costs of dismantling nuclear plants and related territorial compensation measures were financed directly through electricity bills via the A2rim tariff component (formerly A2). With the 2023 Budget Law, in response to requests from the Italian Competition Authority and the European Commission, and in implementation of Milestone 7 of Mission 1, Component 2 (M1C2-7) of the NRRP, these costs were transferred to general taxation. The estimate for the years 2008–2022 is based on revenues from the A2/A2rim component as estimated by Lo Schiavo (2023) and, for 2023 and subsequent years, on the Technical Report accompanying the 2023 Budget Law.

[21] In the case of Italy, the national transmission system operator, Terna, has estimated that at least EUR 21 billion in investments will be required in the high- and extra-high-voltage grid through 2032 (Alpino et al., 2024).

[22] Among other tasks, the PNNS is responsible for analyzing the various new nuclear technologies available, which are the only ones considered in the scenarios proposed by the Plan (which excludes large third-generation plants, i.e., those based on technologies developed in the 1990s).

involving the deployment of new small-scale modular technologies currently under design, to be introduced according to the timelines currently envisaged by manufacturers (SMRs beginning in 2030, fourth-generation AMRs around 2040; see the box "Selected Technologies: SMRs and AMRs"). The plan also envisages the installation of microreactors (MMRs) in industrial areas, to exploit the cogeneration of electricity and process heat[23] at high temperatures in hard-to-abate sectors. The public investment envisaged solely for the "preparation of the national ecosystem" amounts to approximately EUR 2 billion (to be matched by at least an equivalent amount of private resources). Finally, the use of nuclear fusion is envisaged close to 2050. According to PNNS estimates, the installation of 8 GWe using the new small-scale modular technologies would require at least EUR 40 billion in direct construction costs, excluding financial costs.

Under the scenario envisaged by the PNIEC, installed capacity between 2030 and 2050 would amount to approximately 8 GW (including 1.3 GW in cogeneration mode and 0.4 GW from nuclear fusion[24] by 2050). The new plants would number between 22 and 42, and their output would cover 11 percent (64.2 TWh) of projected electricity demand in 2050 (PNNS, 2025). According to PNNS estimates, the total installable capacity by 2050 amounts to around 16 GW, while the PNIEC assumes that approximately half of this capacity will be installed under a "conservative" scenario. According to the PNIEC, the installation of SMRs, Advanced Modular Reactors (AMRs), or fourth-generation microreactors would be "economically and energetically advantageous" and would make it possible both to satisfy greater energy demand (compared with a scenario without nuclear energy) and to reduce electricity generation from fossil fuels (mainly natural gas with Carbon Capture and Storage – CCS technology).

3.2 The Delegated Bill on Nuclear Energy

On February 28, 2025, the Government held a preliminary discussion on a delegated bill aimed at restarting the use of nuclear fission—particularly through new modular or advanced technologies—or fusion for civilian purposes. The measure has been approved by the Parliament and is currently being examined by the Senate, envisages granting the Government delegated powers (to be exercised within 12 months of the law's entry into force) to adopt one or more legislative decrees regulating nuclear electricity generation in Italy, including fusion and the production of nuclear-generated hydrogen.

The delegation is expected to provide for:

1. approval of the national program for sustainable nuclear energy and the regulatory framework governing the related competencies, as well as possible support measures for plant construction and electricity generation;
2. the provision of information and training instruments on nuclear energy for the population;
3. alignment of national legislation with European and international provisions and coordination with other electricity market regulations;
4. regulation governing the siting, construction, testing, decommissioning of nuclear plants and facilities for processing nuclear fuel and storing spent fuel;

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[23] Process heat production accounts for approximately two-thirds of the industrial sector's total energy demand, nearly half of which relates to high-temperature heat (above 400°C; PNNS 2025).

[24] Nuclear fission is a process involving the generation of heat through the bombardment of heavy atoms, such as uranium (or thorium), causing them to split (fission) and release heat that can either be used directly or converted into electricity. Nuclear fusion, by contrast, "is the nuclear reaction that occurs in the sun and other stars, producing enormous amounts of energy: two nuclei of light elements, such as deuterium and tritium, at high temperatures and pressures, fuse to form nuclei of heavier elements such as helium, releasing large quantities of energy." (MASE, Nuclear Fission and Fusion, website consulted on March 13, 2025).

5. research and development on nuclear fission and fusion, including through incentives;
6. promotion measures for the territories concerned;
7. training schemes for professional figures aimed at developing the skills required by the nuclear industrial sector;
8. regulation concerning safety, supervision, and control, including the possible establishment of an independent nuclear authority;
9. regulation establishing a system of guarantees for plant management and decommissioning.

According to the guidelines outlined in the bill, the testing, construction, and operation of new plants would be subject to authorization measures under the responsibility of MASE. Furthermore, in order to facilitate implementation and reduce the length of the authorization phase, the plants and related works would be classified as being of "public utility, urgent and non-deferrable," and the authorization title could include "a declaration of immovability and the imposition of expropriation constraints."

It should be noted that when the draft of the bill was first elaborated there was no unanimity within the governing majority regarding the choice of nuclear power, with differing positions both among and within political parties concerning the various technological options. The decision to focus on SMRs and research, rather than on already available technologies, may therefore reflect the intention to open a broader debate involving market operators on these issues.

Selected Technologies: SMRs and AMRs

Definitions and Advantages - The strategy chosen by the Government in the 2024 PNIEC for medium- to long-term nuclear development centers on new small-scale nuclear technologies: Small Modular Reactors (SMRs), Advanced Modular Reactors (AMRs), and Micro-Modular Reactors (MMRs). These are nuclear fission reactors, generally with a capacity below 350 MW (below 10 MW in the case of MMRs). SMRs are based on third- and third-plus-generation Light Water Reactor (LWR) technology. AMRs are based on fourth-generation technologies incorporating new cooling systems, moderators, fuels, and functionalities. Although AMRs are less mature, they appear more competitive in terms of resource utilization, reduction of nuclear waste, and greater flexibility (Dodaro and Tarantino, 2023). Beyond their smaller power ratings (which also characterized the first plants built in the 1960s, including Italy's first three nuclear plants), these new reactors differ in that they are designed for serial production (generally in factories) and subsequently transported to the site for final assembly. It should be noted, however, that only a limited number of projects are currently active or have reached the construction phase.

The smaller scale of these technologies entails reduced use of nuclear fuel, thereby lowering plant safety risks. Some of the new reactors also employ advanced fuels and technologies that are more resilient to unexpected events and temperature increases. They rely on more advanced passive safety systems that exploit natural laws, such as gravity, and do not require operator intervention or backup power supplies in order to activate (IEA, 2022; NEA, 2024). The combination of these factors could also allow for smaller emergency evacuation zones (NEA, 2024). However, the introduction of new technologies requires updates to safety assessment criteria, and therefore the enhanced safety of several new projects has yet to be demonstrated (NEA, 2024). As of December 2023, construction permits or design approvals had been obtained, in addition to already operational reactors, for six reactors based on new technologies (two in China, one in Argentina, one in South Korea, one in the United States, and one in Russia; NEA, 2024).

Factory-based construction and on-site assembly of pre-manufactured modules should reduce the time, uncertainty, and costs associated with plant construction (IEA, 2022; Boarin and Ricotti, 2014; for a discussion of costs see also Section 4.1). According to estimates available in the literature, construction times for reactors currently under design are expected to amount to 4–5 years for first-of-a-kind (FOAK) prototypes and 3–4 years for subsequent nth-of-a-kind (NOAK) units (Mignacca and Locatelli, 2020).

Projects – In 2024 there were 98 projects based on SMR, AMR or MMR technologies in the world. Some of these were suspended due to lack of funding or in the embryonic development stage, the remaining 56 were operational (3), or under construction (4) or in the concrete development stage (NEA, 2024); 18 companies carrying out the 56 projects are located in the United States or Canada, 16 in Europe, 7 in Asia, 2 in Russia, 2 in Africa, 1 in the Middle East and 1 in South America. The majority of projects in the development stage are based on LWR and the power range goes from 1 to 300 MWe. The new technologies have a great heterogeneity of characteristics so not all of them offer the advantages listed above. Furthermore, most of these technologies are not yet actually available for commercial use and it is difficult to establish whether and with what timescales and costs they will be successfully applied[25]. This implies a high degree of uncertainty about the characteristics, benefits, and provenance of the projects that will be available within the timeframe envisaged by the PNIEC for the installation of the first reactors.

Only three of the 56 plants are currently operational[26]. The first is located in China, in Shidao Bay, in the eastern tip of the Shandong region. It is a high-temperature gas-cooled reactor. It was originally planned to consist of two 100 MWe units and be built in 3 years at a total cost of USD 2,000/kWe (Schneider and Froggatt, 2024). However, construction of the plant, which began in 2012, lasted 9 years, and a further two years of testing (from 2021 to 2023) were needed before commercial operation could begin. Furthermore, the total power of the reactors was reduced to 150 MWe, and by 2017 the nominal construction cost had already tripled (not taking into account the power reduction; Schneider and Froggatt, 2024). Two tests were conducted on the reactor to verify passive safety systems, specifically a grid disconnection to monitor core temperature trends (Zhang et al. 2024). The results showed the systems' ability to cool naturally, thus providing reassurance in the event of a nuclear meltdown. China has not yet replicated the construction of this model nor begun mass production.

The second and third operational SMRs are located in Russia; these are “floating” reactors mounted on the unique Akademik Lomonosov vessel and based on a 32 MWe pressurized water reactor (PWR) technology. Construction began in 2007 and was expected to take 3 years (Schneider and Froggatt, 2024). Construction was completed in 2018, and it took another year to connect to the grid and 6 months before the reactors were in commercial operation. Since construction began, costs have tripled (Schneider and Froggatt, 2024). Rosatom has not replicated the construction of this model and is currently developing other projects. Currently, the Akademik Lomonosov is docked in the remote region of Chukotka, providing electricity to an otherwise isolated area.

In 2025, four new-technology reactors were under construction: one in Russia, one in Argentina, one in China, and one in the USA (KAIROS)[27]. The model reactor under construction in Argentina, called

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[25] For example, in South Korea the System-Integrated Modular Reactor (SMART) model was developed and licensed in 2012, but by 2024 no concrete agreements had yet been reached for reactor construction, apparently mainly due to its high costs (Schneider and Froggatt, 2012). Significant obstacles and unforeseen issues have also affected the three reactors currently in operation.

[26] In addition, there is a completed test reactor in Japan, built to demonstrate the potential use of nuclear power for heat production, which is currently undergoing maintenance in order to be used for hydrogen production (NEA 2024; TEHA Group, 2024).

[27] The KAIROS prototype currently under construction can only be used for thermal energy production.

CAREM, has a power of 25 MW. Construction began in 2014, and the first tests were initially scheduled to begin in 2016. The completion date has been postponed several times, also due to several work suspensions, and in 2024 it was scheduled for 2028 (Schneider and Froggatt, 2024). Construction of the US model reactor began in July 2024 and in 2025 was scheduled for completion in 2027 (IEA, 2025). A fifth reactor, using US technology, has been recently added to these as its construction started in Darlington, Canada, on April 22nd, 2026. Its connection to the grid is scheduled for 2030[28].

For SMR, AMR or MMR models developed by industry-leading companies and whose construction has not yet started, the developing companies plan to build the first prototypes within a timeframe of 2029 to 2039 (IEA, 2025).

The European Commission and Industrial Development – On February 6, 2024, the European Commission announced the launch of the "European Industrial Alliance on SMRs" to accelerate the development and implementation in Europe of projects based on new small-scale nuclear technologies. More generally, the Alliance aims to revitalize the EU's nuclear value chain.

Public and private entities active in the field of SMRs, AMRs, and MMRs are eligible to join the Alliance (more than 300 entities were members as of December 2024). To achieve the objectives outlined above, the Alliance provides support for the development of new nuclear technologies, identifying potential obstacles and working to overcome them. With a particular focus on project financing methods, the development of an adequate European supply chain and workforce, support for research into new technologies, engagement and awareness-raising among the public and potential industrial users, networking among stakeholders (project promoters, authorities regulating safety criteria), and the promotion of European technologies on the market outside the EU.

