

Non-electric Applications of Small Modular Reactors in Slovenia

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ABSTRACT

Small Modular Reactors (SMRs) are increasingly recognised as flexible low-carbon energy systems capable of delivering not only electricity but also heat, hydrogen, and industrial energy services. This paper analyses the potential of non-electric SMR applications in Slovenia, focusing on district heating, industrial process heat, and hydrogen production. The results indicate that SMRs represent a technically viable solution for decarbonising heat-intensive sectors and enabling cogeneration-based energy systems. Particular emphasis is placed on identifying potential end-users and evaluating business models suitable for Slovenian conditions. The findings highlight the importance of integrating SMRs into urban and industrial clusters, where combined energy supply can improve overall system efficiency and reduce dependence on fossil fuels.

Keywords: SMR, cogeneration, district heating, process heat, hydrogen, industrial decarbonisation

1 INTRODUCTION

The transition towards a low-carbon energy system reveals a fundamental imbalance between the decarbonisation of electricity generation and the broader structure of final energy consumption. While electricity production is increasingly based on renewable and nuclear sources, a substantial share of energy demand remains in the form of heat, steam, and chemical energy carriers. In Slovenia, this is particularly evident in district heating systems and industrial processes, which still rely predominantly on fossil fuels.

This structural gap is becoming more pronounced as electrification progresses in some sectors while others remain difficult to decarbonise. Industrial processes that require high-temperature heat, as well as urban heating systems, cannot always be efficiently electrified without significant infrastructure upgrades or efficiency losses. As a result, alternative low-carbon heat sources are required to complement the ongoing expansion of clean electricity generation.

Small Modular Reactors (SMRs) offer a potential solution by extending the role of nuclear energy beyond electricity generation. Their modular design, operational flexibility, and suitability for deployment closer to end-users enable integration into various segments of the energy system. In particular, their capability to provide both electricity and thermal energy positions SMRs as a promising technology for addressing sectors that are difficult to decarbonise using electrification alone. In addition, their scalability allows gradual deployment aligned with demand growth, reducing financial and implementation risks compared to large-scale projects.

2 SMRS AS MULTI-PURPOSE ENERGY SYSTEMS

The key enabler of non-electric SMR applications is nuclear cogeneration, or combined heat and power. In this mode of operation, part of the reactor's thermal output is used directly for external applications, while the remaining energy is converted into electricity. This approach allows

more efficient use of primary energy and supports the gradual replacement of fossil fuel-based heat generation.

A further advantage of SMRs lies in their operational flexibility compared to conventional large nuclear power plants. Although primarily designed for baseload operation, SMRs can be configured to adjust the balance between electricity and heat production depending on demand conditions. This capability is particularly relevant in systems with high shares of variable renewable energy, where electricity demand and supply may fluctuate significantly over time.

SMRs are capable of supplying thermal energy across a broad temperature range, enabling applications in multiple sectors. Low-temperature heat can be used for district heating, while higher temperature outputs are suitable for industrial processes and advanced energy systems. This versatility allows SMRs to act as central energy hubs, delivering multiple energy products from a single source and supporting sector coupling within the broader energy system [1].

3 KEY NON-ELECTRIC APPLICATIONS IN SLOVENIA

Three main non-electric applications of SMRs are identified as particularly relevant for Slovenia.

District heating represents the most immediate opportunity due to its compatibility with SMR temperature outputs and the presence of existing infrastructure. Heat demand in urban areas is relatively stable, which supports efficient operation and high utilisation rates. The transition from fossil-based heat sources to SMRs would significantly reduce emissions while maintaining reliability. In addition, integration with existing district heating networks allows relatively rapid implementation compared to other applications.

Industrial process heat offers substantial long-term potential, particularly in energy-intensive sectors such as chemical production, paper manufacturing, food processing, and pharmaceuticals. These industries require continuous and reliable heat supply, making them well suited for integration with SMRs. The use of nuclear heat in such processes enables direct decarbonisation without significant changes to existing industrial systems. Moreover, stable energy prices from SMRs can enhance industrial competitiveness by reducing exposure to volatile fossil fuel markets.

Hydrogen production represents a strategic application with growing importance. SMRs can support hydrogen generation through electrolysis and thermally assisted processes. In the future, hydrogen could serve as an energy carrier for industry, transport, and energy storage. The integration of hydrogen production with SMRs can also provide operational flexibility by allowing energy output to be redirected depending on market conditions [1].

4 IDENTIFICATION OF POTENTIAL ENERGY USERS

The deployment of SMRs depends on identifying users with stable and continuous demand for energy, particularly heat. In Slovenia, the most relevant groups include urban district heating systems, industrial facilities, and selected critical infrastructure.

