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Small Modular Reactors in Romania's Energy Future. Two Essential Perspectives: Capital Costs and Public Perception

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Abstract. *In 2023, during the annual United Nations Conference on Climate Change (COP28), Romania joined the Net Zero Nuclear Initiative and the Ministerial Declaration for the tripling of nuclear capacity by 2050, which recognizes the key role of nuclear energy in achieving net zero goals worldwide. In this context, wanted to implement national projects and strategies to achieve the global goal of tripling nuclear power generation capacity by 2050 (taking 2030 as a reference) and to act to ensure that nuclear power plants are operated in security conditions. This paper examines the potential of Small Modular Reactors (SMRs) in Romania's energy landscape, considering the country's recent commitment to the Net Zero Nuclear Initiative and the goal of tripling nuclear capacity by 2050. The focus is on integrating new nuclear technologies, particularly SMRs, and modernizing existing facilities like the Cernavodă Power Plant. The study also explores the economic benefits, public perception challenges, and the role of European and American expertise in advancing SMR technology. For the first time, using specialized literature and data from public sources, the study aims to analyze the prospects for SMR projects developed in Romania to overcome two essential perspectives: capital costs and public perception in many communities where concerns related to nuclear safety, radioactive waste management, and potential risks associated with nuclear technologies exist.*

Keywords: Nuclear Power, Small Modular Reactors, SMRs, Romania, Energy Policy, Technology Innovation, Public Perception

Introduction

In the context of global efforts to achieve net-zero emissions, Romania's commitment to expanding its nuclear capacity, including the adoption of Small Modular Reactor (SMR) technology, marks a significant strategic direction.

In the latest National Energy Strategy (Ministry of Energy, 2022), Romania aims to achieve, by the perspective year 2030, a 43.9% reduction in emissions from ETS sectors compared to the 2005 levels, and a 2% reduction in emissions from non-ETS sectors compared to the 2005 levels. This primarily involves phasing out coal-based production capacities. This implies the need to replace old coal technologies with non-polluting alternatives. According to the Strategy, one solution for this replacement is the "development of SMR-based energy capacities, utilizing zero carbon emission technologies, replacing a decommissioned coal-fired plant, earliest by 2028-2030" (Ministry of Energy, 2022). *For such a perspective to become a reality, several economic, political, and social factors must be considered, including the availability of capital for investments, approval of new technologies, political decisions on co-financing, and the community's perception of the risks associated with nuclear technologies.*

Literature review

SMRs, typically defined (Todreas, 2015) as reactors with outputs between 10 MWe and 300 MWe, incorporate simplification, modularisation, and standardisation. These features, coupled with

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factory-based construction, enhance economic feasibility through series production. The International Atomic Energy Agency (IAEA, 2020) currently lists 70 SMR concepts , models like :water-cooled SMRs, both for fixed installations and marine-based, other (non-water-cooled) SMR concepts such as high-temperature gas-cooled concepts, fast neutron spectrum, molten salt reactor concepts, lead-cooled reactor concepts, and micro reactor concepts. An NAE-OECD report classifies SMRs into the following broad categories :

