ARE SMALL MODULAR REACTORS THE VEHICLE TO SUPPORT A NUCLEAR RENAISSANCE SCENARIO?

Editorial

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The history of nuclear electricity was marked by important achievements. The most significant is the consistent contribution to the reliability of the baseload supply. This has been particularly important for ensuring grid stability and meeting the electricity demand of industrialized nations. Another important contribution is the low-carbon energy provided with minimal greenhouse gas emissions during electricity generation. This has contributed to efforts to combat climate change by reducing carbon dioxide emissions, making nuclear power a valuable tool in the transition to cleaner energy sources. Several emerging economies, such as China and India, have invested heavily in nuclear power to meet their growing energy demands while reducing their reliance on fossil fuels. This has contributed to the regional and global development.

During the time, many nuclear reactors have demonstrated the capability to operate for several decades, often surpassing their originally planned operational lifetimes. This longevity has allowed countries to maintain a stable source of electricity while amortizing the initial construction costs over a longer period. Significant advancements in reactor design, safety protocols, and regulatory oversight have been implemented. Modern nuclear reactors incorporate enhanced safety features to mitigate the risk of accidents. Progress has been made in managing and storing radioactive waste generated by nuclear power plants operation. Advanced technologies and secure disposal methods have been developed to handle and store more safely nuclear waste. International agreements and safeguards, such as the Treaty on the Non-Proliferation of nuclear weapons (NPT) and the International Atomic Energy Agency (IAEA), have been instrumental in preventing nuclear weapons proliferation while enabling the peaceful use of nuclear energy.

The historic evolution of nuclear energy has been greatly influenced by three events classified as severe accidents, at Three Mile Island (1979), Chernobyl (1986), and Fukushima Daiichi (2011). These nuclear accidents raised public awareness about the potential risks of nuclear power and prompted governments and international organizations to reevaluate and strengthen nuclear safety measures. They continue to shape nuclear policies and public perception of nuclear energy worldwide.

In the last decades some countries decided to reduce their nuclear share in the electricity-mix or to phase-out completely the nuclear capacities. While motivations may vary by country, several common factors for the phase-out in some EU countries include: (1) safety concerns resulted from the major nuclear accidents (Chernobyl, Fukushima Daiichi), (2) shifting of the public opinion (concerns about the safety of nuclear facilities, radioactive waste disposal, and the environmental impact of nuclear energy have led to anti-nuclear sentiment and influenced government policy), (3) environmental concerns (some EU countries decided to reduce greenhouse gas emissions based only on the increase of renewable energy sources as a better option to nuclear), (4) aging infrastructure (many nuclear power plants in Europe have reached or exceeded their originally planned operational lifetimes), (5) energy diversification (reducing the dependence on a single energy source, such as nuclear power), (6) economic factors (high costs of nuclear reactors, considering the entire life cycle), (7) technological alternatives (advances in renewable energy technologies, such as wind, solar, and energy storage, have made these sources more economically viable), (8) political shifts (changes in political leadership and government priorities).

On the other hand, some countries continue to invest in nuclear and operate nuclear reactors as part of their energy mix. The decision to invest in nuclear or to phase-out nuclear reactors is a complex one, influenced by a combination of safety, environmental, economic, and political factors specific to each country.

Despite this polarization, nuclear remains a crucial sector for energy production in the EU, offering powerful contribution for energy security, large contribution to the decarbonization goal, and creating a strong local supply chain with high-quality jobs. Nuclear electricity in EU is a major contributor to the decarbonization strategy, currently representing around 40% of the free-carbon electricity production.

A set of EU Member States keep nuclear in the national energy mix, based on the extension of the lifetime of the current fleet. Other countries intend both long-term operation (LTO) and the building of additional capacities. LTO is already decided or in advanced progress for some NPPs such as: Kozloduy (Bulgaria), Dukhovany and Temelin (Czech Republic), Krško (Croatia and Slovenia), Loviisa and Olkiluoto 1&2 (Finland), Paks (Hungary), Cernavoda U1 (Romania), Bohunice U3&4 (Slovakia), Borssele (Netherlands). In France, a large LTO project (grand carénage project) is in progress. Some new nuclear power plants are planned to be built in some EU countries. On the other hand, the current policies of several EU MSs are considering nuclear plants as a feasible option to meet their growing energy needs, especially based on the

deployment of small modular reactors (SMRs). SMRs offer numerous advantages, including enhanced safety features, reduced upfront costs, scalability, potential for easier siting, and flexibility in deployment for both grid and non-grid applications. However, the SMRs implementation is facing the high costs of the implementation (at least in the initial phase, until the achievement of serial production).