The Alliance also envisions the creation of working groups focused on specific SMR development projects that meet certain criteria[29]. In October 2024, an initial group of projects was selected, the characteristics of which are briefly described in Appendix A.

In the work program presented in February of 2025 (see section 4.3), the European Commission also expressed its intention to present the 2025 Nuclear Illustrative Programme and define a strategic plan for the European SMR Alliance[30].

4. The Benefits of Returning to Nuclear Power in Italy Identified by the Government

The Italian Government has outlined its position in favor of a possible return to nuclear power on the basis of three potential contributions:

1. reducing electricity costs for consumers;
2. decreasing energy dependence on foreign countries;
3. achieving greenhouse gas emission reduction targets.

During the 2008–2011 debate on reviving nuclear power in Italy, Faiella and Lavecchia (2012) highlighted both advantages and drawbacks associated with these issues. In particular, their analysis showed that the impact in terms of reducing final costs for consumers was uncertain, whereas there was a potential

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[28] “Darlington SMR project's foundation module milestone” – World Nuclear News.

[29] See Appendix I to the “Terms of Reference” of the European Industrial Alliance on Small Modular Reactors.

[30] The Nuclear Illustrative Programme was published on June 13, 2025.

contribution to reducing price volatility (which remains an important factor, especially for firms). As regards energy dependence, the authors pointed out that although new forms of dependence linked to different technologies and fuels could emerge, replacing fossil fuels (or investments in renewable sources) with nuclear energy would have the advantage of diversifying the energy mix (and suppliers). Finally, the main contribution of nuclear power appeared to the authors—and still appears today—to be its role in achieving decarbonization targets, particularly as a complement to investments in renewable energy sources. From an environmental perspective, however, it remains essential to take into account issues related to the management of spent fuel.

The following paragraphs examine the three potential contributions mentioned above in light of technological and geopolitical developments and the experience accumulated in recent years.

4.1 Possible Cost Reductions

Generation Costs

The levelized cost of electricity (LCOE) is a standardized measure of the life-cycle cost of electricity generation[31]. It should be borne in mind that, in the case of nuclear energy, this measure is characterized by a high degree of uncertainty because numerous factors contribute to determining it, while the number of observations on which estimates can be based—particularly in recent times—is relatively limited (De Paoli, 2025). According to Lazard's (2024) estimates for the United States, referring to 2024, the LCOE for traditional nuclear power plants, under conservative assumptions, is close to that of utility-scale photovoltaic plants (commercial-scale generation facilities) with storage systems, but above that of onshore wind plants with batteries and utility-scale photovoltaic plants without storage systems.

Similarly to renewables, nuclear costs, when assessed over the entire life cycle (from construction to operation, decommissioning, and waste management), consist predominantly of fixed costs associated with plant construction and financing. Operating costs, such as maintenance and fuel, are relatively limited. In large traditional nuclear plants, fixed costs account for between 80 and 85 percent of total costs, compared with 90–95 percent for utility-scale solar with storage and onshore wind with storage (Lazard, 2024). Operating costs account for less than 10 percent of total costs, compared with 14–28 percent for coal and natural gas. In absolute terms as well, operating expenditures (OPEX, including fuel, maintenance, personnel) are relatively low, unlike fossil-fuel-based generation technologies and similarly to renewables, which however suffer from intermittency and therefore require complementary storage facilities.

The predominance of fixed costs makes investments in current nuclear fission technologies extremely sensitive to the cost of capital required for plant construction, which in turn depends on technological and operational factors (for example, whether the plant is a first-of-a-kind prototype or not[32]), financial factors (the builder's creditworthiness; the guarantee of adequate cash flow once the plant becomes operational), and institutional factors (regulatory and political uncertainty increase project risk and

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[31] Specifically, LCOE is a measure that makes it possible to compare the cost of electricity generation across different technological sources. It takes into account generation levels, capital expenditures (capex), operating expenditures (opex), and financing costs. However, it does not account for the additional infrastructure costs (interconnections and transmission grids) required for the use of intermittent and dispersed sources such as renewables. The IEA has introduced another metric, the value-adjusted levelized cost of electricity (VALCOE), which incorporates not only electricity generation costs but also the contribution each technology can make to the system in terms of grid stability.

[32] First prototypes may require a series of adjustments that unexpectedly extend construction times (and costs). For example, NUCLEUS-PRIS data show that in the case of the French "N4 REP 1450" reactor, construction of the first unit (begun in 1984) required 12 years, while construction of the fourth plant based on the same reactor model required approximately 8 years.

therefore the cost of capital required to compensate investors for the associated risk premium). Nuclear plants require lengthy design and authorization processes; construction works are complex and frequently subject to delays. Furthermore, they are continuously subject to upgrades in line with the latest safety standards (so-called “backfit requirements”) and inspections by multiple supervisory and regulatory authorities, all of which affect final costs. This entails financial requirements that are highly significant relative to the size of the investment. For example, interest costs for a plant completed in five years with a 5 percent interest rate amount to 17 percent of direct construction costs (excluding financial costs). If a plant with the same direct costs is completed in seven years with a 10 percent interest rate, this share rises to 49 percent (De Paoli, 2025).

The serial production of new technologies should partly reduce the time and uncertainty associated with plant construction, potentially lowering the required cost of capital. However, the actual costs of new nuclear technologies remain highly uncertain because, in most cases, first-of-a-kind units have not yet been built (IEA, 2025). Steigerwald et al. (2023) estimate the costs of 19 different SMR, AMR, or MMR projects using two distinct production models. For all technologies analyzed, estimated costs are (sometimes significantly) higher than those declared by manufacturers, especially for certain AMR types. Estimated LCOEs depend on the technology considered. The highest uncertainty concerns sodium-cooled fast reactors, for which the LCOE ranges from USD 805 to USD 7,519/MWh. These are followed by boiling-/pressurized-water reactors, for which the range is between USD 188 and USD 991/MWh. The lowest costs are associated with high-temperature gas-cooled reactors, whose LCOE ranges between USD 99 and USD 158/MWh[33].

Considering a cost metric developed by the IEA that incorporates the contribution of a technology to the efficiency of the energy system (the so-called VALCOE), by 2040 in Europe new small-scale nuclear plants would be competitive with utility-scale photovoltaic plants equipped with storage systems only under assumptions of particularly low capital costs (see box “Other Cost Estimates”).

OTHER COST ESTIMATES

The LCOE does not take into account the different contribution that distinct energy sources can make to the electricity system in terms of flexibility and continuity of generation. For this reason, the IEA developed an indicator called VALCOE, which also incorporates the contribution of technologies to the system (IEA, 2025). The figure reports estimates for the European Union referring to 2040 under the “Announced Pledges Scenario.” This scenario takes into account the policies that governments have declared their intention to implement, including any renewable energy subsidies or carbon pricing systems[34].

LCOE and VALCOE in Europe by Energy Source

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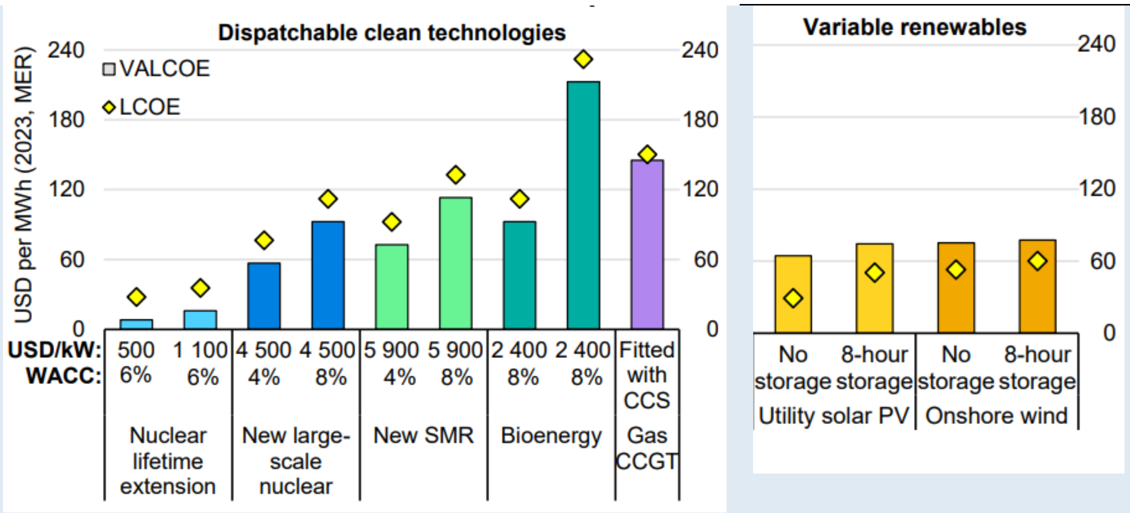
[33] By way of comparison, the same study estimates the LCOE for utility-scale photovoltaic plants (without storage) at between USD 30 and USD 41/MWh; for wind power (without storage) at between USD 26 and USD 50/MWh; and for combined-cycle gas plants at between USD 45 and USD 75/MWh.

[34] More specifically, under this scenario the IEA assumes that all climate commitments made by governments, including emission reduction targets, will be maintained.



Panel A Panel B

Notes: The figure reports the levelized cost of energy (LCOE) and the value-adjusted LCOE (VALCOE) for different energy sources. "Gas CCGT fitted with CCS" refers to combined-cycle gas generation with carbon capture and storage. "New SMR" includes all new small-scale modular nuclear technologies (SMRs, AMRs, and MMRs). The weighted average cost of capital (WACC) is assumed to be 4–5 percent for solar photovoltaics. The nuclear capacity factor (potential operating time net of interruptions for refueling, maintenance, etc.) is assumed on average to be 75–90 percent. The reference year is 2023. Source: IEA (2025).

As can be seen, for nuclear power plants both average LCOE and VALCOE vary significantly depending on the cost of capital. According to IEA VALCOE estimates, traditional nuclear plants and new nuclear technologies (grouped by the IEA under the category "New SMR") are competitive with utility-scale photovoltaics with storage only under the assumption of a weighted average cost of capital[35] equal to 4 percent (an optimistic assumption considering that the IEA generally assumes 8–9 percent for nuclear technologies). This also assumes that, for new technologies, the NOAK plants to which the estimates refer will exhibit significantly lower costs than FOAK units (IEA, 2025).

To the best of our knowledge, just a few estimate focus specifically on Italy. One was carried out by TEHA Group (2024) in collaboration with Edison and Ansaldo Nucleare[36]. According to this estimate, the cost of new nuclear technologies would be lower than that of 20 MW utility-scale photovoltaic plants with storage and wind power with storage. However, it would remain higher than the LCOE of the same plants without storage systems. Specifically, TEHA Group estimates an LCOE for new nuclear technologies ranging between EUR 90 and EUR 110/MWh, compared with EUR 125–160/MWh for wind power with storage and EUR 120–140/MWh for 20 MW utility-scale photovoltaics with storage. According to the technical documents released by the PNNS (2025), the average overnight cost for SMRs amounts to approximately EUR 5,000/kW. Another study by Agostini et al. (2025) simulates the electricity system in 2040 under four scenarios: two based exclusively on renewable energy sources and two featuring a mix of renewable energy and different shares of third-generation nuclear power. Using a metric that accounts for energy storage systems (LCOTE), the authors show that the scenarios including nuclear power achieve decarbonization with a smaller increase in costs, relative to 2023, than scenarios based exclusively on renewable energy sources. This suggests that a higher share of nuclear energy in the current energy mix would increase costs in the short term, but would become advantageous as the energy transition progresses (see Section 4.3 for further details).

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[35] The weighted average cost of capital is equal to the average market value of all outstanding securities weighted by the required rate of return.

[36] The information contained in the final PNNS reports (2025) does not make it possible to calculate the LCOE, since estimates are lacking details on the the cost of capital, plant availability factors, and operating and maintenance costs. For further details, see: "Le discutibili certezze della Piattaforma nucleare," Staffetta Quotidiana, April 4, 2025.

