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Powering Sustainable Development with SMRs

A qualitative study examining the potential effects of Small Modular Reactor deployment in Southern Sweden

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With deepest appreciation,

Signature

Alixander Kanaan

Marcus Magnusson

Abstract

Europe has been immensely impacted by the recent turmoil in the continent and an energy crisis has emerged. Energy prices have soared over a period of two years and the price of energy is still at elevated levels throughout Europe and a high dependency on fossil fuels for energy production has become inevitable. The Swedish energy system, one of the most renewable systems in a historical context has recently experienced the same faith as the rest of Europe by spillover effects of energy prices due to an interconnected international energy system. The rise of questions regarding the stability of the Swedish energy system has also seen an upswing since the start of the energy crisis, which has sparked a debate whether Sweden should once again expand their nuclear energy production fleet to alleviate the symptoms of an unhealthy transmission system from a holistic perspective.

In collaboration with Uniper Sweden, the following research aims to investigate the sustainability implications of an SMR introduction in the energy area SE4 in Sweden, while also having relevant innovation theories in mind. This study shows that SMRs are a result of eco-innovation and innovation diffusion, and the result of implementing SMRs into SE4 from a sustainability perspective are deemed to be positive.

The literature review focuses on innovation theories that are relevant for energy producing technologies and their specific attributes. Eco-innovation and innovation diffusion are concepts that pertain relevance for identifying contributions to adoption of the SMR technology. Sustainability was also thoroughly examined in the literature review in order to gain a deeper understanding of what the term actually means and how it applies in todays rising concerns. Three different dimensions of sustainability have been identified within the literature, and they are ecologic, economic and social. These dimensions were found to be interrelated and important to jointly understand how they impact one another.

This study is conducted through a qualitative research method and combines both primary data in the form of interviews and secondary data in the form of industry reports, news and scientific literature, which is thoroughly presented in the empirical chapter. In order to validate that the identified effects were relevant for our purpose and scope but also to enhance the objectivity, we used three different criterions to make sure that the data corresponded with our study in general and that the answers were valid from a scientific point of view.

The analysis structure is closely connected with grounded theory that suggest an iterative method for comparing data points. A framework that shows the identified effects have been constructed based on the iterative analysis and is presented in the conclusion. Effects such as increased energy security, increased green energy production, improved incentives for investments and overall contribution to diffusion of innovation has been identified.

Key words: *Small modular reactors, Sustainability, Eco-Innovation*

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Abbreviations

SMR	Small modular reactor
IAEA	International Atomic Energy Agency
SVK	Svenska Kraftnät/ The Swedish TSO
TSO	Transmission System Operator
OECD	Organisation for Economic Co-operation and Development
IEA	International Energy Association
MW	Megawatt
MWh	Megawatt hours
TWh	Terawatt hours
LNG	Liquified Natural Gas
KPIF	Consumer Price Index without mortgage rates

1. Introduction

This introductory chapter aims to provide an explanation of the background and context of the study as well as address key aspects that are important to understand before proceeding with the research.

1.1 Background and context of the study

The global climate crisis along with the urgency to reduce greenhouse gas emissions, has led 196 parties to commit to the Paris agreement in 2015. The fundamental goal of this agreement is to keep the global temperature increase below 2°C compared to the pre-industrialized age (UN**).** It could be argued that the questions revolving energy are more important than ever and nations all around the world are making efforts to ensure energy security, stability, and affordability for their citizens, while simultaneously exploring environmentally neutral options.

Why the recent price increases have occurred is seemingly due to the Russian instigation of war in Ukraine, effectively forcing many countries to sanction Russia. The European commission (2022) reported that around one fourth of the total European energy consumption came from the combustion of LNG, with 26% of this being attributed to the production of electricity and heat. They also argue that Russia started to weaponize their energy exports by artificially increasing prices and reducing availability which also indirectly affected the price. Chart 1 visualizes the price development of LNG from 2018 through 2022.

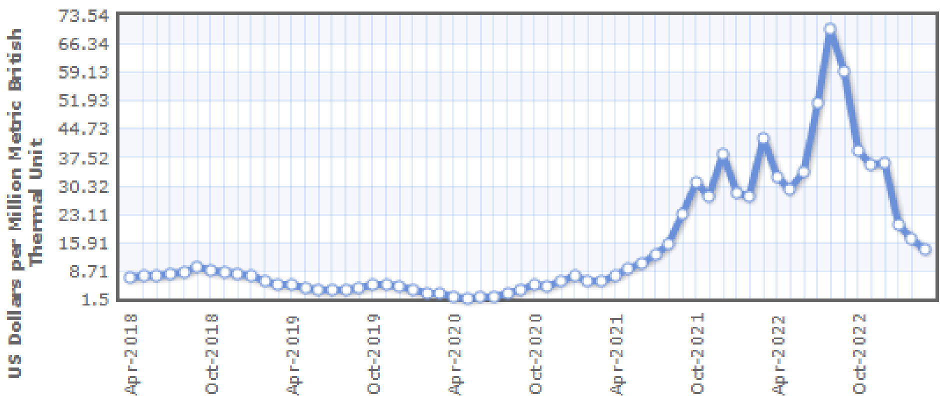

Chart 1: LNG prices between 2018 and 2022, Source: Indexmundi (2023)

1.1.1 The Swedish context

The Swedish energy system has undergone a multitude of changes that has had various implications. The national grid in Sweden was expanded alongside a handful of different nuclear power plant investments and worked in tandem to provide the Swedish society with reliable energy. These developments began in the 1950s and were realised through activation of 12 nuclear power plants between 1972 through 1985. Arguably a large investment into a reliable energy system. The grid was also constructed with these nuclear sites in mind, providing an effective structure for where both the supply and demand was historically located.

The history of the how the Swedish grid was constructed is also important to understand. Historically since the 1930s, Sweden has been dependent on hydropower, which is the electricity producing source with the lowest marginal cost per unit produced. This caused however unwanted consequences when a dry season occurred. Due to concurring events, such as a dry spell and the oil crisis in 1970, rationing of electricity, fuel and heat was put in place for the general public. These events ultimately led to the introduction of nuclear power in southern Sweden to mitigate instability, diversify the electricity producing portfolio and to equally distribute it throughout the country. At the beginning of the 1990s, the energy system was deemed adequate. (Elsystemkrisen 2022)

Many different events and developments have since transpired to ultimately create the system that we have today. 6 of the twelve nuclear reactors were decommissioned due to separate reasons between 1999 and 2020. As we can see in Figure 1, the placement of the nuclear power plants was placed in what we since 2011 call energy area SE3 and SE4. The reason for this decision was to provide southern Sweden with a reliable energy source, since SE1 and SE2 had access to hydropower as there is an abundance of lakes and rivers in the north of Sweden, which were at the time utilized at full capacity (Elsystemkrisen 2022). The incremental reduction of plannable energy production in SE3 and SE4 have increased the import dependency from neighbouring areas (both national and international) that have more energy production than consumption. Because of this need for import and limitations of transmission capabilities, a significant price difference appears between SE1 and SE4.

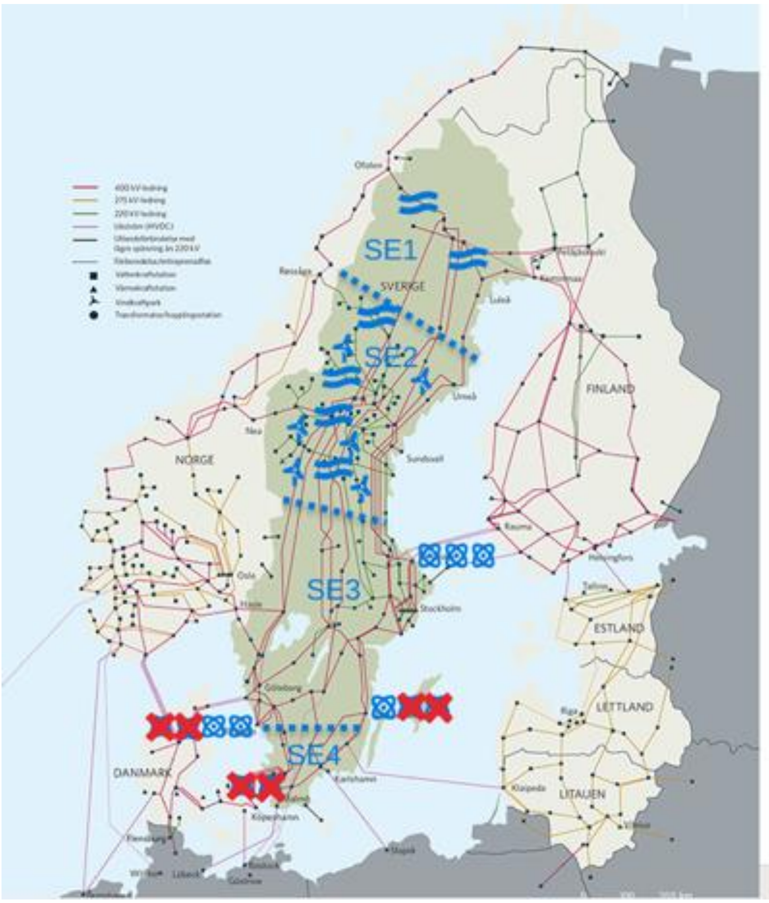

Figure 1: Source, Uniper, Henrik Svensson

Chart 2 shows the difference between electricity price between SE4 and SE1 over a 10-year period. The decommissioning of Ringhals 1 and 2 is also marked, which clearly shows a connection between those events and how the price difference was affected by these decisions.

