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The Potential Of Using SMR Reactors At Coal-Fired Power Plant Locations

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ABSTRACT

Coal is responsible for the largest share of carbon dioxide emissions from the energy sector, making its phase-out key to tackling climate change. On the other hand, the International Panel of Climate Change (IPCC) considered 90 pathways with emission reductions to limit average global warming to less than 1,5 °C. The IPCC found that on average, the pathways for the 1,5 °C would require installed nuclear capacity to reach 1.160 GW by 2050, up from 394 GW in 2020. This growing role for nuclear power will complement variable renewables, which are set to rapidly grow in all climate mitigation pathways. The ambitious target to triple installed nuclear power until 2050 can be achieved with long-term operation of existing plants, building large-scale Generation III/III+ new builds and with deployment of Small Modular Reactors (SMRs).

The development of SMR reactors is dynamic and, in the future, the SMRs can play important role in the low carbon energy policies in the world. Many countries aim to abandon the use of fossil fuels for electrical energy production, particularly coal-fired power plants. The location, infrastructure and employees in coal-fired power plants have the potential for restructuring and deployment of SMR reactors.

In recent years, several studies have analyzed the possibility of implementing SMR reactors at coal-fired thermal power plant locations.

The first part of the article provides a brief overview of SMR development and the recent coal-to-nuclear projects and studies. The second part of the article represents the overview of coal-fired power plant systems and buildings that may be applicable to SMR power plants and discusses potential benefits of coal-to-nuclear projects and challenges to be addressed in the near future. The last part of the article analyses the options for deploying SMR reactors on the sites of Slovenian coal-fired thermal power plants.

1 INTRODUCTION

Coal constitutes the largest contributor to global electricity generation, accounting for approximately 35 % of the total power produced. With its substantial footprint, coal-based electricity is the foremost emitter of carbon dioxide, releasing a staggering 12 $GtCO_2$ annually. The existing coal-powered plants boast an installed capacity of 1,9 TWe, primarily concentrated in key regions such as China, India, the USA, and Japan. These four nations collectively hold over 65 % of the world's coal-generated capacity. Recent trends reveal a global increase in coal-based generation, predominantly driven by China and India, even as the US and Europe witness a decline [1].

In alignment with the International Energy Agency (IEA), the pursuit of net-zero emissions necessitates a complete cessation of coal-based generation on a global scale by 2040. A substantial portion of the coal infrastructure is already subject to net-zero policies.

The progression of Small Modular Reactors (SMRs) remains a highly dynamic field, commanding considerable attention across diverse public sectors due to its potential for innovation, prospects for development, educational significance, and avenues for entrepreneurial endeavours.

Recent years have witnessed the emergence of several feasibility studies exploring the viability of integrating small modular reactors into the sites of coal-fired thermal power plants, aligning with energy policies. This article aims to delve into the evolution of small modular reactors, providing an overview of ongoing projects aimed at replacing coal-fired thermal power plants. Furthermore, it will delve into the feasibility of substituting coal-fired thermal power plants in Slovenia with SMR reactors.

2 DEVELOPMENT OF SMR TECHNOLOGY

SMRs are powering innovation across many industries and bringing new opportunities. The unique attributes of SMRs in terms of expected efficiency, flexibility and economics, as well as reduced needs for emergency planning due to inherent safety features, may position them to play a key role in the transition to clean energy. In this respect, the nuclear community is pursuing innovation in technology, market design, financing, regulation and project delivery. There are over 80 proposed designs for SMRs worldwide reflecting both the enthusiasm around their potential, and the wide spectrum of possible nuclear reactor technologies [2].

According to the IAEA data from 2022 [3], there are two SMR reactors in commercial operation, Chinese HTR-PM (HTGR reactor) and Russian KLTS-40S (floating PWR reactor) and two more demonstration HTGR reactors (HTTR and HTR-10). Three more SMRs are under construction, Argentinian demonstration land based PWR reactor CAREM, Chinese land based PWR reactor ACP100 and Russian BREST-OD-300 LMFR reactor. Another 66 designs are in the several design phases.