As in previous studies, these estimates are highly sensitive to the cost of capital: the higher the financing cost, the higher the overall system cost.

From Generation Costs to Retail Electricity Prices - In European countries, the equilibrium price on the wholesale electricity market is determined according to the system marginal price (SMP), or pay-as-cleared mechanism, whereby all accepted sell offers on the wholesale market used to meet demand are remunerated at the highest accepted price bid (Ranci and Pototschnig, 2022). This mechanism entails the construction of an hourly supply curve (every 15 minutes in Italy since 2025), ordering bids submitted by different plants in ascending order according to their marginal costs.

How the marginal price system works

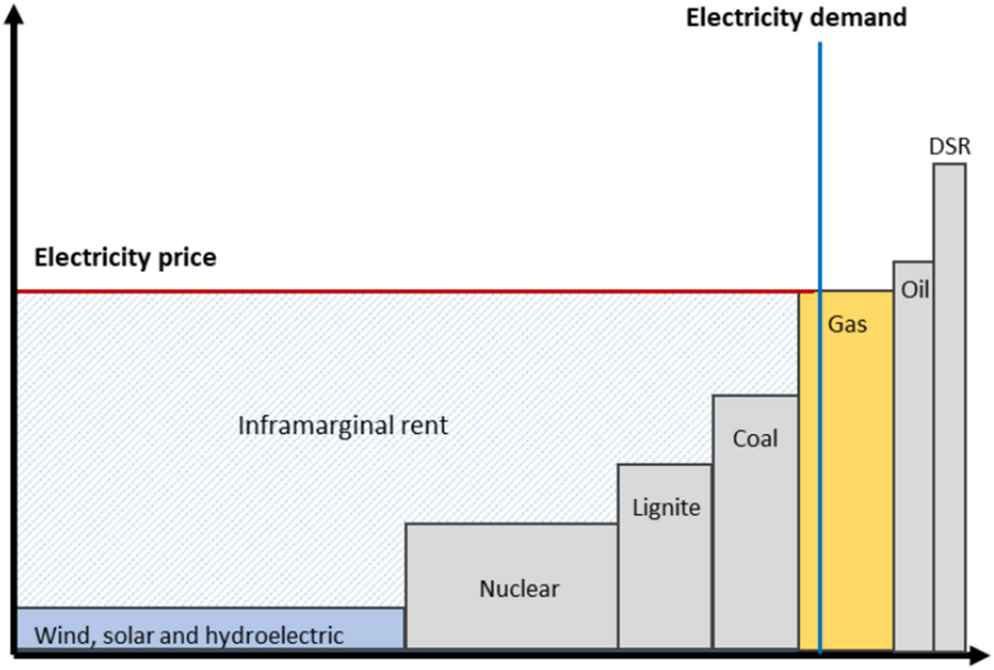

Fig. 2: The figure shows how technologies on the European wholesale electricity market are ranked according to their marginal cost and how the price of electricity is set at the highest marginal cost of the technologies required to cover the estimated electricity demand. "DSR" refers to Demand Side Response, the mechanism that involves users modifying their electricity consumption based on their energy supplier's instructions, in order to obtain tariff benefits. Source: Gasparella et al. (2023).

The equilibrium price results from the intersection between estimated demand for that hour and the supply curve (Figure 2), thereby reflecting the marginal costs of the last plant required to come online in order to satisfy demand in the relevant zone (in Italy, typically fueled by natural gas, followed by hydropower and imports; RSE, 2024)[37]. This price is then applied to all accepted bids within the relevant

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[37] The day-ahead market ("*Mercato del giorno prima*" - MGP) is the most important spot market for electricity in Italy and consists of seven zones defined according to the constraints existing within the national electricity transmission grid. From 2002 to 2024, the weighted average of zonal prices constituted the national single price (PUN), which became the benchmark wholesale purchase price for the entire country. At the urging of the European Commission, a transitional regime (PUN Index) has been in force since January 1, 2025, after which, in order to ensure greater efficiency, benchmark purchase prices will be determined by zonal equilibrium prices. According to RSE (2024) estimates, this will generate savings of EUR 118 million over three years, mainly benefiting

time slot, allowing the marginal plant to cover its operating costs while enabling all other plants to earn revenues above their respective marginal costs (the so-called "inframarginal rents"), thereby recovering investment costs. Renewable energy plants participate in market sessions with bids at marginal costs close to zero, followed by other plants, including thermoelectric plants (which, in Europe, add the price of EU ETS emission permits to their operating costs). The "marginal" technology is, for most hours of the day, natural gas. Nuclear, characterized by high fixed costs and low variable costs, falls somewhere between renewables and fossil fuels.

Consequently, even given nuclear's significant contribution to the national energy mix, it seems highly unlikely that, under current rules, it could become the marginal plant for most hours and, therefore, contribute to a reduction in final costs[38]. This is at least until nuclear and renewables are sufficient to cover all demand at various times of the day. Currently, only in Sweden, where there is a unique energy mix (40 percent hydroelectric, 29 percent nuclear, and the remainder other renewables), nuclear is the marginal technology during certain hours. However, some simulations show that this should happen in more countries by 2030 (Gasparella et al 2023).

On the other hand, the high electricity prices that characterized the three-year period 2021-23 (due to tensions in the natural gas markets) have triggered a debate on the possibility of "decoupling" the electricity market from the natural gas market, to reduce price variations in the short term. This has also led to a debate on possible reforms of the system marginal price, despite the problems of alternatives (Ranci and Pototschnig, 2022). On April 1,1 2024, the European Parliament approved a reform of the electricity market rules that aims to make decarbonization the primary objective, promoting the use of long-term contracts, such as power purchase agreements (PPAs)[39], while maintaining the system marginal price mechanism for determining the equilibrium price on the wholesale market[40]. These contracts are typically used for technologies characterized by low variable costs and high fixed costs (such as renewable sources or nuclear). This is because if a significant component of production costs were exogenous and highly volatile (such as fuel costs in the case of fossil fuel plants), suppliers would be unlikely to assume the risk of fixing sales prices in the long term. Thanks to this type of contract, the introduction of nuclear power (replacing fossil fuels, which are unlikely to benefit) could reduce price volatility[41], especially for the large industrial consumers who sign them.

Southern Italian regions. Additional markets and instruments also exist to ensure electricity system security and, with the growing volatility of renewable supply, these are becoming increasingly important (and costly).

[38] As an example, Jarvis et al. (2022) estimated that the impact of Germany's progressive nuclear phase-out between 2012 and 2019 increased the price on the German wholesale market by only 0.6 euros/MWh.

[39] PPAs are contracts, usually long-term, in which a buyer commits to purchase energy, at a set price, from a supplier.

[40] For a description, see: "Più rinnovabili e meno mercato nel settore elettrico europeo", Lavoce.info, 3 May 2024.

[41] It should be noted that, alongside the growing penetration of renewables, there is an increase in episodes, especially in Northern European countries, of particularly unfavorable weather conditions (no wind and overcast skies) that persist over time, also known as "dunkelflaute." To balance the system in these cases, wholesale market costs increase exponentially. The latest ACER report (2025) reports that on December 12, 2024, a "dunkelflaute" episode in Germany caused electricity prices to rise to almost €1,000/MWh (well above the annual average of €81/MWh).

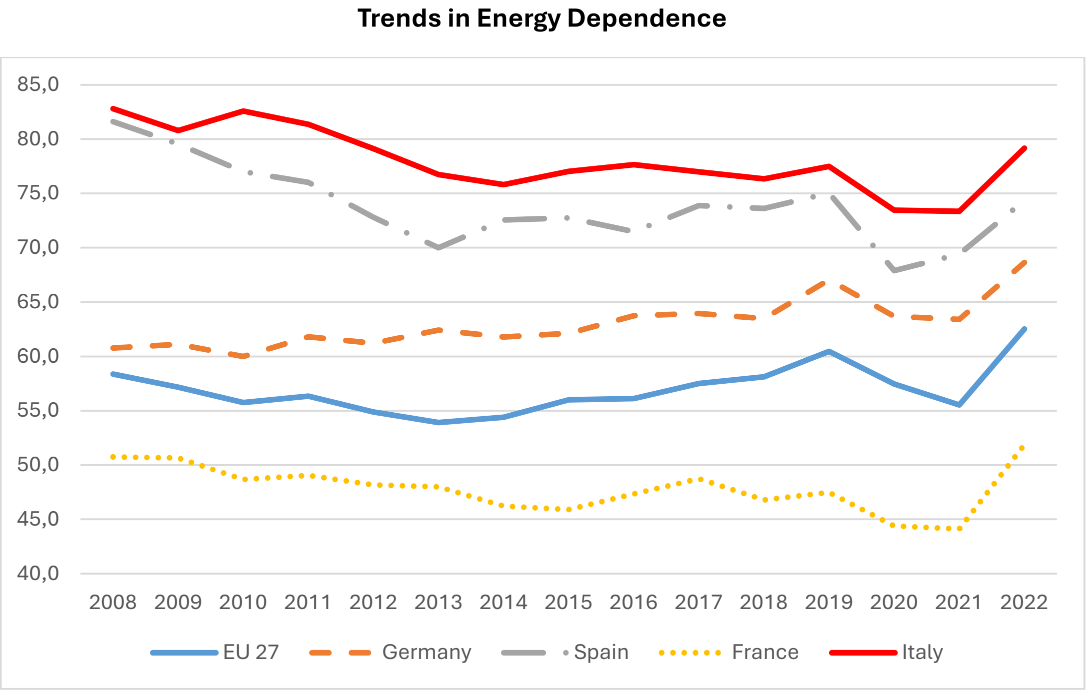

Fig. 3: The figure shows trends over time in energy dependence for a selection of countries and for the European Union. Energy dependence is measured as the ratio of total net imported energy to total primary energy required by each country. Source: authors' elaboration based on Eurostat data.

Finally, it should be noted that the price of electricity on the wholesale market represents only a portion of the final price paid by households and businesses. According to Eurostat data[42], on average over the last three years, it has contributed to no more than 75 percent of the final price paid by households on their bills (80 percent for businesses)[43]. In the case of households, according to ARERA data, a share that has fluctuated between 10 and 18 percent of the final price is used, among other things, to finance subsidies for renewable sources (formerly component A3, now Asos), while the remainder are regulated and fiscal components. Furthermore, until 2023, the price of electricity included a component (A2) to cover the costs of nuclear decommissioning[44].

The presence of regulated or quasi-fiscal components indicates that the final price of electricity is not only a function of production technologies, but it also responds to other objectives defined by the legislator. The significant quota of consumers' final bill covered by these components limits the effect that a reduction in the wholesale price could have on it. If the government were to decide that subsidies to producers are necessary to facilitate the return of nuclear power to the national energy mix, and decided not to burden the public budget with them, these subsidies could be included among the costs paid by consumers, as has already been the case for renewables over the past 15 years, thus placing further pressure on final electricity prices[45]. In short, the construction of nuclear power plants, given

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[42] Source: Eurostat, Electricity prices for household consumers - bi-annual data (from 2007 onwards; table nrg_pc_204) and Electricity prices for non-household consumers - bi-annual data (from 2007 onwards; table nrg_pc_205).

[43] This quota includes both the price of electricity on the wholesale market and the mark-up applied by the supplier.

[44] Similarly, for businesses, Eurostat data shows a component to cover the costs of decommissioning nuclear power plants, inspections, and installation fees. Between 2019 and 2023, Italy, Belgium, and Slovakia were the only European Union countries with this tax in place.

[45] The hypothesis of such a choice is supported by the statements of the Minister of the Environment and Energy Security, Picchetto Fratin ("Pichetto, valuteremo interventi in bolletta per il nucleare", ANSA, 3 February 2025.

the current design of the electricity market, may not have a significant impact on price levels. Rather, it could reduce price volatility for long-term contract holders, helping to stabilize electricity costs.