1) Single-unit LWR-SMRs – Utilizing well-established Light Water Reactor (LWR) technology and fuels, these stand-alone units can replace small fossil-fuel facilities or serve as distributed generation sources. (Rowinski, M et al, 2015)
2) Multi-module LWR-SMRs – Also employing LWR technology, these modular units can function as a replacement for mid-size baseload capacity or operate within a distributed generation framework, depending on their generating capacity. (OECD-NAE, 2021)
3) Mobile/transportable SMRs – Currently utilizing LWR technology, these reactors are designed for easy relocation from one site to another. This category encompasses floating reactors (OECD-NAE, 2021)
4) Generation IV (Gen IV) SMRs – Incorporating advanced, non-LWR technologies, these SMRs include concepts explored by the Generation IV International Forum (GIF) over the years.
5) Micro modular reactors (MMRs) – Representing designs with a capacity of less than 10 MWe, these reactors are often capable of semi-autonomous operation and offer improved transportability compared to larger SMRs. Typically not based on LWR technology, MMRs employ a diverse range of technological approaches, including Gen IV technologies. (OECD-NAE, 2021). The studies and specialized literature analyzed in this paper reference at least 20 of the SMR models outlined above. One approach aims to assess the efficiency of this technology compared to other renewable energy sources, such as wind and photovoltaic, which play a crucial role in the process of decarbonizing the energy sector. As demonstrated by Tan, S et al. (2023), photovoltaic solar panels generate energy that varies depending on time, latitude, and season, and daily and seasonal weather conditions affect wind energy production. This variability poses a challenge for national energy systems that require a consistent amount of energy to meet demand. Unlike photovoltaic panels and wind fields, SMRs consistently deliver energy to national systems. Additionally, the design of SMRs includes a load-tracking function (Tan, S et al., 2023), allowing for the adjustment of output power in line with fluctuations in electricity demand. SMRs can operate flexibly in electrical systems with variable residual loads (Tan, S et al., 2023).

Another important perspective demonstrated by numerous studies (Locatelly et al., 2014) is related to the fact that SMR technology involves lower costs compared to large nuclear reactors. Flexibility is another advantage of SMRs (King et al., 2011) compared to large nuclear reactors is the project, flexibility generated by the relatively short construction period for most models, a period ranging between 2 and 4 years.

These technologies are at different stages of development across Europe, USA, Asia or Russia. The NEA (2016) conducted an investigation into the potential market for Small Modular Reactors (SMRs) in the near term, specifically by 2035. Two scenarios were developed to account for uncertainties in market development (OECD /NEA 2021): An optimistic high-deployment scenario assumed the successful licensing of SMRs, along with the establishment of factory production and a supply chain, leading to cost competitiveness.

A conservative low-deployment scenario anticipated that SMRs would be perceived as expensive to construct and operate, resulting in a limited number of completed projects, primarily prototypes and plants in remote or isolated areas (OECD /NEA 2021).
These scenarios considered various market drivers, including grid development, the expected
Penetration of intermittent generation, developments in new nuclear build according to International Energy Agency (IEA) scenarios, and national nuclear policies.

In the high-deployment scenario, it was envisioned that up to 21 gigawatts-electric (GWe) of SMRs would be deployed by 2035 in different regions globally, constituting approximately 3% of the total installed nuclear capacity worldwide. It is anticipated that post-2035, the SMR market will likely continue to develop, aligning with decarbonization objectives that emphasize the need for low-carbon dispatchable electricity. Recognizing the diverse market opportunities for SMRs is crucial for accurately estimating their long-term market potential. (IEA/NEA. 2020. Projected Costs of Generating Electricity, 2020 ed.)