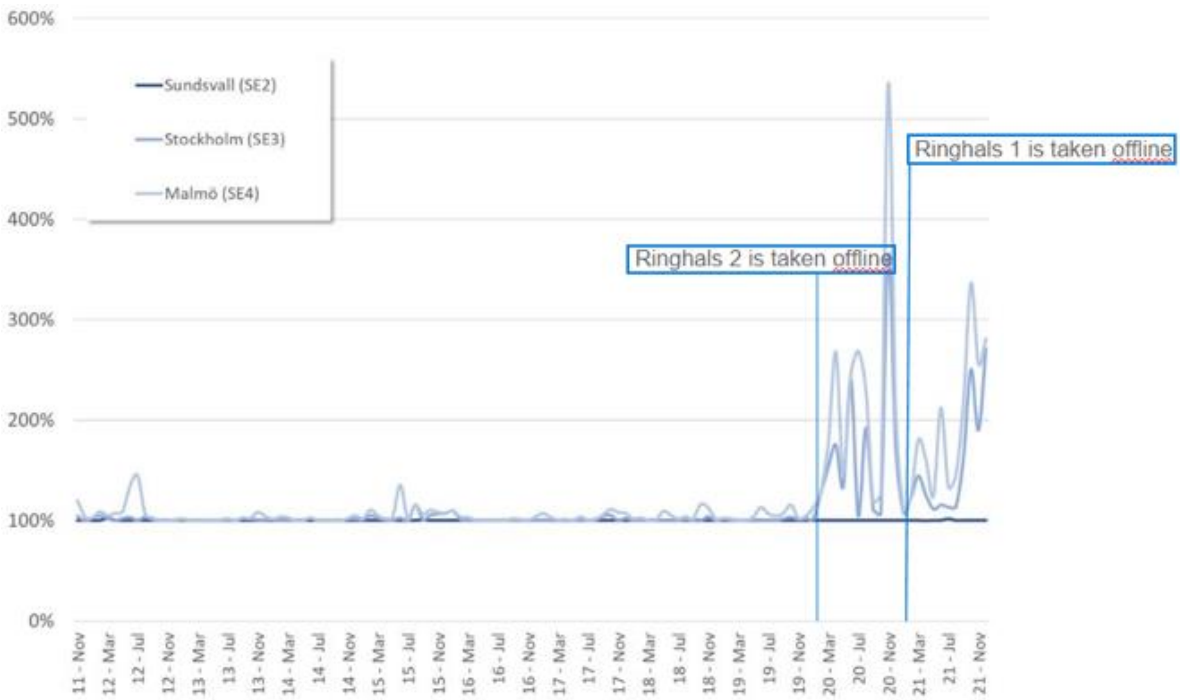

Chart 2: Source, Uniper, Henrik Svensson

The introduction of energy areas in Sweden was an effect of the Danish energy commission notifying the European Commission regarding restrictions of electricity exports being activated between southern Sweden and Northern Denmark. The reason for the restricted exports was because of cold weather that increased the electricity usage, and this was deemed an appropriate action to take by SVK in order to secure the supply within the Swedish borders. This notification resulted in a demand from the European Commission for SVK to find alternative solutions for the transmission limits that existed within Sweden to eliminate the discriminatory effects that an export restriction has according to European laws. The solution put into effect was to divide the Swedish energy system into four separate areas with separate price mechanisms. (Energimarknadsinspektionen, 2023) By studying the effects that can be connected with the term "sustainability" we can gain an understanding about what benefits would appear if a re-introduction of nuclear power in the form of SMRs at the Barsebäck site, that is geographically located within energy area SE4.

1.1.2 Small modular reactors on the rise

Climate concerns have been on the global agenda for many years and governments, industries and organizations worldwide have a crucial part in supporting innovative solutions, not the least of which advance green energy technology. Furthermore, the IAEA predicts that by 2050, half of the emissions reductions required to achieve net zero will come from technologies that are not yet commercially available. According to the IAEA (2022) this presents an opportunity for SMRs to bring forth the next phase of nuclear innovation while simultaneously playing a crucial part in reaching net zero by 2050. Furthermore, they exemplify by stating that SMRs can facilitate the decarbonization of the power industry as well as other industrial sectors through the production and utilization of low-carbon heat or hydrogen. Additionally, they could be seen as a viable option to replace commonly used fossil fuels like coal-powered electricity plants and diesel generators. This innovative nuclear technology has garnered increased attention in recent years. These reactors are designed to be manufactured in a factory and transported to their intended installation locations. SMRs offer a number of prospective benefits over conventional large-scale nuclear reactors. These include enhanced safety features, shortened construction times, decreased initial investment costs, and greater deployment and grid compatibility flexibility.

The potential introduction of small modular reactors (SMRs) into national energy landscapes is a topic of increasing global interest and significance. Sweden, with its longstanding commitment to sustainability and innovative energy solutions, is not an exception. Over fifty percent of Sweden's energy supply comes from renewable sources such as hydro and wind power. Nonetheless, as the nation endeavours to meet its climate objectives and rising energy demands while phasing out fossil fuels, the exploration of additional low-carbon energy sources is essential. This scenario lays the groundwork for a comprehensive investigation into the potential role and sustainability impacts of SMRs in the Swedish energy system.

1.2 Problem discussion

We can clearly see an increase in electricity price at the end of 2021 and an elevated electricity price during 2022 (chart 3) as well as a discrepancy in price between different areas (chart 2). While it is difficult to predict exactly why this has happened, a deduction from the explained international and national events that has transpired could be the reasons for the current situation.

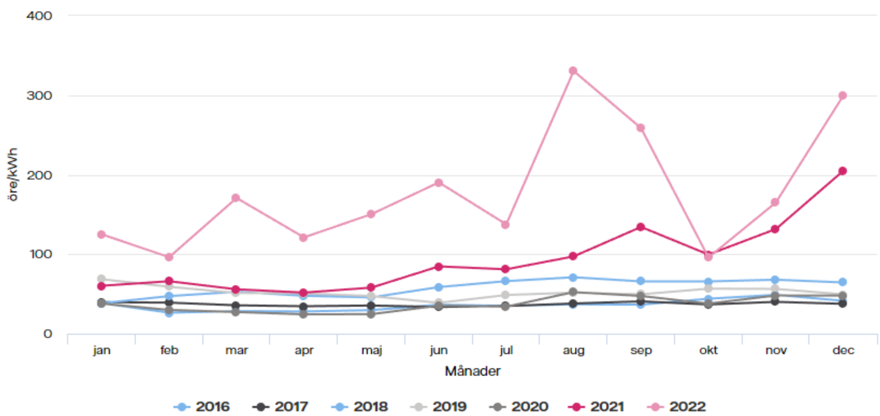

Chart 3: Electricity prices in SE4 during 2016-2022, Source: Vattenfall

The previous research on SMRs has mainly focused on the technical and financial capabilities and has therefore seemingly overlooked their potential societal and sustainability effects. Countries are racing to find the next best producer of clean energy production in order to future-proof and aid the current energy situation in their respective countries in a sustainable way. A study such as this one evaluates the efforts of one of these potential energy producing technologies and brings us one step closer to understanding how energy systems can aid in working towards sustainability as a whole and hopefully bring attention to other issues than just the ecological dimension.