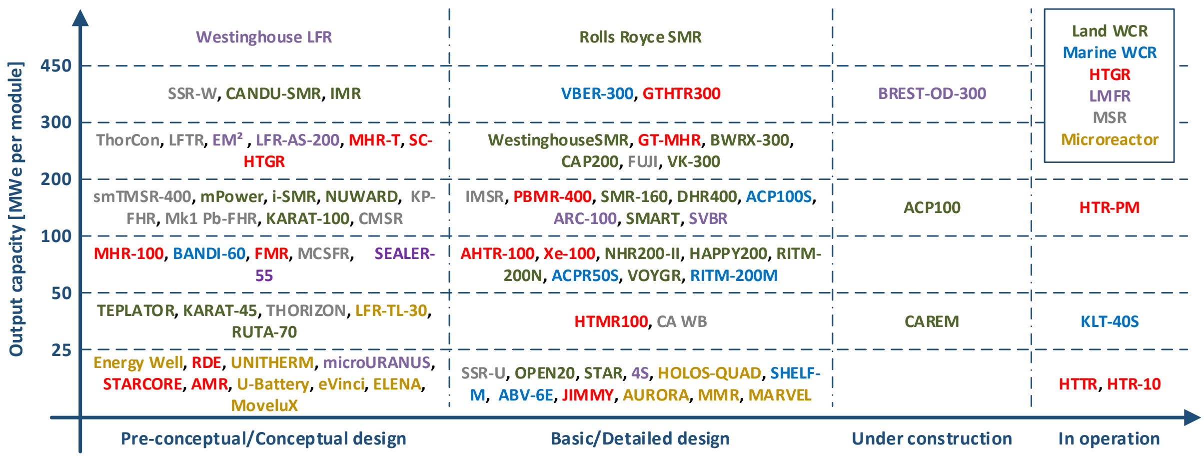

Figure 1: Stage of design/Deployment of SMRs in terms of their output capacity [3]

Water-cooled technology is the most widely used technology of nuclear reactors. Currently, over 90% of operating and under-construction nuclear reactors are water-cooled reactors, with the majority of them utilizing Pressurized Water Reactor (PWR) technology. Water-cooled technology is also expected to dominate the landscape of Small Modular Reactors (SMRs). Refer to Figure 2 for a projected timeline outlining the development and deployment of the most promising water-cooled SMR designs.