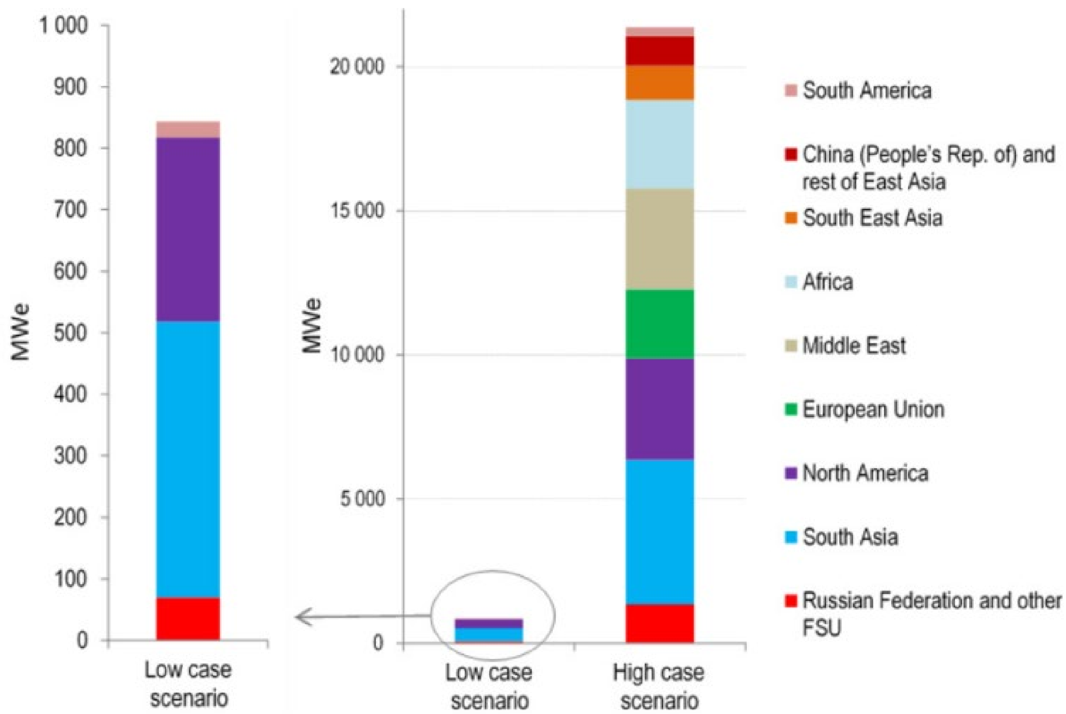


Figure 1. Estimated SMR capacity by region in 2035

Source: NEA (2016).

In Romania, two American companies, NuScale and Last Energy, are already carrying (Constatin, M et al, 2023) out two SMR projects through agreements that have been signed with Nuclearelectrica (SNN) and Romanian National Company for Nuclear Technology (RATEN).

NuScale (U.S), model PWR VOYGR-6 In 2019, Nuclearelectrica (SNN) and NuScale Power initiated a Memorandum of Understanding (MoU) and a commercial agreement to construct a six-module VOYGR NuScale plant by 2028 (SNN, Project for Small Modular Reactors ,2022).

By September 2020, the U.S. Nuclear Regulatory Commission (NRC) approved NuScale's 12-module design (50MWe per module), making it the only Small Modular Reactor (SMR) design endorsed by the NRC to date (NRC Certifies First U.S, 2023). In January 2023, the NRC certified NuScale's SMR design for a plant capable of housing up to 12 modules. During the same month, NuScale submitted a Standard Design Approval application to NRC for an updated SMR design, based on a VOYGR-6 configuration powered by a 250MWt (77MWe) module . In January 2021, the U.S. Trade and Development Agency (USTDA) provided a non-refundable grant of $1.27 million to support the identification of potential SMR sites in Romania and to develop a licensing roadmap. The siting study results were disclosed in July 2022, revealing Doicești, a commune approximately 90 km north of Bucharest. The chosen site, a former coal power plant owned by Romanian company Electrogroup, was identified, although details of the siting study remained undisclosed. In September 2022, Electrogroup's subsidiary, Nova Power, and SNN jointly established RoPower Nuclear, the project company dedicated to developing a NuScale SMR in Doicești. Two months later, in Portland, Oregon, NuScale and RoPower Nuclear signed a contract for Front-End Engineering Design (FEED) work—an eight-month project involving environmental assessment, geotechnical study, and cost estimation for the VOYGR-6 SMR project. The IAEA's comprehensive overview of Small Modular Reactors (IAEA ,2020), particularly NuScale's VOYGR-6 project, reveals a versatile and scalable solution in the realm of nuclear energy. NuScale's Power Module (NPM) is highlighted as a small, light-water-cooled pressurized-water reactor (PWR) with a nominal capacity of 60MWe, adaptable to a 720MWe gross capacity in a single facility by incorporating 12 modules (IAEA ,2020).