4.2 Possible Reduction in Energy Dependence

Italy has historically been a net importer of energy products and displays one of the highest levels of energy dependence in the European Union, measured as the ratio of total imported energy to total available energy (Figure 3). According to Eurostat data[46], on average over the past 20 years, 78 percent of the energy consumed in Italy has been imported from non-EU countries, compared with 57 percent for the EU-27 as a whole. Over the last fifteen years, Italy's degree of energy dependence has declined by 4 percentage points, although remaining at high levels, in contrast to the EU-27 overall and to large countries such as France[47] and Germany, where it has increased. The possible use of nuclear power as a tool for diversification and reduction of energy dependence had already featured in debates in previous decades. However, the issue of dependence in the case of nuclear power must also be examined taking into account the required imports of technology and fuel.

Technological Dependence - With regard to technological dependence, the dominant technologies over the past 25 years have been Chinese technologies, developed mainly for the domestic market, and Russian technologies (see Figure 4). Of the 62 reactors under construction worldwide in 2025, with a total capacity of 64.4 GW, half were located in China (29 reactors for 30 GW), followed by India, Turkey, and Egypt (Table 1).

Countries of Origin of Reactors

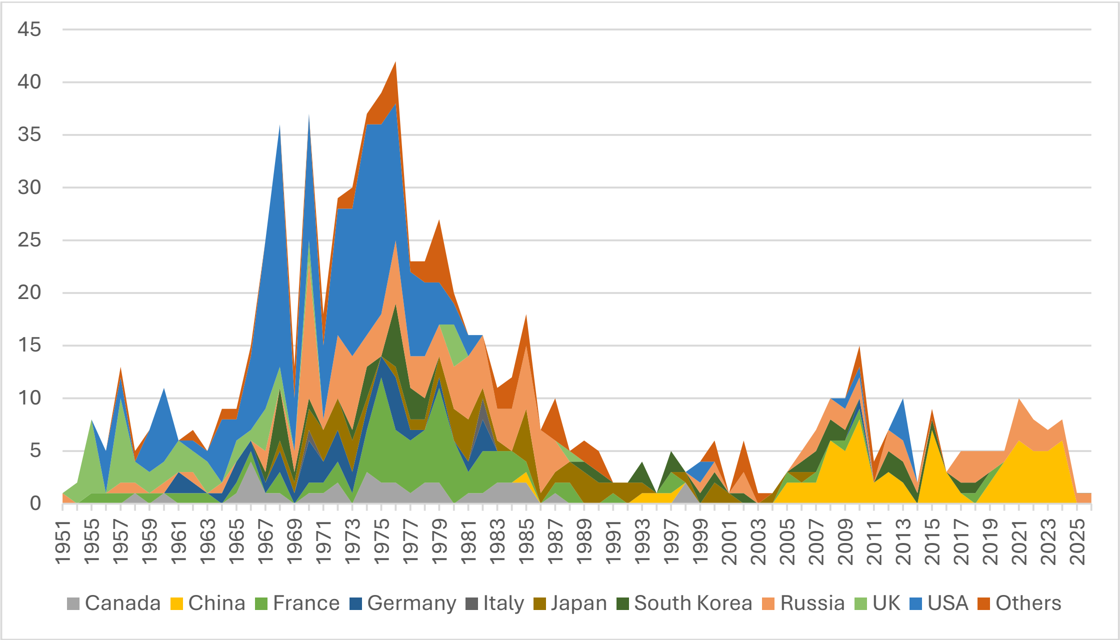

Fig. 4: The figure reports the number of reactors by country of origin and year in which construction of the corresponding plant began. "Others" includes: Argentina, Belgium, Czech Republic, India, Kazakhstan, the Netherlands, Spain, Sweden, and Switzerland. Source: authors' elaboration based on IAEA PRIS data.

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[46] Source: Eurostat, Energy imports dependency, table nrg_ind_id.

[47] It should be noted that uranium imports benefiting France are not included in this indicator, which therefore underestimates French energy dependence (by around 13 percentage points in 2007; Faiella and Lavecchia, 2012).

Russia in particular is currently involved in the construction abroad of reactors totaling more than 23 GW, especially in developing countries such as Bangladesh, Egypt, India, Iran, and Turkey. These agreements involve not only the transfer of technology and know-how, but also financial support during the construction phase. This approach of Russian "nuclear diplomacy," with the Rosatom group[48] acting as a one-stop-shop (i.e., managing projects from financing through final plant implementation), constitutes a strategy aimed at creating long-term lock-in effects for recipient governments.

Table 1: Characteristics of Nuclear Plants in Selected Countries

Country	Number of Operating Reactors	Number of Reactors Under Construction	Average Age of Operating Reactors (years) (1)	Average Construction Time (years) (2)	Average Construction Time Since 1987 (years)
France	56	1	39	5	13
Spain	7	0	40	10	n.a.
Sweden	6	0	43	6	n.a.
Belgium	5	0	46	6	n.a.
Czech Republic	6	0	34	10	16
China	56	29	11	6	6
India	20	7	22	10	10
South Korea	26	2	24	6	6
Japan	13	2	38	5	4
Russia	36	4	31	8	10
United States	94	0	43	9	10
Canada	19	0	42	7	n.a.
Turkey	0	4	0	n.a.	n.a.
Egypt	0	4	0	n.a.	n.a.

Notes: (1) Calculated from the "Commercial Date."
(2) Construction times refer to the period between the start of construction and the "Commercial Date"; plants still under construction (or whose construction was suspended or canceled) and permanently shut-down plants are excluded. Source: Authors' elaboration based on data from the IAEA Power Reactor Information System (PRIS).

These countries remain dependent on Russia over the long term because of financing arrangements, fuel supply, technical expertise, and personnel. The Russian government already exercises this type of

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[48] The Russian government acts through the company Rosatom and its subsidiaries, including: Atomenergomash (engineering company); Atomstroyexport (foreign construction activities); ARMZ and Uranium One (uranium mining); TVEL (which alone controls 38 percent of global uranium conversion capacity and 46 percent of enrichment capacity); and TENEX (uranium and fuel trading).

influence over Armenia, Belarus, Hungary, Slovakia, and Uzbekistan[49], and seeks to extend this model of dependency to Egypt, Iran, and Turkey (Szulecki and Overland, 2023).

In the Italian case, from a technological standpoint it may prove necessary to rely on a foreign partner, with the associated geopolitical and security risks. Although the PNNS expresses a positive assessment of the technological know-how of Italian operators (PNNS, 2025), their experience remains limited, particularly in plant construction.

Dependence on Fuel[50]

Natural uranium production is highly concentrated: 17 countries contribute to it, and in 2022 six of them (Kazakhstan, Canada, Namibia, Australia, Uzbekistan, and Russia) accounted for 90 percent of total output. Kazakhstan alone accounted for 43 percent of global uranium extraction. Several recent geopolitical developments have had a significant impact on the market: the 2022 civil protests in Kazakhstan and the resulting strengthening of the country's ties with Russia; Russia's invasion of Ukraine; and the revocation by Niger of mining permits held by the French company Orano and the Canadian company GoviEx Uranium (respectively in June and July 2024) for two uranium mines in Niger[51], where the military junta, as in other Sahel countries, has been forcing the withdrawal of Western troops (and companies) in exchange for Russian military support.

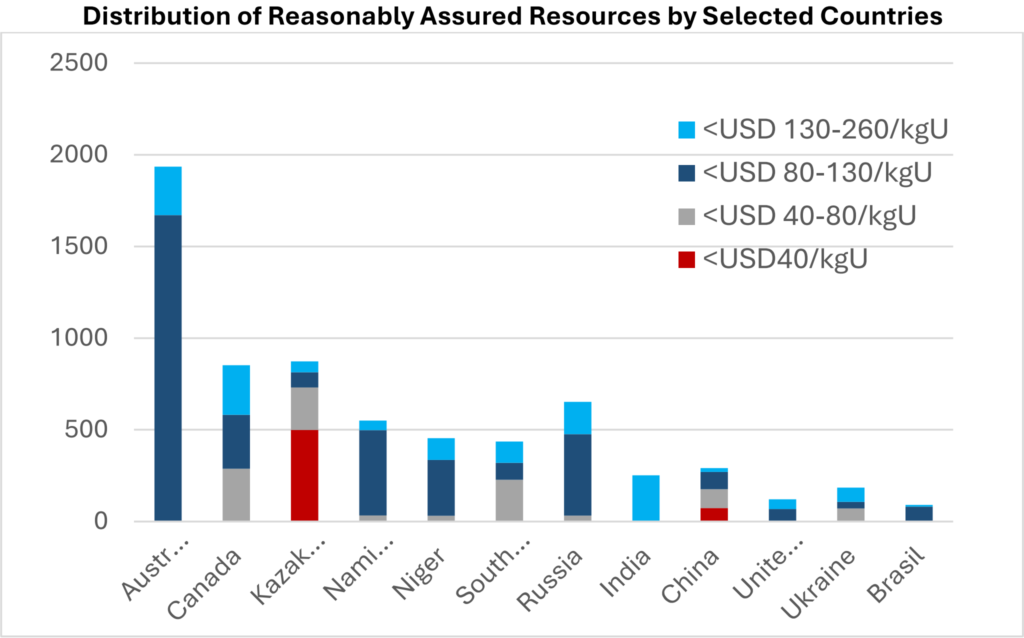
Distribution of Reasonably Assured Resources by Selected Countries

Fig. 5: The figure reports tonnes of identified natural uranium reserves with a significant degree of certainty regarding grade and quantity (so-called reasonably assured resources) by country and extraction cost. Countries were selected according to the relevance of their resource share. Estimates for Niger and South Africa are partial or based on IAEA Secretariat estimates. Source: NEA (2023).

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[49] With the exception of Bangladesh, relations between these countries and the Russian nuclear energy sector date back to the Soviet era. In the case of Uzbekistan, this relationship originated in its role as a supplier of natural uranium, while the other countries were already in more complex dependency relationships.

[50] Regarding global fuel availability, see also Appendix B.

[51] "The 'terrifying' crackdown on mining companies in Africa's coup belt," Financial Times, January 14, 2025.

These developments have generated considerable uncertainty regarding expected production levels (NEA, 2025). Identified uranium reserves[52] are also concentrated in a limited number of countries. At the end of 2022, the latest year for which data are available, 95 percent of reserves extractable at an estimated cost below USD 130/kgU[53] were located in 15 countries, while 60 percent were concentrated in just four (Australia, 28 percent; Kazakhstan, 14 percent; Canada, 10 percent; Russia, 8 percent; NEA, 2025). Kazakhstan in particular accounted for 75 percent of identified reserves with low extraction costs (up to USD 40/kgU; Figure 5). Furthermore, reserves are concentrated in a limited number of sites, as in Australia where 68 percent of the country's reserves (17 percent of global reserves) are located at the Olympic Dam site.

It should also be noted that the development of new uranium mines (which would make it possible to exploit available reserves) requires on average 10–15 years from discovery to actual utilization. Moreover, investment in exploration and production declined by 88 percent between 2014 and 2020 (from approximately USD 2 billion to USD 350 million), although preliminary estimates suggest that between 2021 and 2023 total investment amounted to USD 2.1 billion (NEA, 2025). Expenditure is divided into domestic (within national borders) and foreign. Over the past five years, domestic exploration and production spending has been particularly concentrated in Canada and China, which together accounted for 34 and 25 percent, respectively, of global spending over the period. For most countries, domestic spending increased during 2021–2023 (NEA, 2025). As regards foreign expenditure, according to available information, over the last 15 years it has been carried out by only four countries: China, France, Japan, and Russia (NEA, 2025). In particular, Russian investments in Namibia, Kazakhstan, and Tanzania increased significantly in 2020 and 2021. However, several countries do not report foreign spending; the NEA (2025), for example, notes that Australian and Canadian private companies also frequently engage in such investments.