1.3 Purpose of the study

The purpose of this study is to explore and identify the possible effects that an SMR introduction might have on the SE4 electricity region in Southern Sweden. The effects are looked at through a sustainability perspective broken down into three dimensions: ecological, economic, and social. Moreover, this study additionally aims to answer how innovative theories influence the development of new energy producing technologies, specifically SMRs.

1.4 Research Questions

The following research questions have been formulated to act as a foundation for the entirety of this study and will provide the direction needed to identify crucial areas. In order to most appropriately achieve the purpose mentioned above, the following research question has been formulated:

i. *How does eco-innovation influence the development of Small Modular Reactors?*
ii. *What are the possible sustainability implications associated with the implementation of Small Modular Reactors in the context of SE4?*

1.5 Defining the Scope

"Sustainability implication" is defined in this study as an effect the impacts ecological, economic, and/or social dimensions of sustainability. Moreover, Sweden is divided into four separate electricity regions as can be seen in figure 1. The SE4 electricity region is the one furthest south and it is within the boundaries of this region that this study focuses on. This means that an identified effect needs to be attributed to this area even though it could affect other geographical areas as well. The chain of effects is also limited to time constraints and the analysis ends at the authors discretion based on said time constraints. This means that the study primarily delimits itself to the effects within the SE4 electricity region in Sweden, meaning that national or global effects will not be examined thoroughly, they may however be mentioned in order to provide context into a more holistic viewpoint. The interpretation of what constitutes sustainability will be determined in accordance with the literature review and thus based on scientific argumentation.

For the purpose of this study, further delimitations have been set in order to properly conduct the research. It is acknowledged that certain delimitations may affect the potential findings and the overall conclusions, meaning that some deviations are in order. This work focuses mainly on a predetermined hypothetical scenario of implementing two 300 megawatt small modular reactors at the Barsebäck site in the SE4 electricity region in Southern Sweden. Neither the design of the reactor nor the exact specifications of it have been analysed in our scenario and it has also not been a factor for discussion during the collection of data (primarily interviews). Additionally, an in-depth technical and/or financial analysis of SMRs and their applications is outside the scope of this thesis. Furthermore, innovative theories and more specifically eco-innovation and innovation diffusion are discussed in this thesis. It must however be acknowledged that this is done in order to provide a context into the development and implementation of SMRs and a deep analysis into the innovation literature and theories is therefore not relevant to our scope, rather we merely introduce certain aspects and discuss them briefly in order cohere with the holistic objective.

2. Literature Review

Chapter 2 provides an explanation and review of literature that address innovation and certain concepts within it, as well as sustainability.

2.1 Innovation theory

In this section of the literature review, we will explore the existing research on innovation. First, we will define the concept of innovation and its different types. Thereafter, we will discuss the theories and models that have been developed to explain the drivers and barriers of innovation, including the role of technology, market conditions, and organizational factors. We will also examine the outcomes of innovation, such as improved performance, competitiveness, and social welfare.

Author	***Suggested interpretations of "innovation"***
Schumpeter (1934)	*"A process by which new products and techniques are introduced into the economic system"*
Rogers (1983)	*"An innovation is an idea, practice, or project that is perceived as new by an individual or other unit of adoption"*
Baregheh, Rowley & Sambrook (2009)	*"Innovation is the multi-stage process whereby organizations transform ideas into new/improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace"*

Table 1: Compiled suggested interpretations of the term "sustainability"

Innovation is a broad term referring to any new idea, product, process, or service that creates value for individuals, organizations, or society as a whole (Chesbrough, 2003). It can adopt many forms, from incremental improvements of existing products or processes to radical breakthroughs that create entirely new markets. Innovation essentially leads to the development of new or improved product or service that better meet the customer's needs or even create new markets. This type of innovation is often associated with technological advances and can involve both incremental and radical changes. A number of factors, including technological advancement, market circumstances, and organizational issues, have an impact on innovation. The innovation system approach, which stresses the significance of interactions between various players, such as businesses, universities, and government agencies in fostering innovation, is the most frequently acknowledged model of innovation (Lundvall, 1992). Technology change is a key factor in innovation since it gives businesses new opportunity to produce novel goods, procedures, and services. New businesses and business models may develop as a result of the dissemination of new technologies like blockchain and artificial intelligence (Brynjolfsson and McAfee, 2014).

A company's desire to adapt to shifting customer needs and preferences or to acquire a competitive edge might be influenced by market conditions, which are seen as drivers of innovation. For instance, the emergence of the sharing economy has sparked the creation of novel business models that have challenged established markets, like Uber and Airbnb (Hamari et al., 2016). Organizational characteristics have the power to both support and impede innovation. The capacity for innovation within a company may be significantly impacted by elements including leadership, culture, and resources. In contrast to more hierarchical and bureaucratic companies, those that are more decentralized and have flatter organizational structures may be better equipped to innovate (Nonaka and Takeuchi, 1995). Damanpour (1991), argues that innovation can allow for numerous effects, including greater competition, enhanced performance, and societal improvements. Innovation may boost a company's market share, profitability, and client loyalty while additionally increasing output, effectiveness, and quality.

2.1.1 Eco-Innovation

Environmental Innovation, also known as "eco-innovation," emerged in the 1990s as a concept in the field of innovation theory (Kemp & Foxon, 2008). The Ministry of Environment of Denmark (2020) defines eco-innovation as the advancement of eco-efficient technologies that directly or indirectly benefit the environment. This includes technologies that reduce pollution, promote eco-friendly products and production processes, enhance resource management, and implement technological systems to mitigate environmental impacts.

Kemp and Foxon (2007) offer a comprehensive definition of eco-innovation as the creation, application, or exploitation of novel goods, services, production processes, organizational structures, or management methods that, throughout their life cycle, lead to reduced environmental risks, pollution, and negative impacts on resource utilization (including energy) compared to relevant alternatives. Such innovation can result in cost savings for environmental improvements or generate greater environmental benefits compared to older models. It may also involve the development of new technologies to address emerging environmental issues.

Eco-innovation encompasses various forms of innovation, including technological advancements, process-related improvements, organizational changes, and systemic transformations. For example, transitioning to a renewable energy system exemplifies a systemic eco-innovation. Andersen (2005) identifies five categories of eco-innovation as follows:

- Add-on innovations: technologies and services for pollution and resource management.
- Integrated innovations: cleaner technological processes and products.
- Eco-efficient technological system innovations: new technological pathways.
- Eco-efficient organizational system innovations: new organizational structures.
- General-purpose eco-efficient innovations, such as renewable energy technologies and information and communication technologies (ICT).

Kemp and Foxon (2007) also present specific environmental technologies, such as pollution prevention measures, bioremediation for cleaning purposes, cleaner technologies, process internal recycling (reusing material waste, heat, and water), and pollution and process measurement technologies. They further provide a detailed taxonomy of eco-innovation with three classes and multiple sub-categories.

It is also important to distinguish between disruptive and incremental/sustaining innovations. Disruptive innovations have the potential to overthrow existing dominant technologies or products in the market (Christensen, 1997), while sustaining innovations build upon the existing knowledge within the innovating company to serve current product markets and users. Sustaining eco-innovations, such as the catalytic converter improving the environmental performance of internal combustion engines, help maintain the dominance of established technologies (Kemp and Foxon, 2007).

2.1.1.1 Eco-innovation benefits

Researchers have recognized the advantages of eco-innovation and the regulations that help guide them. According to Rennings (1998), businesses can benefit from environmental regulations, which promote economic growth and are commonly known as "ecological modernization." Kemp and Foxon (2007) highlight various direct benefits for companies involved in eco-innovation. These benefits include improved operational efficiency resulting in cost savings through better resource productivity and logistics, as well as increased sales through commercialization. Eco-innovators also experience indirect benefits such as enhanced company reputation, improved relationships with suppliers, customers, and authorities, strengthened innovation capacity through collaborations with knowledge holders, better health and safety outcomes, and increased worker satisfaction.

However, it is crucial to consider the costs incurred by companies when evaluating these benefits. Many companies lack sufficient knowledge about the costs and benefits associated with their environmental activities. As a result, they often perceive environmental considerations as burdens rather than valuable assets. This perception acts as a significant obstacle to eco-innovation. To address this issue, it is necessary to share experiences and information regarding the net benefits derived from eco-efficiency (Kemp and Foxon, 2007). A study conducted in 2000, which reviewed 52 case studies, demonstrated that certain efficiency measures offer non-energy benefits that are comparable in magnitude to their energy-related benefits. This finding supports the credibility of the "Porter hypothesis," which suggests that investments aimed at reducing environmental impacts can lead to productivity gains.