Last Energy (U.S), model PWR 20MW In March 2022, Last Energy and the Romanian National Company for Nuclear Technology (RATEN) signed an agreement to construct a demonstration project at the Mioveni nuclear platform. The Last Energy PWR-20 is described (Constatin, M et al, 2023) as a fully modular micro-pressurized water reactor (PWR) with a scaled-down one-loop design. Its key innovation lies in being fully modular and factory-built, utilizing industry-standard equipment from nuclear power plants (NPPs) and thermal power plants. The SMR design incorporates existing supply chains, making it fully modular and factory-made, with modules fitting into standard shipping containers. The fuel comprises standard PWR fuel bundles, allowing additional PWR-20 units to be deployed at a single location to meet changing demand.

Methodology

The research is based on an analysis of technical and financial data regarding two projects intended for implementation in Romania. The data is gathered from public sources, specialized literature, and information provided by Nuclearelectrica (SNN), the state-owned company currently overseeing the development of the nuclear energy segment. I will focus on two aspects: estimating the costs of the projects Romania aims to develop and assessing public perception because the placement of new nuclear power plants near communities/cities involves, according to the law, not only a comprehensive environmental approval but also the consent of the respective community. The production and operating costs for Small Modular Reactors (SMRs) are a significant concern for both business developers and public authorities involved in their implementation. Estimating the Levelized Cost of Electricity (LCOE) for SMRs is subject to wide ranges and uncertainties, often presented by developers in a non-standardized manner, leading to variable projections influenced by factors such as technological maturity, financing costs, state support, and certification expenses. (Steigerwald,B et al., 2023). The use of LCOE in evaluating energy projects is one of the first important steps in the analysis process to gain a clear perspective on the costs associated with energy production per unit and contributes to determining the financial feasibility of the project. LCOE plays a crucial role in facilitating comparisons between different energy production technologies, such as wind, solar, and nuclear energy sources. This metric allows financial analysts to make objective comparisons, eliminating differences in lifespans, capital costs, project sizes, and associated risk levels (Lyons, R. E. 2020). Another important aspect of LCOE is its ability to neutralize the influence of variable factors, such as different lifespans of technologies or variable capital costs (Lyons, R. E. 2020, Steigerwald,B et al. , 2023). This aspect ensures objectivity in project evaluation, regardless of the specifics of each project or technology. However, it is equally important to acknowledge that the LCOE method has limitations or inaccuracies caused by the inability to anticipate certain costs over time. LCOE calculations involve summing up expected costs throughout the power plant's lifetime and dividing by total power generation (Lyons, R. E. 2020). Assumptions about technology costs, maintenance, operating costs, capital, fuel prices, subsidies, and capacity factor vary among studies, contributing to the variability in LCOE figures. The relevance of LCOE diminishes in energy systems dominated by variable renewable sources (IEA/NEA, 2020). The International Energy Agency (IEA) provides a wide-ranging estimate for SMRs, emphasizing the uncertainty in cost projections. Comparisons with conventional nuclear plants and renewable technologies highlight the potential cost competitiveness of SMRs, particularly in certain scenarios. System Integration Costs, including balancing costs, profile costs, and grid-related costs, are critical in assessing the overall economic viability of power generation technologies. According to the International Energy Agency (IEA,2022), the estimated LCOE for SMRs is crucial for assessing their cost-competitiveness compared to other low-emission dispatchable power and heat generation technologies. *The current range of SMR cost estimates is wide and uncertain, with varying from $45-110/MWh for projects in advanced economies, depending on technology maturity and discount rates (6% or 9%)((IEA,2022).*

For the VOYGR model that NuScale aimed to implement in collaboration with Utah Associated Municipal Power Systems (UAMPS), the year 2023 brought a massive recalculation of the target price, leading UAMPS to announce that they are dropping the project (Gardner, T. et. M. Mishra , 2023). The original target price in 2020 was $58MWH. The increase is 53% of the original target price generated an increase of $89MWH. For this reason, my cost analysis uses, the adaptation of the LCOE-type estimate to economic, fiscal, and energy indicators specific to Romania *to determine whether the project in Romania is still attractive from a cost perspective.* The estimate includes capital costs, fixed operations, and maintenance (O&M) costs, variable costs that include O&M and fuel costs, financing costs, and an assumed utilization rate for the NuScale VOYGR-6 model.