Urban areas with district heating networks are natural candidates for early SMR deployment. These systems already provide a framework for distributing heat, and their demand characteristics are well aligned with steady energy supply. Replacing fossil-based heat sources with SMRs would improve sustainability while maintaining operational reliability. Furthermore, the concentration of demand allows for efficient utilisation of thermal energy.

Industrial users represent another key segment due to their high and continuous demand for process heat. Many industries operate continuously, which supports efficient SMR utilisation. The proximity of SMRs to industrial sites also reduces energy losses and simplifies integration. In addition, long-term energy supply agreements with industrial users can improve project economics and reduce investment risk.

Critical infrastructure, such as hospitals and data centres, represents a smaller but strategically important segment. These facilities require uninterrupted energy supply, and SMRs can enhance reliability and resilience. In particular, data centres are becoming increasingly relevant due to their rapid growth and high electricity demand. Although large-scale data centres are not yet widely present in Slovenia, this represents a potential opportunity for future development, including the integration of low-carbon energy supply and heat recovery solutions.

An additional opportunity lies in the reuse of existing energy infrastructure. Locations currently associated with fossil fuel-based generation already have grid connections and suitable industrial environments. Repurposing such sites for SMR deployment can reduce development time and costs while supporting a just transition for local communities [1].

5 BUSINESS MODEL CONSIDERATIONS

The successful deployment of SMRs requires business models that address high capital costs and long investment horizons. Long-term energy supply agreements are particularly important, as they provide predictable revenue streams and reduce exposure to market volatility.

In addition to traditional models, new approaches such as energy-as-a-service and industrial partnerships are likely to play an important role. These models allow risk sharing between stakeholders and align incentives across the value chain. Public-private partnerships may also be necessary, particularly in early deployment phases where investment risks are higher.

The role of government policy is critical in this context. Stable regulatory frameworks, financial support mechanisms, and clear long-term energy strategies can significantly improve investment conditions. Without such support, the deployment of SMRs may face delays despite their technical potential [1].

6 TECHNO-ECONOMIC AND SYSTEM INTEGRATION ASPECTS

The integration of SMRs into the Slovenian energy system requires alignment between technical performance, economic viability, and system needs. One of the main advantages of SMRs is their ability to provide stable energy while supporting non-electric applications, which is particularly valuable in systems with increasing shares of variable renewable energy.

Locating SMRs close to energy users improves overall efficiency by reducing transmission losses and infrastructure requirements. This is especially relevant for thermal energy, where long-distance transport is less efficient. In Slovenia, where industrial and urban demand is often geographically concentrated, such integration can deliver significant benefits.

Economic viability depends on achieving high utilisation of both electricity and heat outputs. Seasonal variations in heat demand may require the use of thermal storage or flexible operation strategies. At the same time, initial investment costs remain a challenge, particularly for first-of-a-kind projects.

In the longer term, cost reductions are expected through standardisation, modular construction, and learning effects. As more SMR units are deployed globally, supply chains will mature and reduce overall project costs. This process will be essential for achieving broader competitiveness with alternative low-carbon technologies [1].

7 CONCLUSION

Small Modular Reactors represent a promising solution for the development of a low-carbon energy system in Slovenia. Their ability to provide both electricity and heat enables effective

decarbonisation of sectors that are otherwise difficult to transform, particularly in the areas of district heating and industrial energy use.

The analysis confirms that the primary value of SMRs lies in their application as cogeneration systems, where simultaneous production of electricity and heat significantly improves overall energy efficiency. This is especially relevant in the Slovenian context, where a large share of final energy consumption is still linked to thermal demand. By integrating SMRs into urban and industrial clusters, it is possible to achieve strong synergies between energy production and consumption, leading to higher utilisation rates and improved economic performance.

District heating, industrial process heat, and hydrogen production have been identified as the most relevant non-electric applications, each contributing to different dimensions of the energy transition. District heating offers the most immediate deployment potential due to existing infrastructure, while industrial applications provide the largest long-term decarbonisation impact. Hydrogen production, although more strategic and longer-term, introduces additional flexibility and supports the development of new low-carbon value chains.

The successful implementation of SMRs will depend not only on their technical performance but also on the ability to integrate them into the broader energy system. This includes aligning production with demand profiles, ensuring high utilisation of thermal energy, and leveraging existing infrastructure where possible. At the same time, economic and regulatory conditions will play a decisive role. Stable policy frameworks, appropriate financing mechanisms, and stakeholder cooperation are essential to reduce investment risks and enable project realisation.

Despite the remaining challenges, including regulatory adaptation, financing structures, and public acceptance, SMRs offer a unique opportunity to bridge the gap between electricity decarbonisation and thermal energy demand. Their deployment can contribute not only to emissions reduction but also to increased energy security and system resilience.

In this sense, SMRs should not be viewed merely as a new generation of nuclear power plants, but as a platform for integrated energy systems that combine electricity and heat into a unified, flexible, and low-carbon energy solution [1].

REFERENCES

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