Raw uranium itself cannot be used directly in reactors, except in certain technologies.[54] The dominant technologies (boiling-water and pressurized-water reactors) require several processing stages, namely conversion, enrichment, and fuel rod fabrication[55]. Uranium conversion is currently carried out in only five plants located in Canada, China, the United States, France, and Russia, with a total capacity of 62,000 tonnes, almost 50 percent above actual demand. Enrichment is carried out mainly by four

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[52] "Identified reserves" refer to uranium deposits identified through a sufficient number of direct measurements to justify pre-feasibility and, in some cases, feasibility studies. These are divided into two subcategories: "Reasonably Assured Resources (RAR)," characterized by fairly precise estimates of uranium grade and quantity, and "Inferred Resources," which require additional analysis before mining activities can begin. Identified reserves are contrasted with "Undiscovered Resources," deposits expected to exist on the basis of geological knowledge from previous discoveries. These are divided into two categories: "Prognosticated Resources," referring to reserves in regions where uranium presence has been confirmed, and "Speculative Resources," referring to reserves in regions where uranium is expected to exist.

[53] By way of reference, in January 2024 uranium reached its highest price in 16 years at USD 275/kgU, whereas between 2016 and 2021 prices fluctuated between USD 52 and USD 78/kgU; at the beginning of 2023 the price stood at USD 130/kgU (IAEA, 2024; NEA, 2025).

[54] Heavy-water reactors, such as the Canadian "CANDU" design, can use raw uranium directly. Boiling-water reactors (BWRs) and pressurized-water reactors (PWRs), which account for 90 percent of installed nuclear capacity, require enriched uranium, i.e., uranium with a higher concentration of the U235 isotope than occurs naturally. This process, which involves the use of centrifuges, is followed by the fabrication of fuel rods assembled into the reactor. After use, fuel rods still contain large amounts of uranium that can be recovered through reprocessing and transformed into new fuel. For further details: Nuclear fuel cycle, World Nuclear News, website consulted on February 13, 2024.

[55] More specifically, the three processing stages consist of:
1. conversion of uranium oxide into uranium hexafluoride;
2. increasing the share of the U235 isotope compared with its natural occurrence (so-called enrichment);
3. fabrication of fuel rods.

companies: China National Nuclear Corporation (15 percent), Russia's Rosatom (40 percent), Urenco (a British-German-Dutch consortium; 33 percent), and Orano (France; 12 percent). Some companies (including Orano and Urenco) plan to expand their capacity (IEA, 2025). Finally, fuel rod fabrication is closely linked to the type of reactor, creating a tight dependence between the plant and a specific supplier although this has diminished over time[56].

Looking specifically at Russia's role in the uranium supply chain, it emerges that in 2020 TVEL, a Rosatom subsidiary, supplied nuclear fuel to 73 Russian-designed reactors (including in Ukraine, Belarus, Armenia, Bulgaria, Finland, the Czech Republic, Hungary, Slovakia, China, India, and Iran), accounting for 16 percent of the world's operational reactors that year (IEA, 2022). Furthermore, in 2020 Russia accounted for 38 percent of global uranium conversion capacity (24 percent of the uranium used in Europe according to Euratom estimates) and 45 percent of enrichment capacity (25 percent of the uranium used in Europe according to Euratom estimates). Most uranium processed by Russia originates from Kazakhstan. Overall, in 2024 the EU imported around EUR 700 million worth of raw uranium, enriched uranium, and nuclear fuel from Russia. The EU's dependence on external actors is particularly acute in two of the four phases of the fuel cycle (raw uranium and fuel rod fabrication), while significant European presence exists only in enrichment activities (Lapenko et al., 2025).

Some of the new small-scale reactors (see box "Selected Technologies: SMRs and AMRs") could offer advantages in terms of fuel supply, while others could create disadvantages. Of the 56 technologies available or concretely under development analyzed by the NEA, around 10 would recycle previously used fuel. According to an estimate by Newcleo (the Italian-French company behind the AMR project known as "LFR-AS-200"), uranium already used by France, if recycled, could cover the country's energy needs for the next 2,000 years (Buono, 2024). However, 50 percent of the technologies analyzed would use HALEU (high-assay low-enriched uranium), with enrichment levels between 5 and 20 percent[57]. This type of fuel was not commercially available in OECD countries in 2023, and its production is concentrated in China and Russia; in some projects, its lack of availability has already caused delays (NEA, 2024). Some countries, however (for example the United States), are increasing production capacity (IEA, 2025).

Italy currently has no active uranium mines and no proven reserves[58]. Furthermore, there are no longer active facilities for uranium enrichment, processing, or fuel rod fabrication. Consequently, Italy would need either to initiate exploration and production activities outside its borders, develop a domestic fuel production chain, or import fuel entirely from abroad.

4.3 Contribution to Decarbonization

According to ISPRA data, national GHG emissions in 2022 amounted to 413 million tonnes of CO_2 equivalent (approximately 0.7 percent of global emissions)[59]. Eighty-two percent of these emissions

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[56] Nuclear Fuel and its Fabrication, World Nuclear News, website consulted on July 1, 2026.

[57] Technologies fueled exclusively by HALEU uranium include: 13 technologies developed in the United States or Canada, 4 in Europe, 3 in Asia, 4 in Russia, and 2 in Africa.

[58] Starting in 1954, several geomineral prospecting campaigns were carried out throughout Italy, particularly in the Alps and Pre-Alps, in search of uranium and thorium. These explorations, conducted by the National Committee for Nuclear Energy (CNEN), formerly the National Committee for Nuclear Research (CNRN), together with Montecatini and ENI, also raised concerns on the part of the United States government, which supplied uranium to operating Italian plants and feared possible military uses. Research focused on the Novazza (Bergamo province) and Val Vedello (Brescia province) sites, geographically close to each other, but the start of extraction activities was repeatedly hindered by local opposition and ultimately abandoned following the 1987 referendum. Furthermore, the estimated reserves at the time—around 1,000 tonnes—would only have sufficed for a few years of operation of the existing nuclear fleet (Candela, 2023).

[59] This estimate excludes emissions from the land use, land-use change, and forestry sector (LULUCF).

were attributable to energy uses. According to Istat's preliminary estimate, GHG emissions declined by 5.3 percent in 2023 compared with the previous year.

The objectives of the European Green Deal are to reduce EU greenhouse gas emissions by 55 percent by 2030 compared with 1990 levels and to achieve climate neutrality by 2050. Given the weight of the energy sector on total emissions, it plays a crucial role in achieving these objectives. For this reason, decarbonization of the energy sector has been the cornerstone of European reforms in recent years.

Nuclear energy can play a significant role in achieving carbon neutrality because it generates emissions that are two orders of magnitude lower than those from fossil fuels (IPCC, 2018; UNECE, 2022; Figure 6) and, unlike renewable energy sources (RES), which are intermittent, it provides baseload supply to the electricity grid. Globally, between 1971 and 2023, electricity generation from nuclear energy—despite accounting for less than 10 percent of total electricity generation—avoided the emission of 72 Gt of CO2 (IEA, 2025). Existing reactors currently avoid emissions of 1.5 Gt of CO_2 per year, around 3 percent of total greenhouse gas emissions. Moreover, greater exploitation of nuclear power (as well as on RES) would bring an indirect benefit by reducing maritime trade, which is responsible for 3 percent of global emissions and devotes one-third of its capacity to the transport of fossil fuels (UNCTAD, 2024)[60].

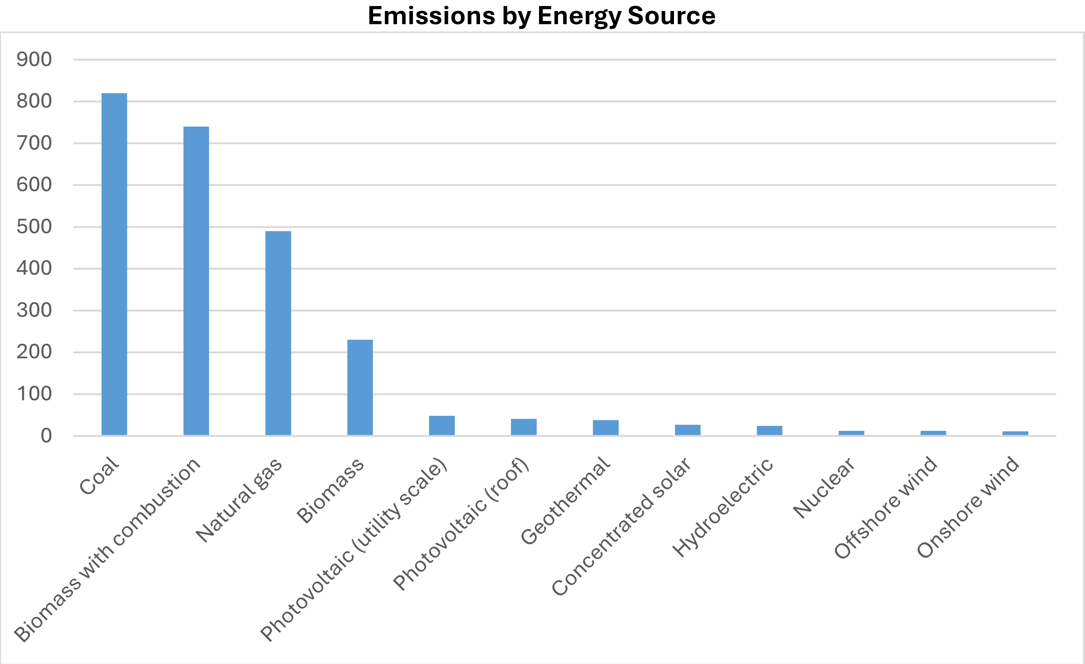

Fig. 6: The figure reports greenhouse gas emissions (gCO2eq per kWh generated) for different energy sources. Source: Intergovernmental Panel on Climate Change – IPCC (2018).

According to the estimates presented in the PNIEC (2024), in a scenario involving greater penetration of renewables into the system, the use of nuclear energy would reduce the need to complement RES with more carbon-intensive flexible sources whose emissions would otherwise need to be offset. By way of counterfactual analysis, the estimate by Errani et al. (2018) is particularly interesting. The authors hypothesize what would have happened in Italy if, following the 1987 referendum, the three operating nuclear plants (Caorso, Trino, and Latina) had remained operational until the end of their useful life and if the Montalto di Castro plant (under construction at the time and later converted into a coal-fired thermoelectric plant) had been completed. The authors estimate that the 3 GW of installed capacity

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[60] Producing one MWh requires approximately 517 kg of coal, 210 m^3 of natural gas, or 24 g of natural uranium.

would have been sufficient to reduce the carbon intensity of Italian electricity generation by 22 percent, avoiding approximately 477 $MtCO_2eq$ of emissions between 1990 and 2016 (for comparison, Italy emitted 399 $MtCO_2eq$ in 2023). They also show that achieving the decarbonization targets for 2030 and 2050[61] without nuclear energy in the energy mix would only be possible at the cost of reduced grid stability.

As already mentioned, despite its lower emissions relative to fossil fuels, nuclear energy does not suffer from several limitations typical of RES, such as reduced flexibility, intermittency, extensive land use, and—in the case of new small-scale plants—location constraints. Since the electricity grid requires a continuous balance between electricity injected and electricity withdrawn, it is necessary to rely on flexible and easily dispatchable plants capable of increasing output during demand peaks and reducing it when demand contracts, or alternatively on storage systems or demand-side adjustments.

Electricity generation from non-traditional RES (particularly solar and wind) depends on prevailing weather conditions and is neither flexible nor dispatchable (i.e., it is subject to intermittent generation). This characteristic implies the need to develop redundancies within the system to compensate for production shortfalls, by installing capacity levels greater than those utilized most of the time, including backup plants (typically gas-fired), smart grids, and control systems, all of which increase electricity system costs borne by end users[62]. Greater penetration of RES into the national electricity system also requires investments to ensure greater system flexibility so that it can promptly adapt to fluctuations in renewable generation. The need to invest in grids and infrastructure is a global phenomenon. According to IEA estimates, hourly flexibility[63] in the global electricity system would need to quadruple between 2020 and 2050 under a net-zero-emissions-by-2050 scenario (IEA, 2022).