Table 1. NUSCALE/VOYGR, Primary reactor design parameters.

Power, MWt/Mwe	250/77
Thermal efficiency	31%
Fuel form	UO2
Burnup, GWd/t	49.5
Uranium enrichment, %	4.95
Charge U, kg/assembly/pebble	255

Source: National Academy of Science, *Overview of Design Optimization Process for a Commercial Nuclear Core*

$$\mathbf{LCOE = \Sigma[(It + Mt + Ft) / (1 + r)t] / \Sigma[(Et/(1 + r)t]}$$

- The initial cost of investment expenditures (I)
- Maintenance and operations expenditures (M)
- Fuel expenditures (if applicable) (F)
- The total output of the power-generating asset will include:
- The sum of all electricity generated (E)
- The discount rate of the project (r)
- The life of the system (n)

Tabel 2. Electricity sales-Nuclear/ SNN(quantities, prices and values) in the first quarter of 2023

Sales by types	**Medium price [lei/MWh with Tg included]**
Sales through MACEE	450,00
Sales on the competitive market (contracts bilateral and sales on PZU), of which:	1000,89
Sales on PCCB contracts – LE Flex, PCCB - NC, PC - OTC, directly negotiated and contracts of supply	1104,04
Sales on PZU	615,99
Total sales in the first quarter of 2023	**754,72**

Source:SNN.

Results and discussions

The results indicate that despite the construction cost increase for the VOYGR model due to inflation observed for materials, reporting the calculations to the average selling cost of nuclear energy in Romania (2023, semester 1) provides a potential profitability perspective upon completing the project in the 2028-2030 timeframe.

Table 3. LCOE for VOYGR Romania

Levelized Cost of Energy (LCOE) VOYGR 77x6

Assumptions (in '000s)	
Initial Investment Cost ($)	16,500
Operations and Maintenance Costs/kWH ($)	0.025
O&M Growth Rate (%)	2.00%
Annual Fuel Costs ($)	-
Annual Electricity Output (kWH)	4,047
Project Lifespan (years)	60
Discount Rate (%)	3.00%
Starting Date	12/31/2024

Total Costs	**Starting Date**	Construction	Operations	Operations	Operations	Operations	Operations	Operations
Date	12/31/2024	12/31/2025	12/31/2026	12/31/2027	12/31/2028	12/31/2029	2030-2083	12/31/2084
Year Frac (From Start Date)		1	2	3	4	5	....	60
Initial Investment	16,500	-	-	-	-	-	....	-
O&M Costs	-	-	0.0250	0.0255	0.0260	0.0265	....	0.0788
Fuel Costs	-	-	-	-	-	-	....	-
Discount Factor		0.971	0.943	0.915	0.888	0.863	....	0.170
Present Value of Costs	16,500	-	0.0236	0	0	0	....	0.01338
NPV of Total Costs	**$16,501.06**							
Total Energy Output	Entry	1	2	3	4	5	....	60
Yearly Output	-	-	4,047	4,047	4,047	4,047	....	4,047
Discount Factor	0.000	0.971	0.943	0.915	0.888	0.863	....	0.170
Present Value of Costs	-	-	3,815	3,704	3,596	3,491	....	687
NPV of Total Output	**108,074kWh**							
LCOE	**$0.153/kWh**							

Source: Authors' own research.

Limitations of methodology

As many of the referenced studies have pointed out, the task of providing precise recommendations and techniques for nuclear cost estimation is uncertain, especially due to the lack of public data on advanced SMR reactor constructions and the inability to predict the selling cost of energy over the 40-60 years of the reactor's lifespan. While utilizing estimates from the literature has inherent constraints, additional challenges arise from the processing of this data. Furthermore, the methodology followed in this study assigns equal weight to all estimates in the literature, compiling and giving the same weight to both official data and projected estimates. Additionally, older datasets are treated the same as more recent ones.

However, it is not only uncertainties related to costs that cause SMR projects to stagnate; another significant issue is the resistance of many communities to having a new nuclear power plant nearby. For this reason, the development of any SMR project must undergo a rigorous cost analysis and, indispensably, a communication strategy to enhance its acceptability at both national and local levels.