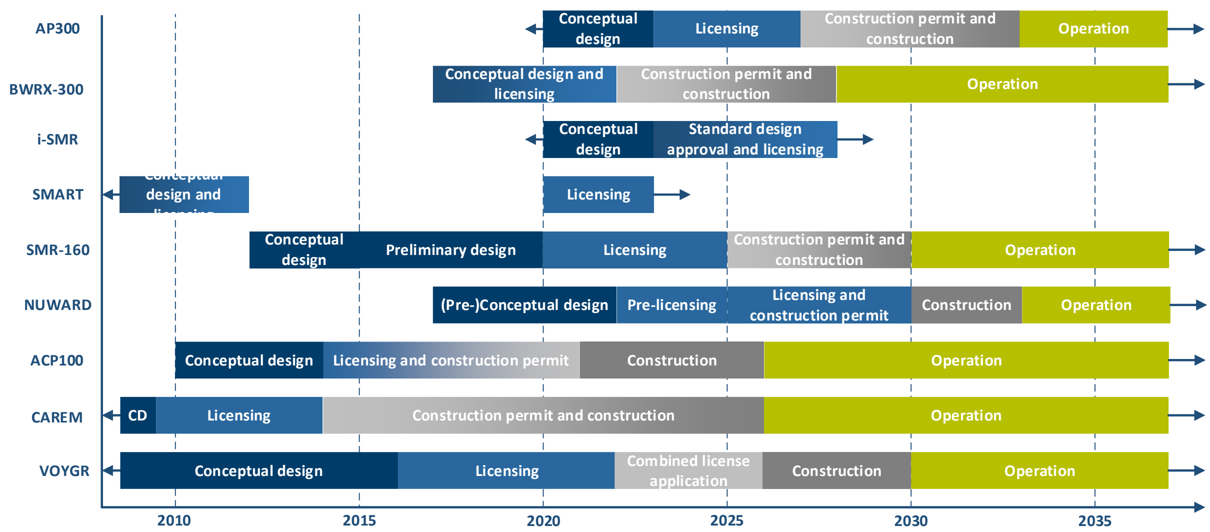

Figure 2: Projected timeline outlining the development and deployment of FOAK water-cooled SMR designs

3 RECENT COAL-TO-NUCLEAR PROJECTS AND STUDIES

Several feasibility studies [4], [6] and [7] have been conducted to explore the potential deployment of Small Modular Reactors (SMRs) at sites currently occupied by coal-fired thermal power plants. Given the current prominence of discussions around transitioning from coal to nuclear energy, an increase in anticipated studies and projects is on the horizon. Notably, Romania and the USA are at the forefront of advancements in repurposing coal-fired thermal power plants for the integration of SMRs.

3.1 Romania coal-to-nuclear project Doicesti

In early 2021, United States Trade and Development Agency (USTDA) awarded a grant to Romanian Nuclearelectrica to conduct a study to identify and assess several sites across Romania, including locations where existing coal-fired power plants could be replaced with SMRs. In 2022, according to NuScale power, the study, performed by US firm Sargent & Lundy, has identified several potential suitable sites including Doiceşti, which Nuclearelectrica has determined to be the preferred location [4].

The Doicesti Power station was a large thermal power plant with 8 generation units, 6 of 20 MW each and 2 of 200 MWe each. It used lignite as a main fuel supplemented by Natural gas. All of the units are already decommissioned.

Doicești location was selected to implement NuScale Power VOYGR-6 model of a nuclear power plant that will deploy 6 SMRs of 77 MW each with a total capacity of 462 MWe. For this project Nuclearelectrica formed a new company RoPower, with equal shares with the plant owner Nova Power&Gas. RoPower signed the contract with NuScale Power for phase 1 of front-end engineering and design [5].

3.2 USA coal-to-nuclear feasibility study

In 2022 the study with title Investigating benefits and challenges of converting retiring coal plants into nuclear plants was carried out by the Argonne, Idaho and Oak Ridge National Laboratories, sponsored by the DOE Office of Nuclear Energy [6]. The study evaluated the siting characteristics of recently retired and those operating coal-fired power plant sites. The study team estimates that 80 % of retired and operating coal power plant sites that were evaluated have the basic characteristics needed to be considered amenable to host an advanced nuclear reactor. For the recently retired plant sites evaluated, this represents a capacity potential of 64,8 GWe to be backfit at 125 sites. For the operating plant sites evaluated, this represents a capacity potential of 198,5 GWe to be backfit at 190 sites.

The study assesses a specific scenario involving the comprehensive repercussions and potential outcomes of transitioning from coal to nuclear energy. Taking into account the range of nuclear technology options and capacities considered for replacing a sizable 1.200 MWe coal plant at the designated site, the capital costs associated with nuclear facilities could experience a reduction of 15% to 35%. This reduction is in comparison to undertaking an entirely new construction project, attributed to the repurposing of existing infrastructure from the coal plant.

In the examined case study, where coal capacity is replaced with a 924 MWe nuclear capacity, the research team discovered that there is a potential for regional economic activity to rise by up to $275 million. Furthermore, this transition could result in the creation of around 650 new permanent jobs within the analyzed region.

