# Challenges of SMR deployment in a Swedish setting

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**Abstract**

Sweden is experiencing a new wave of interest in nuclear energy. This interest is largely driven by the recently changed pro-nuclear political landscape in Sweden and the EU, nuclear being eligible for EU Green Taxonomy, the emergence of new nuclear technologies, and the estimated doubling of national electricity consumption. Through a qualitative study connected to the ANItA (Academic-industrial Nuclear technology Initiative to Achieve a sustainable energy future) competence centre managed by Uppsala University, we investigate how the main nuclear actors perceive the main challenges associated with the future deployment of SMRs in Sweden. This paper presents preliminary findings that indicate that many of the perceived challenges of deploying SMRs are not related to the technology itself, instead, the main challenges are tightly connected to the complex organizational and regulatory context of the nuclear setting including a lack of engineering competence, uncertainty of financing and cost estimates, uncertainty of long-term political commitment, challenges associated with nuclear waste and social acceptance as well as localization and operational challenges.

## INTRODUCTION

With the increased future demand for electricity, more energy production is a necessity to support the electrification of society and the energy transition worldwide. Nuclear power is likely to play an important role in future energy production, especially since it also has been included as an option to be considered for environmentally sustainable investments in the EU Taxonomy in 2022. Sweden witnesses a similar challenge of increasing and securing its future energy production, as it is estimated that energy use will increase from 134 TWh in 2020 to 349 TWh in 2050 [1], simultaneously the goal is carbon-free electricity production by 2040. To meet the projected energy demand and decarbonization goals, where the green transformation of large industry actors is the main driver, Sweden needs to boost the energy production of all fossil-free energy sources, including nuclear power. Several new nuclear initiatives from government, policy-makers, and industrial actors have been initiated. At the same time, previously existing restrictive laws and regulations on nuclear power have been lifted – Sweden has no further restrictions on new build nuclear power plants, their quantity or the site where they can be built[[1]](#footnote-2). Further, in December 2023, the Swedish government announced a new vision to establish new nuclear. The political goal is now to increase the total capacity equivalent of at least two large-scale reactors (2500 MW) by 2035, and by 2045 the government foresees an expansion of nuclear which could correspond to ten large-scale reactors [2]. Not only large nuclear power plants (NPPs) are in focus but also Small Modular Reactors (SMRs) have been pointed out as interesting options for the Swedish nuclear future. The benefits of SMRs mentioned are their possibility to cut both cost and time due to modular and standardized constructions, lower initial capital cost with potentially lower financial risks, and their potentially broader application area compared to large NPPs, such as district heating, hydrogen production, and heat for industrial processes. The two main utility companies, Vattenfall and Fortum, are currently involved in feasibility studies on SMRs, several new actors have entered the nuclear field with the idea of developing SMR concepts, and several government investigations have been initiated to support the future deployment of SMRs in Sweden.

Currently, Sweden, like many other countries, is in the midst of a “nuclear renaissance” witnessing high hopes for new build nuclear, particularly SMRs, as a means to solve the energy and climate crises. Notably, in both media, academic, and political discourses the benefits of introducing and implementing SMRs are put forward, while less is known about the challenges as Sweden has not built new nuclear powerplants in almost four decades (since the last reactor became operational in 1985), coupled with a historical trajectory of attempting to phase out nuclear production after a referendum in 1980. Although Sweden is an established nuclear state with existing collaboration between the government, authorities, utilities, and suppliers, the governmental roadmap to re-establish the nuclear industry in two decades is a massive task. Thus, this paper aims to contribute to a discussion regarding the main challenges of SMR implementation in Sweden. The paper is part of a larger research project connected to the Swedish ANItA (Academic-industrial Nuclear technology Initiative to Achieve a sustainable energy future) competence centre investigating the future deployment of SMRs in Sweden.

## Short note on the method

The paper relies on the ongoing research project investigating the potential of SMRs in Sweden connected to the ANItA competence center. It draws upon qualitative semi-structured interviews conducted with stakeholders actively involved in the Swedish nuclear industry in 2023 and 2024. These interviews encompassed representatives from key actor groups within the nuclear sector including utility companies, senior nuclear experts, research units, and consultants within nuclear; and other related parties. Furthermore, a three-hour workshop was conducted involving four representatives from each of the three principal utility companies (Vattenfall, Fortum and Uniper) responsible for operating the 6 large NPPs in Sweden. In total for the paper, the authors used primary data from around 30 interviews and data from one workshop.