Public Perception and Communication Strategy

Since the commencement of nuclear power plant construction, there has been a steadfast acknowledgment of potential hazards associated with nuclear criticality and the release of radioactive substances during electricity generation. Like other industries, the primary goal in designing and operating nuclear power plants is to minimize the likelihood of accidents and mitigate significant human impacts in case of such events. Over a span of 70 years and across 36 countries, there have been only three major accidents in nuclear power exploitation:

- Three Mile Island (USA, 1979) witnessed severe reactor damage, (Taebi, B et al, 2015) but limited radiation exposure resulted in no adverse health or environmental effects.
- Chernobyl (Ukraine, 1986) experienced a reactor's destruction due to a steam explosion and fire, initially causing two fatalities and 28 cases of radiation poisoning within three months, with lasting repercussions on health and the environment.
- Fukushima Daiichi (Japan, 2011) faced the disabling of three older reactors (along with a fourth) due to poorly managed cooling loss after a massive tsunami. Remarkably, no fatalities or serious radiation-related injuries occurred, despite approximately 19,500 deaths caused by the tsunami. Despite the low number of nuclear accidents over the past 70 years, the post-Fukushima era has imposed various ethical considerations, including radiological protection, or, as noted by Taebi, B et al (2015), the influence of gender on the acceptability of nuclear risk, and environmental, international, and intergenerational justice in the context of nuclear energy. Moreover, *the utilization of nuclear energy for electricity generation is deemed highly safe. Contrary to common perception, nuclear energy plays a crucial role in saving lives by replacing fossil fuels in the electricity mix. Annual coal mining-related deaths and the health and environmental impacts of fossil fuel use are significant compared to the safety records of nuclear energy.* In the United States alone, statistics show that the number of deaths from mining accidents exceeds 10,000, and such data does not reflect the incidence of pollution in the area of surface mining in the number of serious illnesses and deaths resulting from them (Statista Research Department, 2023)