4 THE OVERVIEW OF COAL-FIRED POWER PLANT SYSTEMS AND BUILDINGS THAT MAY BE APPLICABLE TO SMR POWER PLANTS

The basic idea of coal-to-nuclear transformation is to transform coal-fired thermal power plants to nuclear ones and using as much of the existing infrastructure (cooling towers, turbogenerators, grid lines, etc.) as well as the existing workforce of well-trained engineers, practitioners and other staff that is needed to operate the plant. The schematic overview of coal-to-nuclear transformation is presented in figure 3.

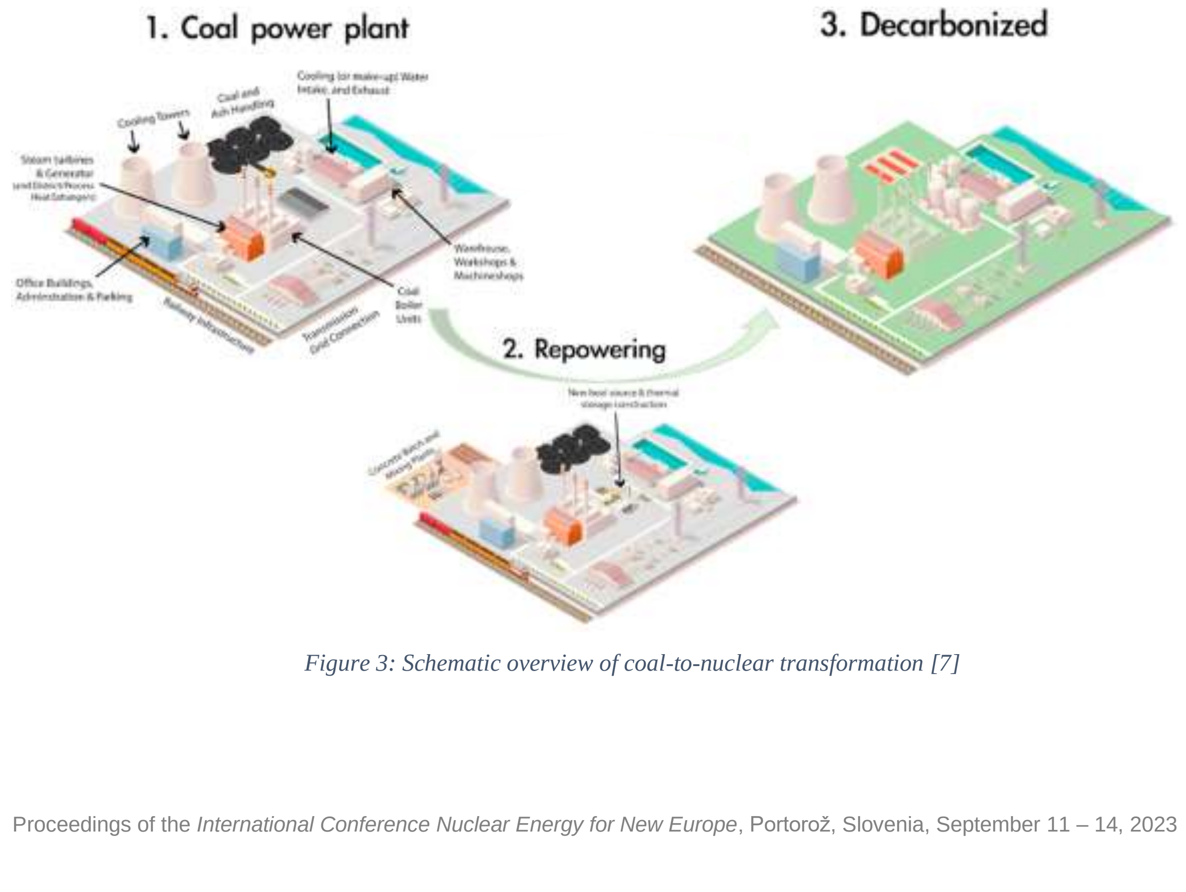

Figure 3: Schematic overview of coal-to-nuclear transformation [7]

Figure 4 represents coal power plant systems that can be potentially reused for SMRs.