Additionally, the value of eco-innovations should be evaluated from a societal standpoint. Societal well-being is enhanced when eco-innovations contribute to overall welfare, rather than solely focusing on economic growth. The net increase in societal welfare occurs when the combined environmental benefits for society and the benefits for companies outweigh the costs associated with achieving those benefits. These costs include expenses incurred by companies and administrative costs related to policy instruments (Kemp and Foxon, 2007).

2.1.1.2 Drivers of Eco-innovation

Factors such as regulations, cost reductions, improving technical efficiency, increasing market shares, profits from commercialization, community pressure, green ethos, and enhancing the company's image (Kemp and Foxon, 2007). Regulation serves as a significant driver for eco-innovation, particularly in the case of renewable energy. Market failure resulting from unaccounted carbon dioxide and greenhouse gas emissions is the primary driver behind renewable energy regulations. Secondary drivers may include energy security and diversity. When operational or commercial benefits are not apparent, regulation becomes the most prominent driver for eco-innovation. Many firms realize that waste generation and pollution in production processes are cost inefficient. By implementing process and system innovations, substantial cost savings can be achieved (Kemp and Foxon, 2007). Additionally, being an early adopter of an innovation can provide firms with a competitive advantage if the innovation is widely diffused in the market. Essentially, as consumers become increasingly conscious of the environmental impacts associated with their purchasing decisions, they exert pressure on companies to reduce these impacts. This growing consumer awareness acts as a driver for eco-innovation, as firms strive to meet the changing demands and preferences of environmentally conscious customers.

2.1.2 Innovation diffusion

In the influential 1983 third edition of "Diffusion of Innovations" by Everett M. Rogers, he provides a comprehensive framework for explaining the innovation diffusion process. Rogers argues that diffusion incorporates the spread of an innovation through specific channels over time among the members of a social system. This process is distinguished by four key elements: innovation, communication channels, time, and the social system. (Rogers, 1983).

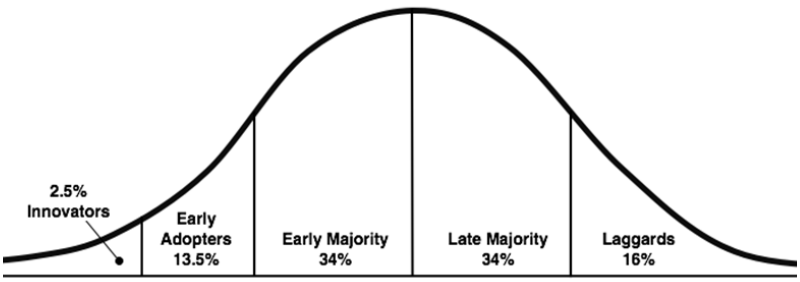

Figure 2: Diffusion of innovation framework, Everett Rogers

Rogers (1983) discusses additional factors that influence the rate of innovation adoption, including the innovation's relative advantage, compatibility, complexity, trialability, and observability. He stresses that organizations and individuals can increase the likelihood of successful adoption and implementation of innovations by gaining an extensive understanding of these factors and the diffusion process.

The diffusion process can be seen as a form of communication focused on disseminating new ideas to potential users. The diffusion process is complicated and can span anywhere from five to fifty years for widespread adoption of new technologies, depending on the innovation (Mansfield, 1968). This duration is primarily influenced by the perceived uncertainty and risk associated with the new technology. Numerous studies have verified a consistent temporal pattern in the diffusion of new technologies: initially slow adoption, followed by a rapid increase, and then a gradual slowdown once a technology-specific "adoption ceiling" is reached. Consequently, the number of adopters over a period of time will result in a "*S-shaped* consumers. *pattern"* (Blackman, 1999), this is shown in figure 2 above. The eventual success or failure of a new product or service relies heavily in the ultimate reaction of the innovators and early adopters in the early stages of development. The early adopters serve as an example for the rest to follow and therefore play a significant role in the diffusion process.

2.1.3 Diffusion of Eco-Innovation

Although previous research is limited, Kemp and Volpi (2008) state that the initial diffusion of clean technology is slow due to limited awareness and higher uncertainty compared to mainstream innovations. However, there are compelling reasons to support the development and dissemination of eco-innovations. Firstly, from an environmental perspective, the world's growing population and the desire for higher living standards have led to increased pollution, climate change, and the depletion of natural resources and biodiversity (Cawsey, 1996). In this context, eco-innovation becomes crucial for sustaining or even improving current quality of life on a social and global level.

2.1.4 Spatial proximity

Spatial proximity becomes an important topic to bring up when you discuss innovation diffusion because of the inherent condition of trust implicitly impacting local communities towards their own inventions or creations. Innovation diffusion requires a form of acceptance from the society as Rogers describes. The geographical proximity dimension of diffusion can be argued has continually been phased out because of the rise of medial proximity with the help of ICT and the relative distances has shrunken over time, but it is still a vital topic for adoption of geographically physical innovations. For example, energy producing technology innovations are ultimately dependent on the spatial and geographical circumstances of each region and needs a fundamental understanding of the specific setting it is ought to be deployed at.

Florian Noseleit (2017) aims to find out how important spatial proximity is to innovation diffusion of renewable energy technologies. Noseleit (2017) argues that adoption of new innovative technologies in general, is more likely when in close geographical proximity to the origin of the invention. He emphasizes the significance of spatial diffusion and interrelationships in understanding the transition between energy production technologies. A case study involving a partnership between an innovative technology provider and a regional energy provider exemplifies the significance of these factors in propelling transition efforts. Noseleit (2017) references Brown (1968), that defines spatial diffusion as the process by which an event extends from one or a few sites of origin within a region over time. Therefore, understanding the impact of technological innovation on the transition process is dependent on the location of technological innovations. Verdolini and Galeotti (2011) argues that spatial proximity is important for understanding inter-regional diffusion of energy technologies. Inter-regional can be ascribed to various levels of geographical proximity. Noseleit (2017) comments that this might give hints that knowledge diffusion and spillover effects can occur over larger distances as well. This observation could be the result of a relative proximity between regions compared to others or proximity in the sense of culture or commonalities between the referenced regions.

2.1.5 Synergetic effects

Because of the high demand for renewable energy sources on a global stage due to the actions and commitments being undertaken by most nations, there are problems associated with these technologies that needs to be addressed. One major problem is the relationship between renewable energy sources and intermittency issues, I.e., issue with controllability of the energy production. Pérez and Batlle (2012) explain why wind and solar generation are intermittent energy sources by stating that intermittency is characterized by two separate factors. These factors are non-controllable variability and partial unpredictability. Pérez and Batlle (2012) do recognize that the predictability of weather has increased significantly, it is far simpler to predict conventional power production from baseload alternatives. Another aspect to consider is that the variability of wind production decreases as you expand the affected geographical area with more wind turbines. Which makes sense because of the increased diversification of used geographical area.

Locatelli et al. (2018) discuss the concept of synergies and cogeneration between different energy sources to combat the issue of intermittency. They also highlight the need for a load following base power alongside the renewable sources to maintain balance in the grid and to not disrupt the price determining mechanism. They also explain that this manoeuvrability of the supply side to balance with the fluctuating demand side is mainly done through coal and oil powered energy production methods. To explain the complexity of the energy situation we can combine these two fluctuating factors of intermittency with renewable energy generation and a fluctuating energy demand. Therefore, the need to be able to control the output of nuclear energy becomes very important for the success of that energy source. The main difference and ultimately drawback with nuclear power as the main load following base energy producing source is the fact that the cost structure of nuclear power is not favourable for this setup. Locatelli et. al (2018) divides the cost structure as shares of the overall investment and conclude that nuclear power costs are mainly fixed as opposed to fossil energy sources, where the fuel costs amount to about 12% for nuclear power and between 70-80% for fossil energy sources. This means that nuclear power needs a certain level of output to cover the 88% fixed costs as opposed to fossil sources. You could argue that this low share of variable costs could contribute to a sustained level of energy prices because the marginal costs are lower and not as dependent on global market trends for fuel costs.