While the adoption of SMRs holds immense potential for addressing the escalating energy demands of MSs, it is imperative to address the financial barriers hindering their widespread deployment. Overcoming these challenges requires concerted efforts from policymakers, industry stakeholders, and the research community to unlock the full potential of SMRs and open in a new era of sustainable nuclear energy production.

SMRs' landscape is marked by an impressive diversity of designs, each offering unique features tailored to meet specific energy needs and operational requirements. These innovative reactor concepts represent a paradigm shift in nuclear energy, offering scalability, enhanced safety, and flexibility in deployment. One notable category of SMRs is the light water reactor (LWR), which builds upon established nuclear technology while incorporating advancements to improve efficiency and safety. These designs leverage passive safety systems and simplified designs to enhance reliability and ease of operation.

Beyond LWRs, alternative reactor concepts present compelling solutions for diverse applications. Lead-fast reactors (LFR), Sodium-cooled fast reactors (SFRs), and Gas-cooled fast reactors (GFR) designs offer high efficiency and potential for closed nuclear fuel cycles, contributing to nuclear energy sustainable development. High-temperature Gas-cooled reactors (HTGRs), like the pebble bed modular reactor (PBMR), utilize helium as a coolant and offer inherent safety features, making them suitable for both electricity generation and process heat applications. Molten salt reactors (MSRs) represent another innovative approach, where the fuel is dissolved in a molten fluoride or chloride salt.

Several factors contribute to the relatively low implementation of SMRs, despite the existence of diverse designs and concepts such as: (1) high initial costs, (2) regulatory hurdles, (3) market uncertainty, (4) limited track records, (5) public perception and acceptance.

The upfront capital costs associated with SMRs, particularly in the early stages of development and deployment, pose a significant barrier to implementation. Building new nuclear infrastructure requires substantial investment, and the costs associated with licensing, design, manufacturing, and construction can be prohibitive, especially for smaller utilities or countries with limited financial resources.

On the other hand, the nuclear power projects are subject to rigorous regulatory scrutiny to ensure safety and security. The complex and lengthy regulatory approval process adds significant time and uncertainty to SMR deployment, deterring potential investors and developers. Moreover, the lack of standardized regulatory frameworks for SMRs can further complicate the licensing process, delaying implementation.

Considering the market context, the energy landscape is evolving rapidly, with increasing competition from renewable energy sources, natural gas, and energy storage technologies. Uncertainty surrounding future energy demand, electricity prices, and government policies, including subsidies and carbon pricing, can undermine the economic viability of SMR projects and deter investment.

In terms of the maturity, despite advancements in SMR technology, many designs are still in the prototype or demonstration phase, lacking a proven track record of commercial operation. Investors and utilities may hesitate to commit to SMR projects due to concerns about technical feasibility, reliability, and performance uncertainties.

SMRs face stiff competition from other energy sources, including renewables like solar and wind power, which have experienced rapid cost declines and widespread deployment in recent years. The flexibility and scalability of renewable energy technologies, coupled with growing energy storage capabilities, pose challenges to the economic competitiveness of SMRs, especially in regions with abundant renewable resources.

Beyond of these, nuclear energy is often met with public apprehension and skepticism, driven by concerns over safety, nuclear proliferation, radioactive waste management, and accidents like Chernobyl and Fukushima. Negative public perception can hinder the social license and political support necessary for SMR deployment, leading to regulatory delays and project cancellations.

Addressing these challenges will require collaborative efforts from governments, industry stakeholders, regulators, and the public to overcome barriers to SMR implementation. This may involve targeted policies and incentives to reduce costs, streamline regulatory processes, enhance public confidence, and promote international cooperation and standardization efforts to accelerate the deployment of SMRs as a key component of a sustainable energy future.

There is a great potential for a nuclear renaissance, and an immense potential of SMRs to contribute, but the real implementation is influenced by the determination of the decision makers to use this option.

In this context, our journal is oriented to publish meaningful results oriented to reflect the efforts of the research and development, education and training, academia and industry, and also the efforts to build sustainable decisions by involving the diversity of the stakeholders.

Dear readers and dear potential contributors, you are welcomed in our journal to participate to a balanced debate on the nuclear issues and moreover to contribute with innovative and valuable solutions to the nuclear development in the context of the modern society sustainable development.