Once construction is completed, nuclear energy could provide the grid with both baseload supply and, with appropriate modifications, the flexibility it requires. Existing large nuclear plants are not necessarily equipped with technologies enabling them to modulate electricity generation immediately. However, with minimal technical modifications, most operating reactors can be adapted to do so (IEA, 2022). The technique most widely used in France is so-called "core ramping," which involves reducing the number of neutrons used in the fission process. According to PNNS (2025), core ramping enables French nuclear plants to vary output by 10 percent within a few minutes and by up to 80 percent over several hours. However, over the long term this technique reduces the reactor's ability to increase output rapidly and subjects the fuel to stress that shortens its operational life, resulting in cost reductions that are less than proportional to the reduction in electricity generated (NICE Future, 2020). Furthermore, doubts remain regarding the applicability of this technique, given that France continues to rely on a substantial combined-cycle gas fleet operating for a limited number of hours to ensure system stability[64].

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[61] The decarbonization targets in force in 2018, and therefore considered by the authors, were: 1. closure of coal-fired power plants by 2030; 2. reduction of CO_2 emissions by 80 percent by 2050 (relative to 1990 levels). It should also be noted that the authors consider only large third-generation nuclear technology.

[62] Another potential problem associated with RES is the reduced level of inertia. Electricity plant turbines generate both electricity and inertia, which together contribute to grid frequency stability. RES, especially solar power, do not provide this contribution and, as penetration increases, an important source of system stability is lost. Inertia can be "simulated" by equipping renewable plants with appropriate technologies (e.g., so-called "grid-forming" inverters) that autonomously regulate frequency instead of receiving it from the grid. The installation of sufficient storage capacity (e.g., electrochemical storage systems or pumped-storage hydropower reservoirs) can also contribute to system stability. Nuclear power, by contrast, with its large turbines, provides greater inertia than other technologies (OIES, 2023).

[63] Hourly flexibility is especially important in systems characterized by greater penetration of photovoltaic plants, whereas wind power requires greater long-term flexibility (over weeks or even seasons).

[64] "La realpolitik di Meloni dietro il tacito 'no' al nucleare," Staffetta Quotidiana, February 7, 2025.

As a thermal energy source, nuclear power can adopt many of the strategies used to make thermal plants more flexible. One such strategy is the partial or total diversion of steam before it reaches the turbines used for electricity generation. Applied to nuclear energy, this approach would allow rapid modulation of output, although it would require excess steam to be used for other off-grid applications to avoid waste (NICE Future, 2020). AMRs currently under design feature a broader temperature range than "traditional" technologies, thereby expanding the range of possible uses beyond electricity generation and potentially contributing to the decarbonization of hard-to-abate sectors (IEA, 2025; Figure 7)[65]. Among these, the steel industry could benefit particularly strongly. In Italy, 85 percent of steel production consists of secondary steel (CDP, 2024) produced using electric furnaces (compared with around 40 percent in other European countries), which require access to low-cost, low-emission electricity throughout the day (PNNS, 2025).

Moreover, the smaller size of new reactors offers greater flexibility in siting, enabling additional off-grid applications.[66] By contrast, the location of electricity generation plants based on RES depends strictly on the availability of the natural resources required to power them (this is particularly true for wind energy; see Alpino et al., 2025). The wide variety of applications beyond electricity generation, together with the fact that plants consist of multiple independent modules, would provide the grid with the flexibility it requires (IEA, 2022).

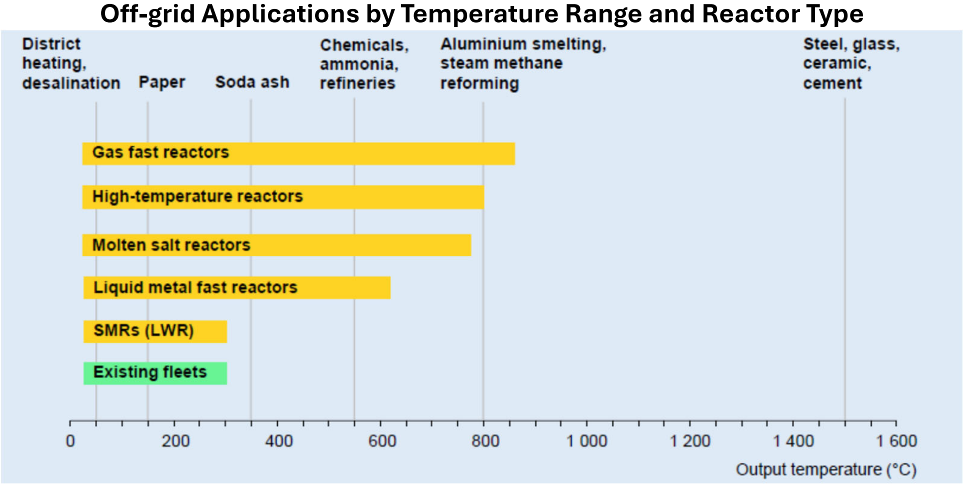
Off-grid Applications by Temperature Range and Reactor Type

Fig. 7: The figure reports, by reactor type and achievable temperature range, the possible off-grid applications (combined heat and power) of nuclear energy production. Source: IEA (2025).

Nuclear power is the energy source associated with the lowest land use (UNECE, 2022). Over its entire life cycle, it requires on average 0.52–1.02 m^2/year per MWh, compared with 0.6–1.2 m^2/year for onshore wind, between 7.6 and 40 m^2/year for ground-mounted solar photovoltaics, and between 1.1 and 21.7 m^2/year for rooftop photovoltaics. According to PNNS estimates (2025), moreover, for the same amount

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[65] Reactors based on LWR technology currently reach maximum temperatures of around 150°C. AMRs under design are expected to reach temperatures ranging from 100°C to 850°C (NEA, 2024). Examples of alternative uses include replacing fossil fuels in cogeneration-based district heating systems, hydrogen production, and commercial applications in the chemical, steel, ammonia, and hydrogen-based synthetic fuel industries (IEA, 2022).

[66] Examples include mines or facilities isolated from the grid that currently rely on diesel systems (which are costly and polluting). Alternatively, some reactors under design and one operational next-generation reactor are specifically designed either to be built on ships or to produce hydrogen directly where it will be used, thereby reducing the high costs of hydrogen transport and distribution (IEA, 2022).

of electricity generated, and considering utilization factors[67], the land used by an onshore wind plant or a photovoltaic plant would be respectively 450 and 1,560 times greater than that used by a nuclear plant.

According to IEA assessments (2022), globally achieving net-zero emissions by 2050 under a scenario in which nuclear energy is scarcely used[68] would entail higher overall costs, greater use of critical minerals both for plants and infrastructure, and greater exposure of end-user electricity bills to coal and gas prices.

Focusing specifically on Italy, according to PNNS estimates reported in the PNIEC (2024), the use of a nuclear share in electricity generation would reduce by EUR 17 billion the cost of achieving the net-zero-emissions target by 2050.

Europe's Vision

In the European vision, nuclear energy falls within the range of energy sources capable of contributing to the transition (at least under certain conditions). The European Union has recently acknowledged the important role that nuclear energy could play in achieving decarbonization objectives. This recognition could facilitate the expansion of this energy source.

Within the framework of achieving the objectives outlined in the Green Deal, the EU created the "EU Taxonomy," a common classification system for defining "sustainable" economic activities. The system aims to provide clear guidance to firms and investors, enabling them to identify activities that contribute to the green transition. The EU Regulation introducing the Taxonomy entered into force in July 2020. In December 2021, the first Delegated Act was adopted, defining sustainable economic activities compatible with the first two objectives (climate change mitigation and adaptation) and the related technical screening criteria (TSC) required to verify Taxonomy alignment. Three further Delegated Acts followed. With the Complementary Climate Delegated Act, published on July 15, 2022, certain activities related to nuclear energy generation were included among those considered "sustainable" under the EU Taxonomy, namely:

- research, development, testing, and implementation of nuclear plants based on advanced technologies[69];
- construction and operation of new nuclear plants (until 2045)[70];
- electricity generation from nuclear energy using existing plants (until 2040)[71].

All these activities are subject to fairly stringent technical screening criteria. Among other things, at the time of project approval, the following conditions must apply in the Member State where the plant is or will be located: an operational fund for waste management and decommissioning must already exist; a

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[67] Assumed equal to 90 percent for nuclear power, in line with IAEA data (2024); 20 percent for onshore wind; and 13 percent for photovoltaics, consistent with average values recorded in Italy by Terna.

[68] The scenario thus defined assumes that in Western countries plant operating lifetimes are not extended and no new projects are initiated, while in emerging economies the average rate of nuclear construction remains equal to that observed between 2016 and 2020. It also assumes the availability of the most mature technologies currently available (including SMRs).

[69] Delegated Regulation 2022/1214, Annex I, point "4.26. Pre-commercial stages of advanced technologies to produce energy from nuclear processes with minimal waste from the fuel cycle".

[70] Delegated Regulation 2022/1214, Annex I, point "4.27. Construction and safe operation of new nuclear power plants for the generation of electricity or heat, including for hydrogen production, using best-available technologies".

[71] Delegated Regulation 2022/1214, Annex I, point "4.28. Electricity generation from nuclear energy in existing installations".

disposal facility for very low-, low-, and intermediate-level radioactive waste must already be operational; and a detailed phased plan must exist to ensure the availability by 2050 of a disposal facility for high-level radioactive waste (for further details on radioactive waste categories, see Section 5). In addition, the Taxonomy sets out a series of criteria concerning emissions, pollution, and sustainable water use, in accordance with the "Do No Significant Harm" principle on which it is based. On February 12, 2025, the European Commission presented its work programme for the year, stating among other things that it intended to simplify the Taxonomy. At present, however, it is not yet possible to determine whether or how this revision will affect nuclear technology[72].

In March 2023, within the framework of the "Green Deal Industrial Plan," the European Commission presented the "Net-Zero Industry Act," which introduces a series of advantages for manufacturing industries producing net-zero technologies or their components. The aim is to scale up European production to achieve at least 40 percent domestic production by 2030. The list of technologies benefiting from the Act also includes technologies related to nuclear energy generation (including those linked to uranium processing).

5. Critical Issues Associated with Nuclear Power Generation

The reintroduction of nuclear power in Italy may raise several challenges, concerning its environmental impacts, its funding and the potential opposition from public opinion.

5.1 Waste Management and Water Use

The first crucial issue concerns the management of waste produced during plant operations. The classification of radioactive waste deriving from electricity generation, other industrial processes, or medical applications is based on radioactivity levels and decay times and consists of six main categories defined by the IAEA (2009)[73]. The first four groups include low-radioactivity/short-decay-time waste (EW, VSLW, VLLW, and LLW), which account for 92 percent of total waste volumes worldwide. Intermediate-level waste (ILW) and high-level waste (HLW) account for the remaining 8 percent of volumes, of which only 0.13 percent corresponds to HLW, although this category contributes to 95 percent of total radioactivity (IAEA, 2022).

At the end of 2023, Sogin and Nucleco—the companies responsible for the decommissioning of closed plants and the management of radioactive waste in Italy—had inventoried 20,346 m^3 of radioactive waste, of which 88 percent was very-low-/low-level waste and 12 percent intermediate-level waste. This included both material deriving from nuclear electricity generation and medical, industrial, and research-related waste. No high-level waste was present (Sogin, 2024). In the future, however, waste from the reprocessing of 938 tonnes of irradiated nuclear fuel will return to Italy, corresponding to 35.86 m^3 of high-level waste and approximately 47.58 m^3 of intermediate-level waste (excluding transport and storage containers) from France and the United Kingdom (PNNS, 2025). Italy currently lacks facilities for storing high-level waste, which requires geologically stable deep repositories located hundreds of meters underground (IEA, 2009). Some of the new technologies under development (see the box "Selected Technologies: SMRs and AMRs") envisage innovative strategies for recycling radioactive waste, thereby reducing its toxicity. On the other hand, some technologies may generate new waste categories requiring redesigned storage systems (NEA, 2024).

