Towards Resilient and Decarbonized Energy Systems: Nuclear Power's Strategic Role in the Digital Era

Editorial

by Marin Constantin, Editor-in-Chief
Institute for Nuclear Research, RATEN ICN Pitesti, Romania

The global energy system is entering a decisive decade. Electrification of economies, digitalization, population growth, and the imperative of deep decarbonization are converging to drive energy demand to unprecedented levels. Looking toward the mid- and long-term horizons outlined in recent global energy outlooks toward 2026 and beyond, it is increasingly clear that the challenge is not only to produce more energy, but to do so reliably, affordably, and with minimal environmental impact. In this context, nuclear power - often discussed in polarized terms - deserves a renewed, evidence-based examination as a cornerstone of future energy systems.

Unprecedented Energy Needs in a Decarbonizing World

Future energy demand growth will be driven less by traditional industrial expansion and more by structural changes in society: electrification of transport, heating, and industry; the explosive growth of data processing and digital services; and the rising energy needs of emerging economies. While energy efficiency and demand-side management will play an essential role, they will not offset the absolute increase in electricity consumption. The key question is therefore not whether new generation capacity is needed, but what mix of technologies can meet this demand while preserving system stability and climate objectives.

Replacing Coal: The Promise and Limits of SMRs

The retirement of coal-fired power plants is a central pillar of the global decarbonization strategies. Small Modular Reactors (SMRs) are frequently proposed as a pragmatic replacement, offering lower upfront capital costs, enhanced safety features, and greater sitting flexibility compared to the large nuclear power plants. In many regions, SMRs could provide firm, low-carbon power while leveraging existing grid connections and skilled workforces at former coal sites.

However, a critical limitation must be acknowledged: the coal-fired power plants have historically provided not only energy, but also operational flexibility. They have played a role in load-following, frequency regulation, and reserve provision. Current SMR designs, while more flexible than traditional large reactors, cannot yet fully replicate the dynamic operational range of coal in all grid contexts. This highlights the need for system-level planning, where nuclear, storage, and grid technologies are co-optimized rather than evaluated in isolation.

Nuclear Power Plants and Baseload: The Data Centre Case

The concept of baseload power is being redefined, but not rendered obsolete. Few sectors illustrate this better than data centres. The rapid expansion of cloud computing, artificial intelligence, and digital services is driving a surge in demand for continuous, high-quality electricity supply. Interruptions, even brief ones, carry significant economic and societal costs.

Nuclear power plants (NPPs), with their high capacity factors and predictable output, are uniquely suited to meet these requirements. Unlike variable renewable energy sources, nuclear energy can provide round-the-clock power without dependence on weather conditions. For large data centers and digital infrastructure hubs, co-location with nuclear generation or long-term power purchase agreements with NPPs are increasingly being considered as viable pathways to both energy security and carbon neutrality.

Power Density: A Fundamental Advantage of Nuclear Energy

One of the most underappreciated attributes of nuclear power is its exceptional energy and power density. A nuclear power plant can generate gigawatts of electricity on a footprint measured in square kilometres, whereas variable renewable energy sources (vRES) such as wind and solar require orders of magnitude more land and materials to deliver comparable annual energy output.

This difference is not merely academic. Land use, material intensity, and grid expansion have real environmental, economic, and social implications. In densely populated regions or areas with competing land-use priorities, nuclear power offers a uniquely compact solution for large-scale, low-carbon electricity generation.

Waste Management: A Clear Challenge versus an Emerging One

Nuclear waste remains one of the most frequently cited concerns in public and policy debates. Yet, it is also one of the most clearly defined and technically addressed challenges. Volumes are small, inventories are well characterized, and long-term management strategies – such as deep geological repositories – are scientifically robust and increasingly moving toward implementation.

By contrast, waste streams associated with vRES technologies are only beginning to emerge as a systemic issue. End-of-life management of solar panels, wind turbine blades, batteries, and associated infrastructure is not yet resolved at scale. As deployment accelerates, these material and environmental challenges will require solutions that are currently less mature than those developed for nuclear waste.

Public Acceptability and Generational Change

Public perception of nuclear energy is evolving. Younger generations, shaped by digital environments and a more abstract relationship with risk, often approach nuclear technology with less historical fear than their predecessors. In an era of "decorporealization", where many societal interactions are mediated through data and virtual systems, the perceived distance from physical hazards alters risk assessment.

At the same time, climate change has become a defining concern for these generations. The recognition that nuclear power is a low-carbon, dispatchable energy source is contributing to a gradual increase in public acceptability. Transparency, education, and continued demonstration of safety and operational excellence remain essential, but the socio-political landscape is shifting in ways that may favour a more balanced appraisal of nuclear energy.

Digitalization as a Driver of Nuclear Relevance

Digitalization is reshaping both energy demand and energy systems. Beyond the growth of data centres, digital technologies – such as artificial intelligence, advanced simulation, digital twins, and real-time monitoring – are changing the way power systems are designed, operated, and secured. These technologies require electricity that is not only low-carbon, but also highly reliable, resilient, and predictable.

For nuclear energy, digitalization represents both an opportunity and an enabler. Advanced instrumentation and control systems, predictive maintenance supported by AI, and digital twins of reactors and fuel cycles are improving safety margins, operational efficiency, and economic performance. At the same time, digitalization strengthens nuclear's position as a backbone for digitally intensive societies, where power outages translate directly into systemic risks.

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.

Moreover, digital sovereignty and cybersecurity are becoming strategic concerns. Energy systems, which are increasingly linked with digital infrastructure, benefit from generation sources that are less vulnerable to weather-driven instability and can be secured within well-defined physical and cyber boundaries. In this respect, nuclear power aligns naturally with the requirements of a highly digitalized economy.

Expected Transformations of Future Energy Systems

Future energy systems will differ fundamentally from those of the past. They will be more electrified, more decentralized at the distribution level, yet more integrated at the system level. Sector coupling – linking electricity with transport, industry, heating, hydrogen production, and synthetic fuels – will increase both demand and complexity.

In such systems, flexibility will be provided through a portfolio of options, including grid expansion, storage technologies, demand response, and flexible generation. Variable renewable energy sources will play a growing role, but their integration at scale will amplify the need for firm, low-carbon capacity to stabilize the system. Nuclear power is uniquely positioned to play this role, both through traditional baseload operation and through hybrid applications such as cogeneration, district heating, hydrogen production, and industrial process heat.

SMRs and advanced reactors may further reshape system architectures by enabling closer coupling between generation and consumption, particularly for industrial clusters and remote regions. Rather than a monolithic grid dominated by single technologies, future energy systems are likely to rely on diversified, complementary solutions – where nuclear energy provides structural stability, long-term reliability, and a hedge against systemic uncertainty.

The long-term role of nuclear power should not be framed as a competition against renewable energy, but as a complementary pillar of a resilient, decarbonized energy system.

As energy demand grows and system complexity increases, technologies that provide reliability, density, and predictability will become more valuable. Nuclear power – whether through large reactors or SMRs – offers these characteristics and deserves a central place in strategic discussions on energy research, development, and deployment in the coming decades.

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.