The proposition of combining energy production and hydrogen production as a form of cogeneration is studied by Locatelli et.al (2018), where the market conditions for energy dictates when to produce what. For example, when the demand for energy is low, the energy production needs to trend downwards to meet the new real-time demand in order to keep the balance in the system. As explained above, this effect is a negative aspect of nuclear power because of the cost-structure. Cogeneration with hydrogen production is a solution to this problem because you can switch the output of energy to produce hydrogen and thus “store” the energy for future use instead of outputting the energy to the grid directly, creating an unbalanced supply chain. The two main ways for producing hydrogen is with the help of either electricity or heat, which are both present in nuclear power generation. The S&P (2023) agrees with the prospect of new generations of nuclear power that operate at high temperatures could be a good way of producing hydrogen, they also state that small reactors (SMRs) are suitable replacements for “hard-to-decarbonize" industrial processes. They continue by saying that the demand for SMRs could be generated by systems that require reliable power or are located remotely. Locatelli et al. (2018) continues by stating that hydrogen production is a suitable product for cogeneration alongside energy for nuclear power because it requires a lot of energy input to produce the actual hydrogen, which can offset other sources of energy that are either more costly, ineffective or unsustainable compared to nuclear power.

Suman (2018) proposes the use of hybrid energy systems that uses the characteristics of plannable and unplannable energy sources to their respective advantages and creates synergies between them. Suman (2018) use nuclear power in pair with renewable sources in her article to explain how they could make a favourable synergetic energy system that could potentially solve issues regarding grid flexibility, public concerns, CO2 emissions, return on investments and energy security. By integrating renewable sources and nuclear power generation with real-time data linkages and communication, the efficiency and stability of the system could dramatically increase.

These reasonings can be deducted to become a three-way synchronization within an energy system by utilizing the shared information between energy sources to determine the relationship between electricity and hydrogen production of the nuclear energy source and ultimately utilize the aggregated energy production as efficiently as possible. What this type of system could contribute to the society will be discussed later in this thesis.

2.2 Sustainability

In following chapters will contain a synthesis of literary works discussing sustainability and what it means or is defined as. The goal of this chapter is to find commonalities between different literary works and comprise a conclusive definition of the term "Sustainability" to adequately assess the identified effects in accordance with our research question. The comprised definition will be presented in the methodology with an argumentative approach that utilizes the LR.

2.2.1 Defining the term "Sustainability"

When examining the literature, it has become apparent that there is an issue with defining the term "sustainability". What does it mean, and can it be defined differently for different contexts? Commonalities between different papers and authors is the conceptualization that "sustainability" refers to three different areas of society. Namely Ecological or Environmental, Economic, and Social.

Kuhlman and Farrington (2010) recognize that the term has been re-interpreted from a term with purely environmental implications towards a broader definition that includes three dimensions; social, economic, and environmental. They argue that this is problematic from a future perspective since the re-interpretation might create an unfocused approach towards realizing what the actual issues are at the present that affect the future negatively. By dividing sustainability into three categories, they argue that one can argue that they are contributing to the sustainable development by focusing on one of these categories, while ignoring or impacting the other two negatively, thus generating an aggregated negative contribution to sustainable development. Montiel et al. (2014) references a survey conducted among management scholars where they were asked to define what corporate/business sustainability was. Around half of the scholars included the three different dimensions as a part of CS, while a few defined it solely as a way of contributing to environmental improvement.

Schoolman et al. (2010) highlights that since the publishing of the Brundtland report back in 1987, that argued for a more holistic approach to sustainability by integrating a balance between economic growth and environmental integrity, there has been a continuation of interdisciplinary interactions to strive for a collective approach towards the new "definition" of sustainability. Urdan and Luoma (2020) highlights different definitions of "sustainability" and references the Brundtland report (1987) where they ascribe the following statement *"A development that meets the needs of the present without compromising the ability of future generations to meet their own needs."-Brundtland (1987).* They continue to argue that definitions that lack precision create uncertainty and risks different societal stakeholders to work in different directions. Urdan and Luoma (2020) however argue that absolute definitions of the term are impossible since the term is considered different based on what context you want to use it in. For example, what does the word "needs" mean in the Brundtland report (1987) presented in table x? As Urdan and Luoma (2020) argue, there is no real context to which this definition pertains to. Anyone can interpret it differently and thus the results are difficult to measure and verify its contribution towards the term "sustainability". Gallopín (2003) highlights the growing acceptance of sustainability transforming into an interconnected perspective, including economic, social, cultural, political, and ecological factors that needs an integrated way of examining their relationships in the decision-making processes. He also states that one cannot simply define the term as it is a very complicated subject that is different for different contexts. He exemplifies this statement with a reference to a compiled table (table 3) created by Bergh and Jeroen (1996), which illustrates how different theoretical perspectives interprets "sustainable development", highlighting the contextual importance of a decision. Table 3 is included to give contextual evidence for the ambiguity of how "sustainability" is defined in the literature as it depends on what situation it is reviewed in.

The general term is identified by several different authors as presented in Table 2:

Author	***Suggested interpretations of "sustainability"***
McMichael et al. (2003)	*"For human populations, sustainability means transforming our ways of living to maximize the chances that environmental and social conditions will indefinitely support human security, well-being, and health. In particular, the flow of non- substitutable goods and services from ecosystems must be sustained."*
Brundtland report (1987)	*"A development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*
Szekely and Knirsch (2005)	*"Building a society in which a proper balance is created between economic, social, and ecological aims."*
Pfeffer (2010)	*"Firms need to encompass a focus on human as well as physical resources."*
Dillard et al. (2008)	*"Sustainability is often thought of as comprised of three overlapping, mutually dependent goals: (a) to live in a way that is environmentally sustainable or viable over the long term; (b) to live in a way that is economically sustainable, maintaining living standards over the long-term; and (c) to live in a way that is socially sustainable, now and in the future."*
Choi and NG (2011)	*"The sustainability problem is one of finding a balance between personal and societal "needs" and nature´s capacity to support human life and activity, as well as ecosystems."*

Table 2: Compiled suggested interpretations of the term "sustainability"

Dillard et al. (2008) highlights an important question regarding the economic dimension being intertwined with the social dimension because of the social well-being of communities heavily depends on the economic development of that region. When the authors examined literature related to the social dimension, they found disagreement on what it is defined as. Some of the literature argued that the difference between the economic dimension and the social dimension of sustainability lies in that institutional practices are performed in an equitable and just way. Dillard et al. (2008) also references the term "social capital" coined by the World Bank with others. They explain that this term initially was used as an analogy to what economic capital is to realize the importance of justice, equity, and strong institutions. By translating these three dimensions to a form of "capital", the authors argue that it simplifies the understanding of what sustained capital over time means. The authors do however find a satisfactory definition of what constitutes social sustainability, provided by Harris and Goodwin (2001), that states: *"a socially sustainable system must achieve fairness in distribution and opportunity, adequate provisions of social services, including health and education, gender equity, and political accountability and participation".* Choi and NG (2011) add to what the social dimension of sustainability means by stating, *"The social dimension of sustainability is concerned with the well-being of people and communities as a noneconomic form of wealth."*

THEORETICAL PERSPECTIVES ON SUSTAINABLE DEVELOPMENT

Theory	Characterization of sustainable development
Equilibrium-Neoclassical	Welfare non-decreasing (anthropocentric); sustainable growth based on technology and substitution; optimizing environmental externalities; maintaining the aggregate stock of natural and economic capital; individual objectives prevail over social goals; policy needed when individual objectives conflict; long-run policy based on market solutions.
Neo-Austrian-Temporal	Teleological sequence of conscious and goal-oriented adaptation; preventing irreversible patterns; maintaining organization level (negentropy) in economic system; optimizing dynamic processes of extraction, production, consumption, recycling and waste treatment.
Ecological-Evolutionary	Maintaining resilience of natural systems, allowing for fluctuation and cycles (regular destruction); learning from uncertainty in natural processes; no domination of food chains by humans; fostering genetic/biotic/ecosystem diversity; balanced nutrient flows in ecosystems.
Evolutionary-Technological	Maintaining co-evolutionary adaptive capacity in terms of knowledge and technology to react to uncertainties; fostering economic diversity of actors, sectors and technologies.
Physico-Economic	Restrictions on materials and energy flows in/out the economy; industrial metabolism based on materials – product chain policy: integrated waste treatment, abatement, recycling and product development.
Biophysical-Energy	A steady state with minimum materials and energy throughput; maintaining physical and biological stocks and biodiversity; transition to energy systems with minimum pollutive effects.
Systems-Ecological	Controlling direct and indirect human effects on ecosystems; balance between material inputs and outputs to human systems; minimum stress factors on ecosystems, both local and global.
Ecological Engineering	Integration of human benefits and environmental quality and functions by manipulation of ecosystems; design and improvement of engineering solutions on the boundary of economics, technology and ecosystems; utilizing resilience, self-organization, self-regulation and functions of natural systems for human purposes.
Human Ecology	Remain within the carrying capacity (logistic growth); limited scale of economy and population; consumption oriented toward basic needs; occupy a modest place within the ecosystem food web and biosphere; always consider multiplier effects of human actions, in space and time.
Socio-Biological	Maintain cultural and social system of interactions with ecosystems; respect for nature integrated in culture; survival of group important.
Historical-Institutional	Equal attention to interests of nature, sectors and future generations; integrating institutional arrangements for economic and environmental policy; creating institutional long-run support for nature's interests; holistic instead of partial solutions, based on a hierarchy of values.
Ethical-Utopian	New individual value systems (respect for nature and future generations, basic needs fulfillment) and new social objectives (steady state); balance attention for efficiency, distribution and scale; strive for small-scale activities and control of 'side effects' ('small is beautiful'); long-run policy based on changing values and encouraging citizen (altruistic) as opposed to individual (egoistic) behavior.