## challenges for deploying smrs in Sweden

### Long-term political will and government support

Historically, government backing has been pivotal for any nuclear power initiatives. The present government in Sweden has articulated a future trajectory for energy production that includes nuclear energy. However, it is essential to acknowledge the transient nature of governmental tenures, typically lasting about four years, compared to the duration of the planning and construction phase of large infrastructural projects, thereby opening up for shifting policy directions in the future. Currently, some political parties in opposition in Sweden are against more nuclear power whereas others have yet to voice a clear opinion on the matter in the changing landscape. Respondents emphasize the necessity for long-term broad political commitment spanning multiple electoral cycles to underpin the implementation of new nuclear and specifically Small Modular Reactors (SMRs) in Sweden. The previous nuclear program in Sweden, spanning from the 1960s to the 1980s, exemplified a close collaboration between governmental bodies, industrial stakeholders, and utility companies. Nevertheless, the contemporary nuclear landscape diverges significantly from its historical counterpart as it is characterized by a more intricate network of stakeholders necessitating consideration of numerous interfaces and more coordination of activities.

### Localisation of SMRs

A key issue will be the future localization of SMRs, regardless of whether they will be located on existing sites or new sites. While regulation has recently changed to allow new builds on new sites, the process of approval on new sites will be long and challenging. This implies the likelihood of SMRs being situated at established sites. However, such an approach compromises the potential utility of SMRs, as their effectiveness is curtailed to approximately 30% of their capacity compared to when they are located nearer to industrial facilities and district heating systems. Substantial investments in ancillary infrastructure and grid accessibility are imperative to optimize the utilization of SMRs at the new sites. The localization of SMRs to existing sites engenders competition with the localization of large-scale NPPs because of the economy of scale. Moreover, these established sites are tailored to maximize the efficiency of large-scale NPP production, thereby complicating the integration of SMRs into such environments.

### Heterogenous design and learning curves

The previous deployment of large NPPs in Sweden relied on joint learning through the partial parallel development of two reactors at a time. Through developing “sibling reactors” (for instance Forsmark 1 and Forsmark 3) it was possible to use one reactor for training sessions, test development etc., to be further implemented on the sibling reactor which facilitated feedback loops and knowledge development. At the moment, more than 100 designs of SMRs are under development worldwide which opens up for variety of design solutions, fuel systems, demands and requirement specifications, which will impact the learning curves among the actors involved. Prior studies of NPPs [3,4] indicate the lack of learning effects when introducing too many new features to reactor types. The interviews for this study indicate the need to decide on one or two SMR designs for the whole of Sweden or even the EU, to facilitate learning and feedback loops. This also relates to a need to standardise other non-nuclear related regulations for buildings, fire and other relevant regulations.

### Operation of SMRs

To date, no SMR has been launched commercially worldwide, and considerable uncertainties exist concerning its operations. For the operations of large NPPs, regulation guidelines state the need for operations personnel on the reactor site all days of the year. Large NPPs require around 25-30 individuals involved in operations each shift, each day and all year around. It will be more expensive for the owner to secure on-site operations to the same extent as large NPPs for operations of individual SMRs. During Sweden's initiation of hydro energy production, manual on-site management was initially employed, subsequently transitioning to remote operational oversight. A similar way of managing can be the future operations of SMRs, however, this transition necessitates not only regulatory revisions but also substantial investments and advancements in cybersecurity infrastructure. Current large NPPs in operations are developed around manual steering with little digital technologies integrated, which is easier to make ‘secure and safe’ and thereby easier to ‘predict’. In contrast, forthcoming SMRs will incorporate more digital technologies, presenting novel operational challenges for personnel and cyber safety systems compared to the relatively straightforward manual operations of large NPPs.