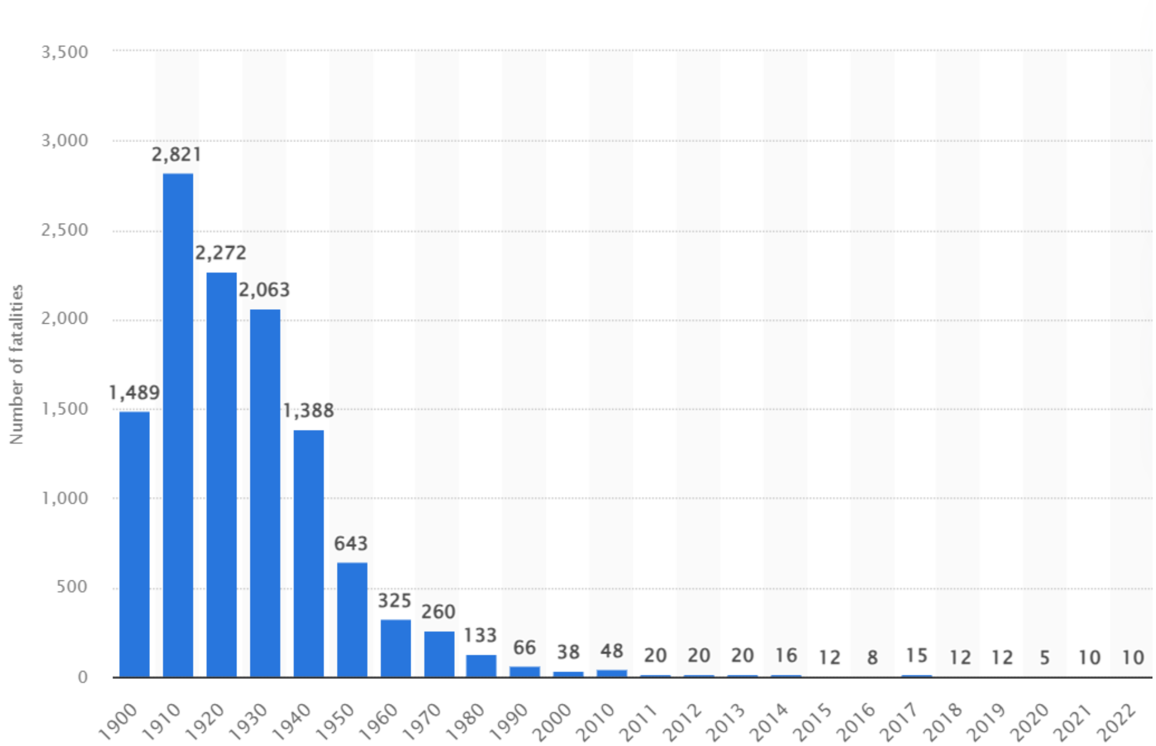


Figure 2. Number of coal mining fatalities in the United States from 1900 to 2022

Source: Statista Research Department, Oct 30, 2023.

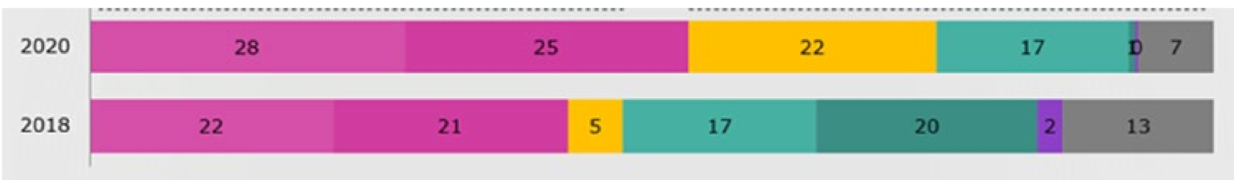
An essential safety metric is the calculated probable frequency of core meltdown accidents or core degradation. The U.S. Nuclear Regulatory Commission (NRC) mandates reactor designs to meet a theoretical core degradation frequency of 1 in 10,000 years, with modern designs surpassing this requirement (WNA, 2022). U.S. utility standards stipulate 1 in 100,000 years, with the best-performing current plants achieving about 1 in a million, and those expected to be constructed in the next decade approaching nearly 1 in 10 million. While the calculated core degradation frequency remains a primary measure for assessing reactor safety, European safety authorities prefer a deterministic approach, emphasizing the actual provision of backup hardware. They also conduct probabilistic safety analyses (PSAs) for core degradation frequency, requiring a frequency of 1 in 1 million for new designs. Additionally, not only is the perception of the risk of accidents at a nuclear power plant important, but also the management of nuclear waste generated from the technological process of the plant. Here, I will specifically refer to one of the few studies that assess metrics for nuclear waste, including those from the NuScale VOYGR model (Take, K et al, 2023). The study indicates that the management of nuclear waste over time can be easier compared to that of a conventional nuclear power plant. The authors base their conclusion on the analysis of depleted uranium (DU) mass, spent nuclear fuel (SNF) mass, volume, activity, decay heat, radiotoxicity, as well as volumes of waste from reactor decommissioning (LLW). Although the results of this study are applicable only to a "once-through" fuel cycle, they suggest that in the case of the VOYGR model, waste can be used with fuel recycling, leading to significant reductions in environmental risks. This aspect is crucial to communicate to the communities near which the SMR VOYGR plant can be built (Doicesti, Romania).

Communication Strategy

Addressing public concerns about nuclear technology is vital. An effective communication strategy should focus on educating the public about the safety, efficiency, and environmental benefits of modern nuclear technologies, including SMRs.