Source: Bergh and Jeroen (1996).

Table 3: Theoretical perspectives on sustainable development

2.2.2 Systems thinking

Turkson et al. (2020) reviews literature about systems thinking in relation to sustainability. They argue that this way of thinking in systems is important for the holistic sustainability objectives, which takes the interconnectedness and relationships between objectives into consideration in a more profound way. They also reference a survey that found empirical suggestions to the growing acceptance of systems thinking in relationship with sustainability beginning from 2010. Gallopín (2003) argues that systems thinking is a way to holistically review the outcomes of a decision by examining the outcomes from different perspectives. He defines a system as:

"…a system is simply defined as a set of interrelated elements (or subsystems). The elements can be molecules, organisms, machines or their parts, social entities, or even abstract concepts. The relations, interlinkages, or "couplings"1between the elements may also have very different manifestations."- Gallopín (2003)

Cafuta (2015) doesn't specifically examine how systems thinking can contribute to a holistic approach to sustainable development but argues that the interconnectedness between different elements of an urban environment is a testament to the proposed interdependency between perspectives. Figure 3 is presented by Carfuta, which visualizes the interdependency between three different perspectives as the literature review has shown to be the three fundamental pillars of sustainable development. It also highlights how these pillars are connected to each other in a useful way.

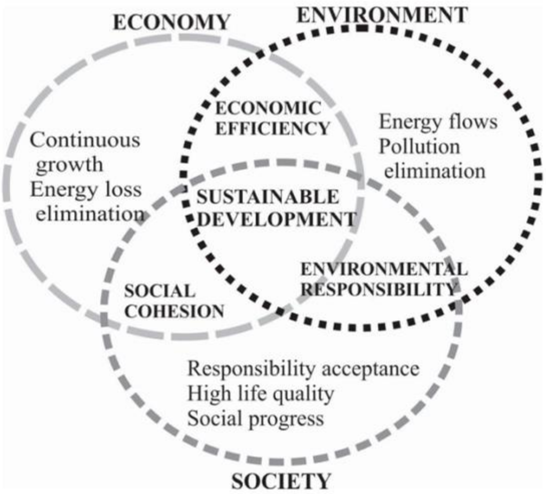

Figure 3 x2: Source Cafuta (2015)

Turkson et al. (2020) mention the terms "weak" and "strong" sustainability, that was introduced by Pearce and Atkinson (1992) as a way to understand how different policy changes or decisions impact the sustainability of the affected area. They explain that economic theory assumes that there are different types of capital, namely manufactured capital, human capital, and natural capital. "Weak" sustainability is a way to illustrate that the aggregate of the total capital at least remains at the same level, even though one type can be substituted for another. "Strong" sustainability refers to the generational inheritance of environmental assets that should be no less than what the previous generation inherited, meaning that each generation need to account for natural capital depletion when making decisions about the present use of these resources. This way of analysing the impacts as being a part of a system, further explains the evolution of how the term sustainability has undergone. Additionally, this way of thinking about the assessment of the sustainability aspect "solves" the worries that Kuhlman and Farrington (2010) highlighted about a decision being called sustainable but is directed towards one of the dimensions and negatively impacting the others. Hacking and Guthrie (2008) examine the "triple bottom-line" approach as presented in figure 3 and they also allude to the importance of this holistic approach to assess sustainability as an interrelated phenomenon. They state that the sustainable development assessment literature is unified towards this holistic way of assessing sustainable development and further explains that the field has evolved to not only focus on the biophysical perspective of sustainability. The assessment of sustainable development must encompass all three dimensions. By adopting this way of analysing how different decisions affect sustainability might lead to more inclusive decision-making process, because it adopts a system thinking approach to the sustainability concept and thus tries to minimize the substitution of one type of capital in favour for another, i.e shifting the focus away from "weak" sustainability. Giampietro et al. (2006) adds to this by stating that each stakeholder within a system carries their own definition of what effects of a decision ought to be describes as an "improvement" or the contrary, which also can be derived from the different definitions based on context in table 3.

2.2.3 The role of energy production in striving for sustainability

What role does energy play when working towards the holistic perspective of sustainability, while not only focusing on the environmental challenges. The need for stable, reliable, and affordable energy becomes ever more important as the society becomes more and more dependent on digital infrastructure to function. Axon and Darton (2021) describes this dilemma between energy security and working towards the holistic picture of sustainability. They explain that fossil fuels have the attributes of being affordable and relatively easy to have access to. This creates a dilemma because of the effects that fossil fuels have on the climate. On the other hand, the use of renewable energy sources poses different problems for the local society in terms of less stability, reliability and need for high upfront investments in infrastructure. The authors conclude their study by stating that *"We suggest that the key to assessing energy security lies in assessing the different types of risk in the energy system."*. This conclusion is important for developed countries to understand as they evolve their energy system into more renewable energy sources, with their specific attributes.

Turkson et al. (2020) points out that sustainability is a major driver for international and national policy adoption when it comes to the energy systems. They also acknowledge the unwanted indirect impacts that renewable energy sources bring along that prevent a holistic sustainability mindset when making decisions about the energy system. They try to define what sustainability means by reviewing multiple sources that tries to define the term. They do recognize that many definitions allude to the environmental sustainability but also brings forward an observation, being done by Finkbeiner et al. (2010), that sustainability should be about a balance between ecological, economic, and social sustainability as mentioned previously, these dimensions of sustainability are mentioned as important by many authors. Turkson et al. (2020) argue that it is crucial to recognize that the key principles of modern sustainability and sustainable development are centred on the synergistic relationship and interconnectedness of various dimensions within a system. This comprehension is essential because the intricate interplay between industrial, social, and ecological systems has a substantial impact on the effectiveness of decisions regarding sustainability (figure 4).

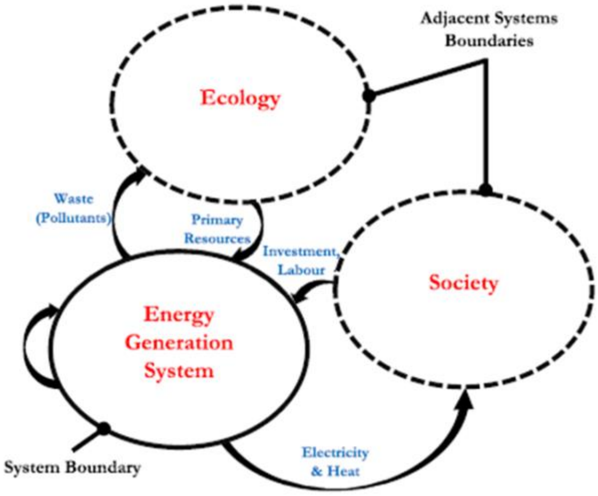

Figure 4: Turkson et al. By adaptation from Foely et.al (2003)

Turkson et al. (2020) references Jovanovic et al. (2009) that states that "*Activities related to the sustainable development of energy systems include a reduction in emissions and pollutant gases, increased safety of energy supply, use of renewable energy sources, improved energy efficiency and improved quality of life. Energy, therefore, has implications on the environment, economic development, and social welfare. Ensuring that affordable and reliable energy is derived from environmentally appropriate supply sources is critical for sustainable development".* The importance of energy sustainability is emphasized by Turkson et al. (2020), considering the far-reaching environmental impacts associated with various energy production methods. The authors stress that energy consumption not only fosters social and economic development but also acts as a major contributor to greenhouse gas emissions, particularly carbon dioxide (CO2) emissions and air pollution. The combustion of fossil fuels to fulfil energy needs is the primary cause of these emissions.