### Competence

As a consequence of the renewed global interest in nuclear energy, the demand for competence within nuclear technology has increased, resulting in competition for nuclear expert knowledge and specialists. This means that the labour market for nuclear technology is international, leaving countries such as Sweden competing with other European countries for its skilled workforce. Hence, a key challenge for the future deployment of SMRs is how Sweden can attract nuclear experts to support the future deployment of SMRs. The respondents in the study all emphasised the whole plethora of engineering competencies as necessary for the future. The competence to manage nuclear power plants exists in Sweden, even though the number of individuals has decreased due to the closing of several reactors within the last 10 years, and existing competence and expertise working in the nuclear industry seem to be in the hands of a few very experienced individuals. Our interviewees also emphasised a lack of regulatory and ‘non-nuclear’ expertise. For instance, project management competencies in planning, designing, and coordinating the actual construction of large infrastructure projects are generally lacking within Sweden and this is a necessary competence to build SMRs in Sweden. The close relationships between current NPPs and their joint ownership (Uniper, Vattenfall and Fortum jointly own existing NPPs) have been necessary for developing expertise, joint competence and knowledge development across NPPs. For the actual competence to develop, build and run SMRs in particular Swedish nuclear actors need to look abroad to learn from others at the forefront of SMRs, for instance UK and Canada. Yet, few individuals are going abroad for competence development, hence Sweden needs to engage more in exchange activities and international collaboration to bridge the lack of competence concerning SMRs in particular.

### Regulations

A key challenge of the future deployment of SMRs in Sweden relies on the adjustment of regulations related to the licensing of new nuclear facilities. Sweden has a rather complex regulatory system for the approval of nuclear facilities. Swedish Radiation Safety Authority (SSM) is the regulatory authority in charge of approval of licencing of nuclear facilities concerning radiation and safety of the new facility. Current regulations are not adjusted to SMRs in particular but only to the existing NPPs. As an example, the actual cost of applying for a license to the SSM is currently (May 2024) 100 million SEK (nearly 9 million Euro) just for the application. Paying 100 million SEK for each SMR is too costly and will impact the profitability of the SMR. To get approval, the nuclear facility has to be approved not only by radiation safety and nuclear laws but also by 5 different environmental courts. This will impact the approval time and thereby the cost of deployment of SMRs which then will limit the benefits of cutting time and costs of deploying SMRs instead of large NNPs. The respondents of the study also pointed to the challenge of conventional legislation, such as the Plan and Building Act, which will impact the localization and actual construction of any SMR. In general, these legislations are spread across different government ministries and agencies. The respondents point out that nuclear safety-related legislation is often in focus while other relevant laws are not considered until “the shovel is in the ground”. Olkiluoto 3 in Finland was brought up as an example where some of the delays were connected to conventional building and safety regulations that had nothing to do with radiation safety regulations. The respondents thus call for more understanding of various laws, nuclear and non-nuclear, and how these are interrelated when constructing new nuclear.

### Waste management

To be approved as a license holder by the authorities, nuclear waste has to be managed. Sweden has a very well-developed system for nuclear waste, some indicate that it is at the forefront worldwide [5], but it is established and developed around large conventional NPPs and their waste. The existing nuclear waste company, the Swedish Nuclear Fuel and Waste Management Company (SKB), is jointly owned by the utility companies operating the 6 large NPPs. SKB’s estimation of future waste is based on the previous direction to work towards phasing out nuclear – which indicates less waste year by year - with the new nuclear vision in place indicating large quantities of nuclear waste to be managed. The deployment of SMRs will also add to the stockpile of nuclear waste, and if the owner of the SMR is not any of the existing utility companies, the question remains – who will take care of the waste from these new SMRs? Depending on what fuel the SMRs use and where they are located, new categories of waste need to be developed calling for changes in existing transportation, packaging, and storage that also need to be solved and approved by authorities. Thus, a main challenge remaining before any SMR can be deployed in Sweden, significant changes to the existing waste management system are necessary.

### Public acceptance

The respondents highlighted the need to establish public acceptance of all levels of society including the national, regional and local levels. Previous research [cf. 6] mentions the need for public acceptance for any nuclear facility to be deployed. In Sweden in particular public acceptance has been a key issue for large NPP owners, especially concerning acceptance on the local community level [7]. Hence, public local acceptance of SMRs is critical as the municipality (in total 290 spread over Sweden) has a local veto to resist any new nuclear facility. Given previous examples, it takes time and money to establish local acceptance on new sites, other larger energy infrastructure projects such as wind and natural gas have met resistance [8]. Without acceptance in the local milieu the deployment of SMRs outside of established sites will not be a reality, and thereby not being able to achieve a key benefit of SMRs, i.e. locating it close to the energy demand and consumption. Findings indicate that if it is possible to connect SMRs to the local industries and tax revenues public acceptance could be facilitated on new sites. In the short-run deployment of SMRs on existing sites is seen by many stakeholders as a natural step.