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[72] European Commission, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions, Commission work programme 2025. Moving forward together: A Bolder, Simpler, Faster Union.

[73] For a detailed description, see Appendix C (in Italian), "Decommissioning e gestione delle scorie" in Faiella and Lavecchia (2012).

Another particularly relevant issue, especially in light of ongoing climate change and the resulting reduction in water availability, concerns water consumption. To ensure both plant safety and the production of steam necessary for electricity generation, most nuclear plants currently in operation use purified water[74] both as moderator and coolant[75]. Globally, in 2021 energy uses accounted for 10 percent of total freshwater consumption, corresponding to 54 billion cubic meters (IEA, 2023). Electricity generation alone was responsible for approximately one-third of this consumption.

In the case of nuclear energy, 97 percent of the water withdrawn in France – where nuclear energy accounts for 65 percent of domestic electricity generation – is subsequently returned to the water bodies from which it was taken. The water effectively consumed (the remaining 3 percent) contributes significantly—around 12–14 percent—to France's total water consumption[76]. With rising summer temperatures, there have been cases of French nuclear plants reducing or halting operations because the water returned to rivers would have exceeded legal temperature limits (thermal pollution)[77], thereby causing damage to aquatic flora and fauna[78].

In summary, nuclear energy has environmental impacts in terms of waste generation and water resource use. Given the high uncertainty and variability regarding the characteristics of new technologies, it is difficult to determine the impacts that a possible reintroduction of nuclear energy based on such technologies might entail in these respects.

5.2 Financing

A second crucial issue in any discussion concerning the return of nuclear power to Italy concerns financing methods and, consequently, the cost of capital. Financing nuclear plants is among the most expensive types of projects for a country, comparable to major transport infrastructure projects but characterized by even greater uncertainty and risk (IEA, 2025). The scale of required investment implies a financial effort that is difficult to sustain exclusively through private market actors. Furthermore, constructing plants in a context characterized by limited expertise and know-how may generate delays that investors would ultimately bear, requiring higher returns to compensate for risk premiums (which would increase financing costs). Finally, regulatory risk that may arise in the absence of clear and precise authorization procedures and a credible political commitment further increases uncertainty and therefore the cost of capital[79].

Securing bank financing for projects of this type is extremely difficult. First, the financial commitment—besides being substantial and often subject to significant unforeseen cost increases—extends beyond the normal time horizons of corporate bank lending. Standard nuclear plants currently require between 10 and 20 years from the start of construction before generating initial revenues, well beyond the usual evaluation periods for this type of financing. Resorting to multilateral development banks as a de-risking strategy, especially for developing countries, is also difficult unless accompanied by private financing

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[74] Seawater can only be used after appropriate demineralization processes in order to avoid corrosion and other processes harmful to plant safety.

[75] Other reactor designs, including first-generation models, use alternative substances as moderators or coolants, such as graphite, high-pressure gas, lead, etc. However, boiling-water reactors (BWRs) and pressurized-water reactors (PWRs), which use purified water both as coolant and moderator, remain the dominant technologies today.

[76] "How much water do nuclear power plants consume? – 2023 edition," SFEN, August 17, 2023.

[77] European Directive 2006/44/EC establishes the maximum temperature differential permitted between river water and the water discharged back into rivers by nuclear plants, in order to protect aquatic flora and fauna.

[78] "France Cuts Nuclear Output as Heat Triggers Water Restrictions," *Bloomberg*, July 13, 2023.

[79] In 2024, 40 percent of reactors under construction experienced delays due to technological, financial, or geopolitical factors (for example, in the case of plants under construction using Russian technology), while 60 percent of projects completed on schedule were located in China (Schneider and Froggatt, 2024).

(possibly involving greater risk-sharing by the public partner), given that the value of the investment in a single plant exceeds the annual energy lending volumes of the eight largest multilateral banks combined[80].

Alternatively, resources could be raised on financial markets through the issuance of dedicated debt instruments such as green bonds or other sustainable debt instruments. By early 2025, green bonds amounting to a total of USD 5 billion had been issued for the purpose of extending the operating life of existing nuclear plants or refinancing nearly operational facilities (IEA, 2025). In Canada, such instruments have also been issued by electricity utilities, while the federal government included nuclear energy sources within its Green Bond Program starting in November 2023[81]. In France, Finland, and the United States, green bonds issued by plant operators in recent years have likewise been used to finance plant life extensions or new projects. Within the European Union, the inclusion of nuclear energy within the taxonomy of sustainable activities could facilitate support from the European capital markets for such projects.

However, the attractiveness of these financial instruments remains strongly limited by the riskiness of such investments, particularly in the case of new-build plants. Moreover, given the very long-time horizons involved, it is necessary to establish—also through contractual clauses—how inflation risk will be managed once the plant begins generating revenues, in order to avoid erosion of investment value. In summary, mitigating these risks ex ante and encouraging private investor participation would require offering as stable and widely supported a regulatory framework as possible, thereby increasing investor certainty and improving predictability of cash flows, including through instruments such as power purchase agreements (PPAs), contracts for difference (CFDs), or regulated asset base (RAB) models[82].

In all likelihood, direct or indirect State involvement would still be necessary, through financing, subsidies, incentives, regulation, or participation via State-controlled companies. The latter enjoy a competitive advantage relative to private companies because they benefit from an implicit guarantee that reduces their cost of capital. Unsurprisingly, State involvement predominates in the construction of traditional nuclear plants[83]. In particular, State-controlled utilities contribute significantly to nuclear energy investment in developing countries, emerging economies, and even advanced economies (see Figure 8; IEA, 2025).

Such involvement generally takes the form of equity participation, while still leaving room for private financing, especially in advanced economies or in projects for life extension of existing plants (for which funding can also be raised through targeted issuance of instruments such as green or transition bonds).

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[80] The World Bank financing granted in 1959 for construction of the Garigliano plant in Italy represents the first—and so far only—nuclear power plant construction project financed by the institution (see Section 2 and Rigano, 2013).

[81] "Opinion: Financing the future of clean energy—Green bonds in the nuclear sector," *Nuclear Newswire*, October 4, 2024.

[82] Under a contract for difference, the plant constructor/operator receives from the State the difference between the strike price and the wholesale electricity price (if positive); conversely, if the wholesale price exceeds the strike price, the operator pays the difference to the Treasury. Under the regulated asset base (RAB) model, the regulatory authority remunerates an estimate of the "efficient" investment through tariffs over a certain number of years.

[83] Extending the operating life of existing plants is instead easier to finance through market-based resource mobilization.

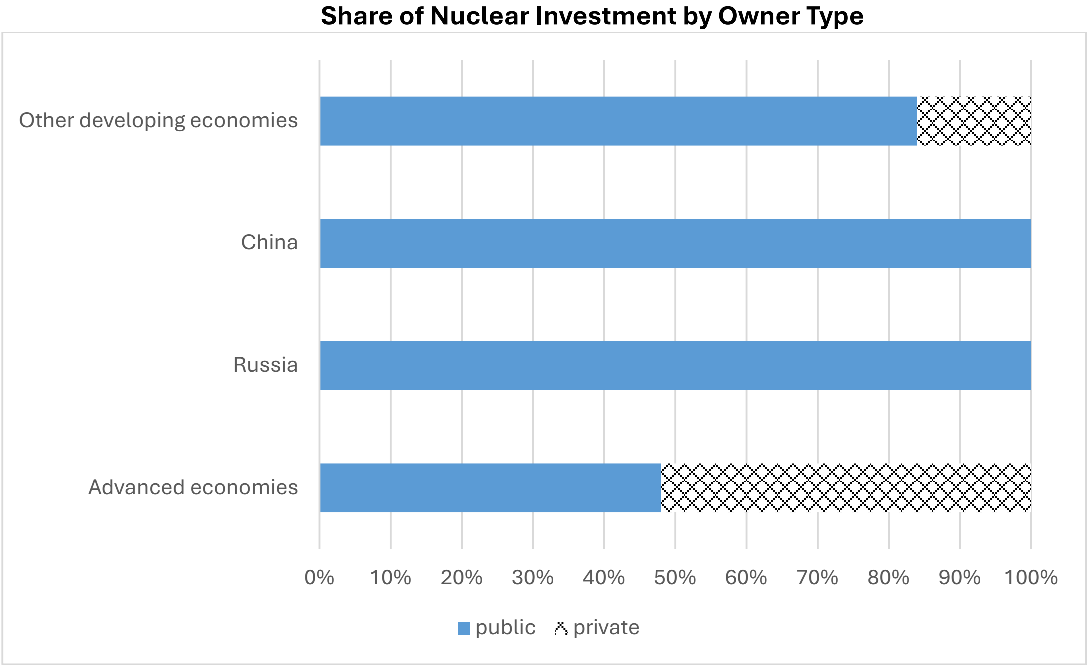

Fig. 8: Share of nuclear investment by owner type and region. Data refer to 2023. Advanced economies include: France, Slovakia, Hungary, Finland, Belgium, Bulgaria, the Czech Republic, Slovenia, Switzerland, South Korea, Sweden, Spain, Romania, the United States, the United Kingdom, Canada, Japan, Mexico, and the Netherlands. Since advanced economies include the United States, the share of public investment in Europe is likely higher than represented here. "Other developing economies" includes: Ukraine, Belarus, Armenia, the United Arab Emirates, Pakistan, Argentina, Taiwan, South Africa, India, Brazil, and Iran. Source: IEA (2025).

The lower costs and shorter construction times associated with plants based on new modular technologies could make investment projects more accessible, broadening the range of potential investors and reducing the need for public intervention (IEA, 2022).

More generally, the introduction of new small-scale technologies such as SMRs could partly mitigate high costs and, above all, reduce uncertainty and risk. Cost reductions could stem from the fact that reactors are designed for serial production, whereby the design of the first prototype is reused for subsequent units, thereby benefiting from learning economies (similarly to the French experience under the Plan Messmer). A further reduction in costs, for these plants composed of multiple small modules, could derive from the possibility of initiating electricity generation as soon as construction of the first module is completed. This would shorten the interval between the start of construction and the arrival of initial revenues (which, as noted, is particularly long in the case of traditional nuclear plants), thereby making investment payback periods more compatible with the practices of institutional investors and the banking sector. Furthermore, these revenues could then be used to finance the construction of subsequent modules, reducing capital costs. However, the scientific literature does not provide a unanimous assessment regarding the advantages listed above and their real impact on costs, particularly in terms of offsetting diseconomies of scale associated with smaller plant capacities (Mignacca and Locatelli, 2020). For example, serial production sufficient to offset diseconomies of scale will only materialize if there is a sufficiently large market capable of absorbing high levels of production (NEA, 2025). Additional cost reductions could derive from greater use of passive safety systems and the possibility of implementing a form of brownfield investment[84].

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[84] This refers in particular to replacing coal-fired plants with SMRs. This would make it possible to exploit existing infrastructure, reducing overall project costs while advancing the decarbonization process. According to an

5.3 Public Opposition

A third factor that could hinder the return of nuclear energy in Italy is opposition from public opinion. Throughout history, Italy's nuclear energy program has twice been halted by referenda (see Section 2). Moreover, even if the reintroduction of nuclear energy was accepted by a majority of the population, actual plant construction could still be obstructed by local opposition (the so-called Not-In-My-Back-Yard, or NIMBY, effect).

According to a Eurobarometer survey conducted in November 2022, 55 percent of Italians believed that, in light of the war in Ukraine, European countries should accelerate investment in nuclear energy (this percentage rose to 86 percent in the case of renewable energy investments; Eurobarometer, 2022). In a more recent Eurobarometer survey conducted between April and May 2024, 32 percent of Italians believed that achieving climate neutrality by 2050 would require prioritizing nuclear energy (a percentage in line with the European average, but significantly lower than support for alternative solutions; Eurobarometer, 2024)[85]. In a survey released in April 2024 and conducted by the company SWG, 51 percent of respondents stated that they would vote in favor of reintroducing nuclear energy in Italy in the event of a consultative referendum (24 percent "definitely"), while 26 percent would vote against[86]. In a survey conducted by Ipsos on behalf of Legambiente in November 2024, 43 percent of respondents opposed to nuclear energy, whereas 38 percent believed that it should be considered if safer technologies than current ones became available[87].