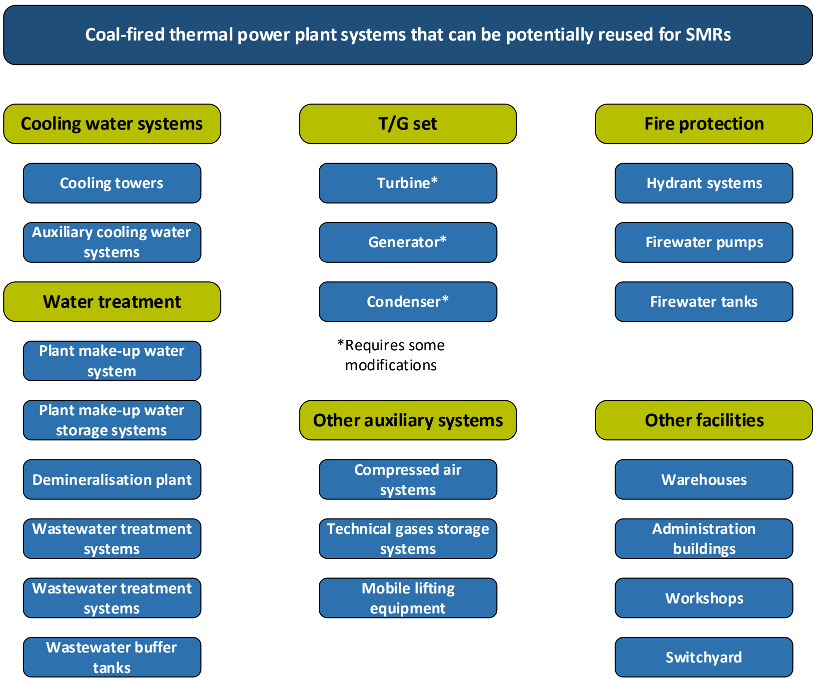

Figure 4: Coal-fired thermal power plant systems that can be potentially reused for SMRs [8]

In addition to the existing systems of a coal-fired thermal power plant, the transition from coal to nuclear energy can also make use of water permits, the pre-existing transmission lines, roads, and, most importantly, the workforce that can be adequately retrained for employment in a nuclear power plant. This retrained workforce would encompass various roles such as O&M staff, engineering, project management, support staff, and more.

Bipartisan Policy Center, the organization which aims to combine ideas from both the Republican and Democratic parties to address challenges in the U.S. such as those around energy and the national debt, [9] analyses the benefits and challenges of coal-to-nuclear transition and highlights recent legislation that may hasten such a transition. In table 1 the potential benefits of coal-to-nuclear projects and challenges to address are described.

Table 1: Potential benefits and challenges to address of coal-to-nuclear projects [9]

Potential benefits	Challenges to address
• Nuclear energy provides firm, dispatchable clean energy, • 77 % of coal plant jobs are transferable to nuclear plants. • Net increase of more than 650 jobs in regions where SMRs repower retiring coal plants. • Jobs at nuclear plants provide higher wages, • SMR scan reuse coal infrastructure, • Repowering of coal plants can reduce SMR construction costs up to 35 %	• Coal plant retirement and SMR operation dates must be aligned for smooth workforce transmission. • Licensing and technology infancy create uncertainties for SMR construction timelines. • 23 % of coal plant positions require extensive retraining or licensing. • Coal plant equipment reutilization is limited, • Public acceptance of new nuclear power plants deployment

5 THE POTENTIAL FOR DEPLOYMENT OF SMR REACTORS ON THE SITES OF SLOVENIAN COAL-FIRED THERMAL POWER PLANTS

Slovenia is presently heavily dependent on coal-fired power plants, which contribute to around one-third of the country's electricity supply. In line with principles of a just transition, the Slovenian government has embraced the National Strategy for a Coal Exit and the Restructuring of Coal Regions [10], with a clear target of achieving a complete coal phaseout by 2033. Consequently, Slovenia faces the task of finding alternative technologies to replace both coal-based electricity and heat production. Among the potential alternatives, Small Modular Reactors (SMRs) stand out as a viable option. Currently, there are four thermal power plants in Slovenia:

- Šoštanj Thermal Power Plant (TEŠ): Utilizes coal-fired generation along with supplementary gas turbines, currently operational.
- Trbovlje Thermal Power Plant (TET): Operated with a combination of coal-fired and additional gas turbines, currently shut down.
- Toplarna Ljubljana Thermal Power Plant (TE-TOL): Operates using a mix of coal, biomass, and supplementary gas and steam units, currently operational.
- Brestanica Thermal Power Plant (TEB): Operates as a gas-fired facility, currently operational."

Figure 5 illustrates a map of Slovenia’s electric power transmission network and coal-fired thermal power plant locations.

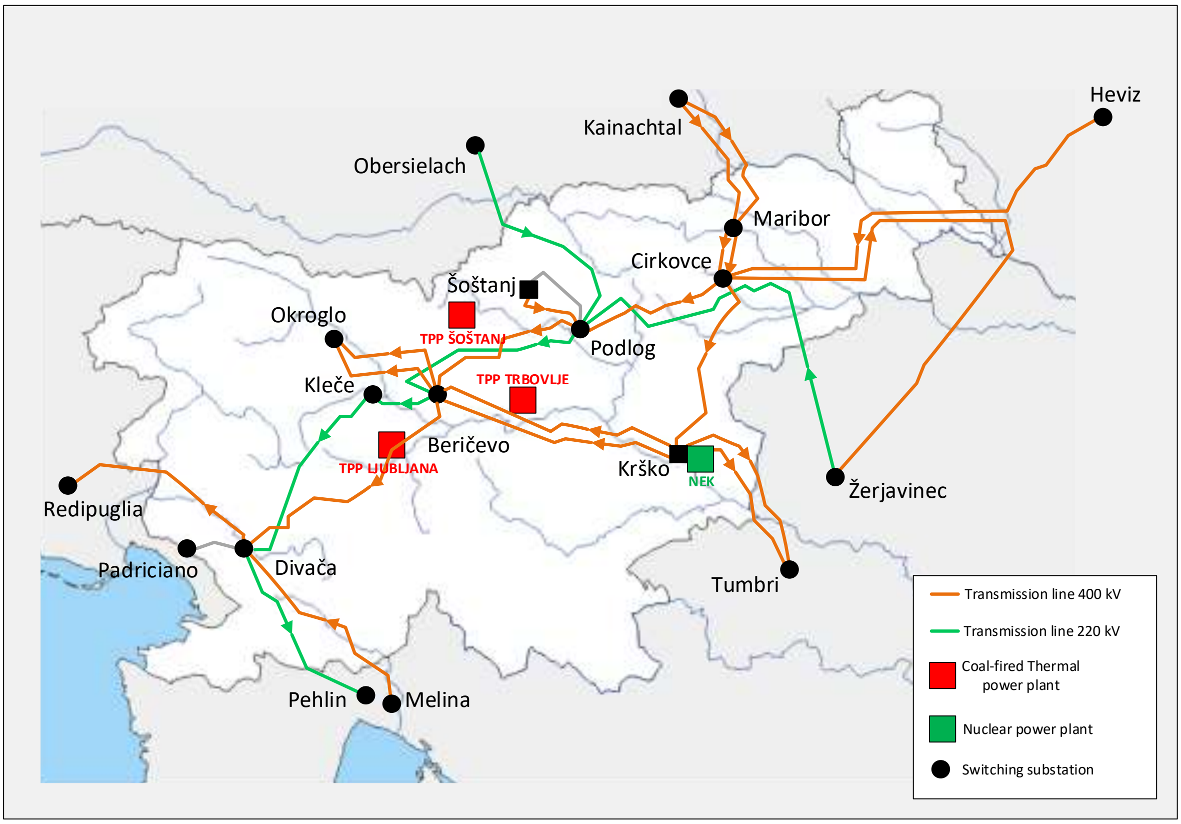

Figure 5: Slovenia’s electric power transmission network and coal-fired thermal power plant locations

Table 2 presents general information about Slovenia's coal-fired thermal power plants and their respective locations.