### Current energy system

The Swedish energy market was deregulated in 1996, building on the possibility of a customer deciding how and from where to purchase electricity. The Swedish grid is constituted of a high-voltage transmission grid and low-voltage local ones. The Swedish system is also a part of the integrated European electricity system with a few transmission connectors, where prices are settled by a pan-European power exchange Nord Pool AS. With a base load in hydro and nuclear, Sweden has a growing production of electricity by wind. The electricity system in its current state is critical for the future deployment of new build nuclear and specifically SMRs, as it has substantial bottlenecks. First, the system is rather unbalanced in terms of electricity prices and their volatility. The prices can differ between the four pricing zones, where the southern part of Sweden suffers the most unstable and high prices. Some price signals are also being “exported” from mainland Europe, which further affects the price differentiation within the country. Second, the current energy system needs to be considerably extended and updated to fit in new nuclear or increasing input of electricity from intermittent energy sources. Significant investments into the grid and storage are required from the government and grid users. Third, the actual grid expansion in Sweden is a very long-term endeavour with an average project exceeding 10 years. These project lead times can significantly affect the potential deployment of SMRs in Sweden. Finally, there is currently no regulating or coordinating body on the systematic energy system development in Sweden, which affects the ability of stakeholders to orient themselves in their business and market opportunities.

### Ownership, investments and financial risks

The current Swedish regulations recognise only some forms of ownership of nuclear plants in particular as a way of safeguarding risk management and responsibility. However, SMRs are likely to interest also other industrial and financial actors which could bring about other business models for the building and operation of SMRs. There is a potential for manufacturing and mining industries to collaborate with utilities on re-establishing nuclear, but there is limited understanding among industry and other stakeholders of how this can be achieved through a viable long-term business case. The main challenge for prospective investors in SMRs highlighted by the respondents is significant price sensitivity and volatility. The central question is how such investments can yield positive returns and profitability for involved stakeholders, and also result in cost-efficient products (e.g., electricity). Moreover, the pioneering aspect of such ventures raises questions about which actors are willing to take on the role of a first mover. Current projections suggest that the initial deployment of SMRs, often referred to as the "first-of-a-kind" (FOAK) in each respective country, will entail considerable costs. However, subsequent SMR projects, referred to as the "number-of-a-kind" (NOAK), are anticipated to benefit from learning curves and economies of scale, resulting in reduced costs over time. The uncertainty of the energy system and the financial risk underscores the need for state intervention, wherein governmental bodies give guarantees and provide various forms of financial support, akin to initiatives observed in the United Kingdom and the Czech Republic. New reimbursement systems and risk sharing thus need to be established and re-structuring of the current energy system might be needed before any investment in SMRs will be a reality in Sweden.

## concluding discussion

Sweden is witnessing a revival of nuclear energy as the current government has shifted focus from dismantling current nuclear facilities to exploring the building of new nuclear power and SMRs, and a variety of stakeholders have started engaging in activities related to new nuclear. While technical challenges with SMRs remain, interestingly, the key actors in the field believe these can be solved. Their concern is more with the other non-technical challenges – some of these in the Swedish context have been discussed above. The challenges identified and discussed are not all novel but some correspond very well to what is already known, including the economic uncertainties surrounding any new nuclear project [9,4] and the difficulty securing the long-term commitment of the government [3,7] and the strict regulatory context of radiation safety [3]. More importantly, several challenges identified are rather unexplored. For instance, accessing competent engineers and the impact of international talent competition within Europe seem critical for the future deployment of SMRs. Additionally, non-nuclear regulations, operations and localization as well as waste management, are significant hurdles to tackle, and local acceptance on new sites will take time. This will impact how far in the future we will see SMRs outside of existing sites.

All identified challenges are inherently complex and difficult to untangle. Particularly important is to note that finding a viable solution to realize new nuclear and especially SMRs requires cooperation and coordination between a whole range of stakeholders including policymakers, utilities, technology vendors, local governments, universities and research institutions, institutional investors, and many others. While engaged stakeholders are looking for first-of-a-kind examples and specific ‘numbers’ elsewhere, key questions for Sweden are related to coordination and cooperation – e.g. which organizations should take the lead, in what forums and formats cooperation can take place, and what forms such cooperation can take.

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