The Ipsos survey also provides some insight into the motivations underlying Italian public opinion. Safety appears to be a concern for only a limited portion of the population. Between 70 and 75 percent of respondents (depending on the technology considered) who expressed an opinion on the issue regarded nuclear plants as safe. Fifty-two percent of respondents believed that safety standards for waste management were sufficiently high. In addition, around 50 percent of respondents opposed to plant construction stated that they would be willing to reconsider their position if there were collective benefits, reductions in electricity prices, or reassurances regarding environmental benefits (compared with other energy sources) in terms of land and natural resource use.

The opposition appears to derive partly from the aforementioned NIMBY effect: the percentage of people in favor of new plants increased by around 20 percentage points if the plants were located far from their homes. This result is consistent with the Legambiente survey.

The Ipsos survey also revealed a perceived lack of public information. Only slightly more than 30 percent of respondents considered themselves informed about new technologies, safety, and waste management, while 57 percent believed that citizens should receive adequate information on these issues.

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esteem, in the United States this approach could reduce nuclear plant construction costs by approximately one-third (IEA, 2025).

[85] Sixty-two percent of respondents believed that energy sources should be diversified, for example through renewables; 51 percent believed that energy efficiency improvements should be pursued; and 46 percent believed that electrification based on low-emission energy sources was the best solution.

[86] https://primapavia.it/media/2024/04/Nucleare-italiano-per-i-cittadini-le-imprese-e-il-territorio-2024-04-15.pdf .

[87] https://www.legambiente.it/wp-content/uploads/2024/11/Forum-QualEnergia-sondaggio-ipsos-2024.pdf#page=21 .

6. Conclusions

This paper analyzes the potential advantages and point of concerns of a return of the nuclear energy in Italy and outlines the strategy recently indicated by the Italian Government. The results of this analysis confirm and update a previous study (Faiella and Lavecchia, 2012).

The analysis confirms that nuclear electricity generation, as a substitute for fossil fuels, could play a role in reducing electricity price volatility (particularly thanks to the possibility of using long-term contractual arrangements), although it would unlikely reduce final price levels significantly. This is mainly due to the structure of the electricity market, as well as to the composition of tariffs and levies that contribute to determining the final electricity price paid by consumers.

With regard to energy dependence, the effects would be ambiguous. On the one hand, the introduction of nuclear power in Italy could reduce imports of fossil fuels and electricity (predominantly nuclear-generated electricity from France); on the other hand, it would require imports of both fuel and technology for nuclear energy generation. At the global level, uranium availability—including reserves in traditionally allied countries such as Australia and Canada—is sufficient even under scenarios involving significant growth in installed nuclear capacity and would therefore not constitute a critical issue. Conversely, the processing, enrichment, and fuel rod fabrication stages are concentrated in a limited number of facilities and largely located in countries characterized by elevated geopolitical risk (primarily Russia). It would therefore be necessary to participate in the ongoing efforts to strengthen the Western nuclear fuel supply chain. As regards technological dependence, over the last 25 years leadership in nuclear plant construction has shifted away from Europe and North America toward, mainly, China and Russia. In this case as well, existing resources—in terms of human capital and industrial firms—would need to be integrated, connected to the educational and university systems, and linked to the few Western companies still active in nuclear plant construction, in order to develop and acquire the necessary know-how and reduce dependence on geopolitically more distant countries.

Finally, the analysis confirms the role that nuclear energy could play in achieving decarbonization objectives, which in the meantime have become more ambitious. Nuclear power combines some of the advantages of renewables—namely low life-cycle greenhouse gas emissions—with those of fossil fuels, particularly the ability to provide baseload supply, flexibility (especially in the case of new modular technologies), and locational flexibility (again, in the case of certain new modular technologies). It also offers advantages superior to all other low-carbon sources in terms of land use. These benefits must, however, be weighed against the significant environmental impacts arising mainly from waste management processes. Given the current orientation toward technologies still at the experimental stage, it is not yet possible to fully assess these impacts. Moreover, Italy has not yet initiated the lengthy process required for the construction of a national repository (or repositories) for storing nuclear waste generated in the past and that which will continue to be generated in the future from industrial and medical applications, irrespective of whether nuclear electricity generation resumes.

The Western nuclear industry is slowly regaining momentum after more than twenty years of near-total inactivity, but continues to face high costs, often subject to significant overruns, as well as considerable delays in implementation. In Italy too, where the history of nuclear energy has been marked by political uncertainty and public opposition culminating in two referenda (1987 and 2011) over the last 40 years, nuclear power is once again being considered as a possible component of the national energy mix.

The PNIEC (2024) envisages the installation of a total nuclear capacity of approximately 8 GW between 2030 and 2050, which would cover around 11 percent of electricity demand by 2050 (with the possibility of increasing capacity to 16 GW). In order to achieve these objectives, the Government has discussed a measure outlining a strategy to reopen public debate on the use of nuclear energy.

This strategy appears to focus on new small-scale modular or advanced fission technologies, in addition to future technologies potentially deriving from nuclear fusion. The former, which currently display a more advanced stage of development, could prove particularly innovative thanks to reduced construction times and investment costs, together with serial production and standardization, which should help limit uncertainty and lower financing costs. This could make such investments more attractive to the private sector, thereby reducing the role of the State. Furthermore, factors such as lower water and land consumption, combined with greater flexibility of use, could make these technologies an attractive solution for Italy.

However, the current stage of development of these technologies does not yet provide guarantees that these benefits will effectively materialize. Moreover, the delays that have characterized the construction of the few operational (in Russia and China) or under-construction prototypes suggest that caution is warranted regarding the timelines within which new modular reactors will become available. In addition, the construction times of the first prototypes must be supplemented by the time required to adapt the supply chain (both for plant components and fuel) to serial production, which, it should be emphasized, has not yet begun for any of the technologies currently under development or available (NEA, 2024). Finally, consideration must also be given to the time needed to adapt technologies to the safety criteria that will be defined in Italy (criteria that could themselves hinder serial production if they are not aligned with those adopted in other countries where the technologies will be deployed). All these factors suggest that a scenario involving the installation of new nuclear technologies in Italy already within the next decade may be excessively optimistic.

In light of these uncertainties, a prudent approach is required when considering the role that the reintroduction of nuclear energy could play in achieving the decarbonization objectives set by the Government, while also evaluating and preparing backup strategies. In this sense, broadening the debate on available options—stimulated by recent government initiatives and open also to technologies still under development—offers potential advantages, as long as it does not hinder or slow the progress of other strategies aimed at diversifying the energy mix, particularly the expansion of renewable energy sources. Finally, it must be acknowledged that, regardless of the technical solution adopted, the construction of new nuclear plants will almost certainly require some form of public participation, either directly as investor through financing or subsidies, or indirectly through State-controlled companies.

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Appendix

A. Projects Selected by the European Industrial Alliance on SMRs

The Alliance also envisages the creation of working groups focused on specific SMR development projects that meet certain criteria[88]. In October 2024, the European Industrial Alliance on SMRs selected an initial group of development projects for new technologies that meet the criteria it has outlined:

- **EU-SMR-LFR**: a lead fast nuclear reactor using mixed oxide fuel (MOX), a fuel made from spent uranium and plutonium (but currently produced by only a few suppliers; NEA, 2024). The project (based on a Westinghouse design) is being developed by the Italian company Ansaldo Nucleare, the Belgian SCK-CEN, the Italian ENEA, and the Romanian RATEN.
- **CityHEat**: a water-based microreactor designed for district heating that uses fuel already produced industrially. The project is being carried out by the French company Calogena and the Danish company Steady Energy.
- **Project Quantum**: a pressurized-water microreactor that uses fuel already produced industrially. The project is being led by the U.S. company Last Energy.
- **European LFR AS Project**: a lead reactor that uses MOX fuel. The project is being developed by the Italian-French company Newcleo (which plans to build a facility for self-production of fuel).
- **Nuward**: a water reactor that uses fuel already produced industrially. The project is being carried out by the French company EDF[89].
- **European BWRX-300 SMR**: a boiling-water reactor based on the design of the reactor developed by the Japanese-U.S. company GE-Hitachi, using fuel already produced industrially. The project is being led by the Polish company OSGE.
- **Rolls-Royce SMR**: a pressurized-water reactor (with three loops) whose design is being developed by the British company Rolls-Royce SMR Ltd. This reactor also uses fuel already produced industrially.
- **Nuscale VOYGR SMR**: a pressurized-water reactor based on the design of the U.S. company Nuscale. The project is being led by the Romanian company RoPower Nuclear S.A. The fuel it uses is already produced industrially.
- **Thorizon One**: a molten salt nuclear reactor that recycles spent fuel and whose design is being developed by the Dutch company Thorizon.

B. Uranium: A Depleting Energy Source?

Global demand – At the beginning of 2023, global uranium demand stood at approximately 59,000 tonnes (on average, 150 tU per GWe of installed capacity). Demand is expected to grow sharply in Asia (and in China in particular), where most of the capacity under construction is concentrated. Forecasts prepared by the IAEA and the NEA for 2050 indicate that global demand should increase reaching an amount between 90,000 and 142,000 tonnes per year by 2050 (under the low-demand and high-demand scenarios, respectively; NEA, 2025), representing a sharp increase compared with the previous version of the report. In 2022, primary reserves covered 85 percent of demand (up from 79 percent in 2020),

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[88] See the appendix I of the "Terms of Reference" of the European Industrial Alliance on Small Modular Reactors.

[89] The Italian companies Edison, Ansaldo Energia, Ansaldo Nucleare and ENEA take part to the project as advisors while EDF is taking agreements with Società Informazioni Esperienze Termoidrauliche (SIET) and ENEA to start an experimental project in Piacenza, Italy (Dodaro and Tarantino, 2023).

while the remainder was covered by secondary reserves[90]. It is worth noting that uranium production exceeded demand from 1950 to 1990, including for military needs, thereby creating stocks (held both by governments and by the companies owning the plants) and reducing pressure on supply, which has since remained below demand (with secondary sources used to bridge the gap). In the EU in 2020, reserves were sufficient to cover almost two years of demand (42,000 tonnes; NEA, 2023).

Supply – Uranium production in 2023 amounted to 54,000 tonnes (NEA, 2025). It recovered after a decline over the previous five years, initially due to a deterioration in market conditions and later to the Covid-19 pandemic. At the end of 2022, the latest year for which data are available, identified uranium reserves extractable at an estimated cost below USD 130 per kgU[91] amounted to 5.9 million tonnes, down from 2021 (NEA, 2025). If a higher extraction cost is considered (up to USD 260 per kgU), identified reserves rise to nearly 8 million tonnes.

According to NEA assessments (2025), identified available reserves are sufficient to cover demand up to 2050, even in a scenario of very high nuclear deployment, consuming approximately 50 percent of identified reserves with extraction costs below USD 130 per kgU and 35 percent including reserves with extraction costs up to USD 260 per kgU. However, even if installed capacity were not to increase after 2050, total identified available reserves would be exhausted in the 2080s under the high-nuclear scenario and in the 2110s under the low-nuclear scenario. Current primary production capacity, by contrast, would cover demand until 2031 or 2027 (in the low- and high-nuclear scenarios, respectively). In the long term, greater coverage could derive from the development of technologies that allow spent fuel to be recycled or non-conventional uranium sources to be exploited (such as phosphate deposits).

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[90] It standard to classify as “primary reserves” those coming from mining activity. The “secondary reserves”, instead, include those coming from recycling, i.e. the reprocessing of spent nuclear fuel or the dismantling and recycling of nuclear weapons.

[91] For comparison, on January 2024 the uranium reached 275 USD/kgU, a record price within the last 16 years, while between 2016 and 2021 it ranged between 52 and 78 USD/kgU and it was equal to 130 USD/kgU at the beginning of 2023 (IAEA, 2024; NEA, 2025).