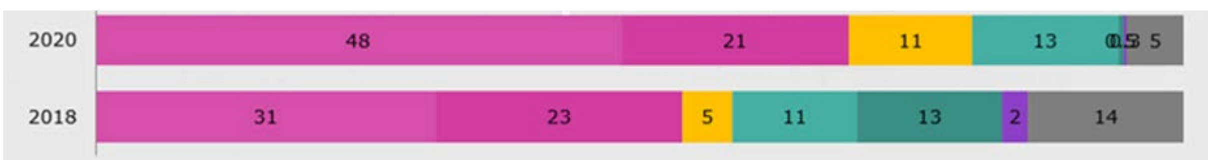
The communication strategy for promoting the safety of nuclear reactors in Romania can be based on relevant statistical data and opinion polls. This approach should highlight the advantages and safety measures implemented in the nuclear industry while emphasizing public confidence in this form of energy production.

In this regard, two surveys commissioned by SNN (Nuclearelectrica) are relevant, demonstrating that Romanians' perception of the comparative benefits and risks of nuclear energy technology is among the highest in Europe. Both in 2018 and 2020, respondents expressed interest in the economic benefits generated by the construction of new nuclear reactors, with over 50% stating a preference for these benefits over the unlikely risk of a nuclear accident (contamination).



Source : https://www.nuclearelectrica.ro/ir/wp-content/uploads/sites/9/2021/04/SNN_RO_Raport-anual-CA-2020.pdf.

The same survey shows that investments in nuclear energy contribute to economic growth. This statement was endorsed by 69% of respondents in 2020, compared to 54% in 2018.



Source : https://www.nuclearelectrica.ro/ir/wp-content/uploads/sites/9/2021/04/SNN_RO_Raport-anual-CA-2020.pdf.

Opinion Surveys: Conduct an opinion survey to assess the level of trust among the population in Romania regarding nuclear energy. Include questions about people's knowledge of safety measures and their perception of the environmental impact of nuclear energy. Identify strong points in public trust in nuclear energy and detect any concerns.

Education and Awareness: Develop clearly structured communication materials, accessible to a wide audience, explaining the benefits and safety measures of nuclear energy. Organize educational events or webinars to address the public's questions and dispel myths related to energy.

Collaboration with Experts and Organizations: Involve experts in the nuclear field and international organizations to support and validate the information presented. Ensure that communication reflects international standards and refers to best practices in the nuclear industry.

Media and Online Partnerships: Collaborate with the media to ensure balanced and informative coverage of the subject. Develop an active online presence, using websites, social networks, and other platforms to disseminate information about nuclear reactor safety.

Results and Feedback: Monitor the evolution of public opinions and adjust the strategy based on received feedback. Periodically publish updates on the performance of the reactor and implemented safety measures. By implementing this strategy, you will be able to strengthen public confidence in the safety of using nuclear reactors for energy production in Romania.

Conclusion

SMRs represent a promising avenue for Romania to expand its nuclear capacity in line with its climate goals. The successful integration of this technology requires balancing technological innovation, economic viability, public acceptance, and international collaboration. Romania can leverage the extensive experience in nuclear technology within the EU and the USA. The EU's Green Deal Industrial Plan, especially the NZIA proposal, provides a framework for advancing clean technologies, including SMRs.

The SMRs are not only an alternative to provide electrical energy in the band for the national energy system, but certain models can be used as a cheap way to heat medium or large cities in a centralized system. In addition, as it appears from the budget executions of big Romanian cities, the price of thermal energy is significantly subsidized from local budgets, the current production cost being far too high for the purchasing power of the population. Also, the individual or collective alternative of heating some buildings with the help of gas plants will be extremely difficult to authorize according to the Commission Regulation (EU) No 813/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council regarding eco-design requirements for space heaters and combination heaters.

Furthermore, subsidies for the installation of stand-alone boilers powered by fossil fuels will not be allowed from 1 January 2025. Thus, fossil fuel boilers will have to be phased out completely by 2040 and subsidies will have to be reduced from 2025 as part of a political agreement reached by EU legislators to modernize the Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955. For these reasons, SMRs can also become an alternative for central heating systems in cities.

Moreover, SMRs can become such an alternative if the Romanian government undertakes campaigns to convince the population that the establishment of new nuclear power plants represents a safe, non-polluting strategy that can also ensure a reasonable cost for both electricity and thermal energy.

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