Turkson et al. (2020) elaborate on the vital role of energy sustainability in social development, asserting that access to energy drives the growth of crucial social systems, including education, health, and employment. Citing Khan's (2015) work, the authors emphasize the significance of fundamental principles such as a high quality of life, human well-being, equal opportunities for all, diversity, and a democratic civil society as core elements of a socially sustainable society. Moreover, the authors highlight the direct connection between a society's development and its energy consumption levels, positioning energy as a critical factor in a nation's economic growth. Gallego Carrera and Mack (2010) created four different holistic criteria for what constitutes social sustainability through interviewing experts in four European countries. These criteria were named "security and reliability of energy provision", "political stability and legitimacy, and "social and individual risks".

Abu-Rayash (2019) says that an indication for if an introduced energy sources ought to be deemed economically sustainable, it needs to have a higher economic benefit with an as short payback-time as possible. It also needs to impact the general levelized cost of energy/electricity of the affected region, simply meaning that energy availability for everyone will increase at a lower average cost. By reviewing the previous literature, we can see a close relationship between the social and economic dimensions of sustainability in the context of energy production. While the technology needs to be economically viable for its investors, it also needs to increase energy availability within the affected region, resulting in an integrated cross-dimensional relationship between these two dimensions of sustainability.

2.2.4 Energy access and economic growth

It is equally important to understand how the relationship between economic growth and energy relate to one another as it is to understand the relationship between energy and sustainability. Komarova et al. (2022) studies how economic growth are dependent on energy consumption and concludes that this relationship is stronger in developing countries than in developed countries. They ascribe this difference in relationship to that developed countries have more interests to accelerate energy efficiency developments because those countries have hit the ceiling for when more energy consumption leads to economic growth.

Szustak et al. (2021) examines the relationship between energy production and GDP in selected European countries. In their study they found no correlation between energy production and GDP and where they found some type of correlation, it was statistically insignificant. They also noted that policies being applied in the selected countries were about pursuing renewable energy sources and improving energy efficiency. This connects well with Komarova et al. (2022) who implied that there was a ceiling for when energy consumption stopped being connected to economic growth, especially in developed countries that instead of increasing their energy consumption tries to lower its consumption by adopting energy efficiency efforts. These studies are contradicting to what Turkson et al (2020) stated with regards to how energy consumption is related to societal development.

2.3 Gaps in literature

When researching relevant topics to discuss in the analysis and use to derive answers to this studies research questions, a gap in the literature was identified regarding how SMRs actively contribute to promoting sustainable advancements. There are a large amount of literature examining how traditional LRs contribute to sustainable advances but the distinct differences that exists between SMRs and traditional LRs is not studied enough to provide relevant insights into this research area. Because of this the authors are forced to deduct their own interpretation of what constitutes "sustainability" by examining different definitions of the term to deduct their own framework for how different aspects are interconnected and interact with one another. There are also gaps in the literature when it comes to how SMRs as a new form of infrastructure are related to the innovative branch of science. The results presented in the analysis will be inductively connected to the identified relevant literature that discuss different theories related to innovation. The analysis will hopefully result in complementary additions to the innovation literature in relation to innovative energy producing technologies and a concrete discussion with regards to how new technology impacts the regional contributions towards a holistic picture of sustainability, including all three identified dimensions.

3. Methodology

This following chapter will focus on the methodology of research and will therefore include the research approach, research strategies and the overall research design. Thereafter, the data collection and the approach for data analysis will be explained. The chapter will conclude with the important factors to consider with regards to the quality, reliability and validity of the data.

3.1 Research strategy

For the purpose of this study, a qualitative approach has been applied where a combination of primary and secondary data will be collected and examined in order to ultimate and precisely answer the research questions. One of the main benefits of adopting a qualitative approach in a study such as this is that it allowed us to acquire a more in depth understanding about specifics such as the current state of SMR technology, its' implementation feasibility and ultimately, it's potential effects on a region. Along with this, an approach of this sort enabled us to obtain the opinions and thoughts of representatives of the region who provided an experience-based interpretation of their point of views. The key for this research to be successful and add value is incorporating a variety of perspectives on the matter. The analysed data will thereafter be used when writing and revising our thesis. Here we will use our research findings gathered from the steps mentioned above in order to comprehensively evaluate the potential effects that an SMR deployment will have on the region. Understanding the words rather than numbers is a crucial action to consider and we will therefore take a subjective epistemological position (Bryman and Bell, 2015)

The thesis adopts both deductive and inductive reasoning. Deductive reasoning is used to test specific hypotheses formulated based on existing literature and theory, while inductive reasoning is used to generate insights and develop a deeper understanding of the research question. Bell et al., (2019) explain that these two approaches quite often entail elements of each other, meaning that we do not have to chooses between one or the other.

While the selected strategy is theoretically deemed most appropriate for our given purpose and research questions, it does still present a few drawbacks that must be addressed. We have identified two potential drawbacks and explain how they will be handled:

i. The first potential limitation is the limited generalizability, this is mainly due to the small and non-random sample size. With this being acknowledged, we have in detail justified our sample selection criteria and explained how the sample can be a representation of the larger population of interest, namely, Southern Sweden. Also, we will use appropriate sampling techniques to ensure that the sample is diverse and captures a range of perspectives.
ii. Secondly, we have identified the possible risk of subjectivity in the results as another potential drawback. This could happen by us influencing the analysis and interpretation of the findings. A crucial step we will take to address this is ensuring accuracy and transparency throughout our research process. This includes documenting the entire research process in detail and providing clear guidelines beforehand for data interpretation.

3.2 Research design

This study incorporates a research methodology known as "grounded theory". Grounded theory aims to develop theories and concepts that are "grounded" in the data collected during the study. Instead of beginning with preconceived hypotheses or theories, the fundamental idea behind grounded theory is to construct a theory that is founded in the data itself. The procedure entails collecting and analysing data in a methodical manner, as well as making use of the data to formulate a theory that provides an explanation for the phenomenon that is being investigated. (Creswell, 2013)

Typically, there are three stages involved in Grounded Theory: Collecting data is the next step in the research process, and it is accomplished by the researchers using a variety of techniques such as interviews, observations, and document analysis. The purpose of this activity is to amass a wealth of information that, when analysed, will shed light on the participants' experiences as well as their points of view. (Creswell, 2013)

Analysis of the data: At this point in the process, the researchers conduct an in-depth examination of the data by comparing and contrasting them in various ways. This involves comparing each piece of data with all the other pieces of data, looking for similarities and differences, and gradually developing codes and categories in order to organize the data. (Creswell, 2013)

In this stage, the researchers use the codes and categories that they developed in the stage before in order to identify patterns and relationships in the data. This is the stage where the theory is developed. They develop a theory that explains the phenomenon that is being studied by using these patterns and relationships as their starting point. (Creswell, 2013)

The focus that Grounded Theory places on constant comparison and iteration is one of the theory's defining characteristics. This indicates that the researcher will continually return to, and adjust, their analysis as new data is gathered, and new insights are gained. The use of theoretical sampling is another feature that distinguishes grounded theory. This feature involves selecting new participants or data sources based on the theory that is emerging from the data. (Creswell, 2013)

3.3 Methods for data collection

3.3.1 Secondary data collection

It is important to review a wide range of literature in order to be able to provide a comprehensive understanding of the research questions. The literature reviews will be divided into aspects in theoretical and practical usage. Initially, academic papers will be used to provide us with the necessary theoretical knowledge. There are several academic papers that address the various aspects of nuclear and SMR technology. These include the technical characteristics, economic viability, and relevant regulatory requirements. We will also analyse and utilize relevant articles that could contribute to a broader and more practical understanding of what the identified effects can contribute towards. Finally, we will review a variety of industry reports. These types of reports will give us a more practical overview and will include relevant market trends, regional concerns, as well as economic considerations. Through carefully reviewing industry reports, we will be provided with valuable insight into the current state of this industry, including deriving valuable insights as to the current needs and demands of the regional areas.