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	Šoštanj thermal power plant	Trbovlje thermal power plant	Toplarna Ljubljana thermal power plant
Capacity	Unit 1: 30 MWe Unit 2: 30 MWe Unit 3: 75 MWe Unit 4: 275 MWe Unit 5: 345 MWe Unit 6: 600 MWe Gas unit 1: 42 MWe Gas unit 2: 42 MWe	Unit 1: 12,5 MWe Unit 2: 24 MWe Unit 3: 20 MWe Unit 4: 125 MWe Gas unit 1: 29 MWe Gas unit 2: 29 MWe	Unit 1: 42 MWe Unit 2: 32 MWe Unit 3: 50 MWe Gas and steam unit: 139 MWe
Fuel:	Brown coal (lignite)	Brown coal	Brown coal/Biomass
Annual electricity production:	~3 TWh	/ (shutdown)	~0,4 TWh
Cogeneration	yes	no	yes
Cooling	Cooling tower	Sava River	Ljubljanica River
Grid connection	RTP Podlog 400 kV	110 kV Transmission line Dislocated form 400 kV switchyard and transmission line	RTP Beričevo 110 kV
Suitability of location for SMR deployment			
Grid connection	RTP Podlog 400/220/110 kV; new Switchyard	110 kV; new Switchyard Dislocated form 400 kV Transmission line	RTP Beričevo 400/220/110 kV; new Switchyard
Proximity to water	Paka River	Sava River	Ljubljanica River
Back-up power supply	Out of all the existing thermal power plants, only the Brestanica Thermal Power Plant is suitable for immediate use as backup power supply for the nuclear power plant. In the case of all other existing thermal power plants, technological adjustments would be necessary to enable the immediate start of the thermal power plant without external voltage.		
Location	Location is situated in Šoštanj town. The area along the Paka River is densely populated. North of the Šoštanj is mining area, on the south part the terrain rises steeply. East and west of the TEŠ the area is densely built up.	Location is in a narrow valley, where is not possible to find large area of plain. The area, which is situated 1000 meters away from the potential center of the future reactor building, does not encompass any existing residential settlements.	Location is situated in Ljubljana. All the areas in the immediate vicinity of TE-TOL are built up. The area, which is situated 1000 meters away from the potential center of the future reactor building, encompass existing residential settlements
Site specifics	Mining area	Narrow valley	Beričevo (confluence of the Kamniška Bistrica and Sava)
Public engagement	The general support for nuclear energy in Slovenia is high and is increasing from every year. All three mentioned locations represent new nuclear sites, so in the case of a decision to build SMRs, it would be essential to establish immediate collaboration with the local community.		

6 CONCLUSION

The development of SMRs is dynamic, with numerous technology providers. The technologies utilized are often derivatives of previously tested concepts. On the other hand, while providers make high promises, the progress made in the last decade has yet to convince potential investors.

A shared characteristic of worldwide energy policies involves the abandonment of fossil fuels and the decarbonization of electricity production. Substituting coal-fired thermal power plants with SMR power plants holds substantial potential for advancing decarbonization. Despite strengths, several challenges must be effectively addressed in the future.

Slovenia currently operates three coal-fired thermal power plants, two of them are operational, while one is permanent shutdown. Slovenia's energy policy outlines a coal phase-out by 2033. When considering the replacement of coal-fired thermal power plants with SMR reactors, undertaking a comprehensive feasibility study becomes necessary. Moreover, conducting additional assessments of potential locations (including evaluations of seismic, geological, and flood safety factors), as well as adapting and enhancing the existing infrastructure and facilitating the required workforce transformation, would all be essential. Collaborating with the public also emerges as a necessary component in accomplishing a successful energy transition of this nature.

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