3.3.2 Primary data collection

The researchers have taken a qualitative approach for the purpose of properly addressing the research topic. A total of nine in-depth unstructured interviews were conducted. The interviews were purposefully designed to be unstructured, meaning that a list of topics and issues was prepared beforehand (Bell et al., 2019) and raised during the interview. It's noteworthy that unstructured interviews are commonly deemed informal and that the questions may be phrased differently depending on the interview. This type of interviewing technique is considered to be favourable according to Bell et al., (2019) with regard to our topic as it enables the interviewee to give a detailed encounter of their thoughts and experiences. Since the researchers aim was to truly understand the various effects that SMRs might contribute to, encouragement of discussions was important. Furthermore, the interviewees were encouraged to talk freely during interview, but it was also important to make sure that the conversation is continually steered in the right direction, meaning that when the conversation went to far off the rails, the researchers needed to take action and bring it back. The reason for this was both due to the time limitations, but also due to the researcher's goal of gaining valuable empirical data relevant to their topic.

3.3.3 Selection of respondents

Selecting suitable interviewees is a process that requires careful consideration as it is deemed to be an important step towards receiving as much valuable information as possible. The process of selecting participants for a study is known as sampling (Bell et al. 2019). Within qualitative research, the sample size is typically smaller and the focus on placed on depth rather than breadth of understanding. Although there are many approaches to sampling in qualitative research, Bell et al (2019) make the case that it is not always a simple process. Sampling involves careful consideration of the research questions, the design of the study as well as the overall purpose of the research.

For this study, the participants for the interviews were selected using a mix-sampling approach by combining purposive sampling and snowball sampling. Purposive sampling essentially means that the researchers do not randomly or on a probability-based form select their respondents. Rather, the aim is to sample the respondents in a strategic manner which will ensure that the sampled bestows the answers and has specific insight with respect to the research questions. Similarly, snowball sampling is also a non-probability method, here however, the researchers identify and recruit participants along the way through the referrals of the initial participants. The snowball sampling is useful for this study as it allowed the researchers to increase the depth of certain topics by receiving recommendations of who to contact by the initial participants. Industry experts were chosen because of the knowledge and accumulated experience within the fields of nuclear energy, sustainability, and business development. Respondents were initially picked based on suggestions from our supervising company, as well as through desk research.

Respondent	Organization	Title	Date	Time	Language	Place
Eero Vesaoja	Fortum	Head of Strategy and Development	2023-03-23	1h	English	Digital
Henrik Svensson	Sydkraft Thermal Power	CEO	2023-03-23	1h	Swedish	Digital
Christian Ekberg	Chalmers University of Technology	Head of Energy and Materials/ Professor	2023-03-30	1h	Swedish	Physical
Marie Pettersson	Kävlinge Municipality	Head of Sustainable Development	2023-04-03	1h	Swedish	Digital
Mats Rosén	Kävlinge Municipality	Head of Business and Tourism	2023-04-04	1h	Swedish	Digital
Carl Berglöf	Energiföretagen	Senior Advisor Nuclear Power	2023-04-04	1h	Swedish	Digital
Maja Lundbäck	Regeringskansliet	Political Advisor	2023-04-14	1h	Swedish	Digital
Christan Sjölander	Kärnfull Next	Founder/CEO	2023-04-17	1h	Swedish	Physical

Table 4: Interviewees for this study

3.3.4 Interview process

Once the initial respondents were selected, the researchers proceeded to initiate contact with them. First, a phone call was made to each respondent to provide a quick and more personal introduction. After briefly explaining the research and the purpose of the phone call, the respondent was asked if they could consider participating in an interview. Thereafter, an email was sent to the respondent with more detailed information about the research as well as the specific topic that they would be asked to discuss during the interview followed by a few example questions. This is according to Bell et al (2019) something that must be done before conducting the interview. This allowed the respondent to prepare beforehand as well as properly reflect on their own ideas without necessarily knowing which questions would be asked during the interview.

As most of our respondents are based scattered around the country, it was deemed most useful to conduct most interviews digitally via Google Meet. The exception being with three of the respondents who are based in Gothenburg, here the researchers asked to have the meeting in person and the respondents accepted. Although Google Meet is considered to be a valuable tool when conducting a meeting, face-to-face in person interviews are still preferred by the researchers as it allows for a more personal interacting, and it eliminates the risk of technical issues disrupting the conversation. Google Meet is however the next most suitable option as it allows for both parties to see each other, as well as enabling the interview to be conducted for a longer period of time. Telephone interviews were not an option for this research, mainly due to the limitations it adheres. Some of the limitations as mentioned by Bell et al., 2019 relate to the risk of misunderstandings due to not being able to interpret body and facial language, as well as the risk of lacking engagement from both parties. Furthermore, the interviews for the researched were estimated and scheduled to take 1 hour, this is according to the authors too long to be conducted over the telephone.

The interviews began with the interviewees thanking the respondents for taking the time as well as giving a general recap of the purpose of the study. It was also explained clearly that as this interview is quite unstructured, we expect them to speak freely and bring up any information that they deem relevant for the topics that were prepared. All respondents were asked if they approve that the interview being recorded, and the purpose of the recording was presented clearly. By the end of each interview, the respondents were informed that a summary of the transcription was to be sent to them before they approved if it could be used in the thesis. By approving the summary, the respondents also agree that they are not anonymous in the thesis.

3.4 Methods for data analysis

The literature review will be analysed for themes and trends, with the relevant information being synthesized and incorporated into the overall analysis of the effects that an SMR introduction could lead to in energy area SE4 in Sweden. To be able to continually analyse our interviews to guide us as grounded theory suggests, we will use the "constant comparative" method, which involves systematically analysing the data to develop organizing codes and categories. The constant comparative method is essential to the data analysis process of Grounded Theory. This method involves comparing each data item with all others, searching for similarities and differences, and developing codes and categories to organize the data progressively. Constant comparison is iterative and ongoing, with the researcher continually revisiting and refining their analysis as new data is collected and new insights emerge. The objective of constant comparison is to identify data patterns and relationships. As codes and categories are created, they are compared to one another and to the data to identify similarities and differences. By employing the constant comparative method of data analysis, researchers can gain a more nuanced and comprehensive understanding of the phenomenon under investigation. They can recognize patterns and relationships that may not have been evident from the raw data alone. This technique also enables researchers to create abstract and conceptual categories, as opposed to merely descriptive ones. (Creswell, 2013)

As we analyse the interviews, we will find commonalities and discrepancies between the interviewees, which will be coded into defined segments and dimensions. These segments aim to divide the analysis into parts that can be thoroughly analysed without the noise that comes from unrelated data segments. To be able to create a holistic picture of the effects we will also use external sources of information and data as empirical results to fill in the gaps in our own data collection. We recognize that our area is open-ended meaning that we anticipate a particular trajectory of answers but cannot confirm our suspicions before conducting the interviews. In order to guarantee that our scope does not accelerate too far away from the core research questions and importance for the region, we will continually make limitations with the help of experts on nuclear power based on the interviews and what we consider out of scope for our research.

3.4.1 Structure of the analysis chapter

Structurally, the analysis consists of each subsequent effects that have been identified through examination of the primary data collection with additional secondary data to verify the arguments and reasoning for the relationships being described. It is important to highlight that the presented criterions in the following chapters are verified differently as the first and second criterion needs a more in-depth analysis in order to be validated. The first criterion will be assessed within the analysis chapter in order to find enough importance for our specific scope. The second criterion is also verified in the analysis chapter by the use of relevant theory presented in the literature review chapter in order to derive a relationship with at least one of the sustainability dimensions. The third criterion is verified in the data coding phase, meaning that if the data is presented in the empirics and subsequently analysed, it has met that specific criterion. Connections with innovative theory are presented through the analysis chapter 5.1 and is not a part of the deducted framework. It is important to clarify that the start of the analysis chapter assumes that an introduction of the specified scenario has occurred, meaning that two 300 MW Small Modular Reactors have been introduced at the Barsebäck site.

3.4.2 Creation of our analysis model

In order to answer our research questions regarding the potential impact that a deployment of SMRs in the energy area SE4 in Sweden could have on working towards sustainability as a holistic concept on a regional level, we need to identify what effects an SMR deployment has on a regional area and determine what constitutes working towards sustainability, which is done in the literature review. We also want to map out the interconnectivity between the different sustainability dimensions and ultimately how different effects of the deployment interact with each other.

By basing our study on grounded theory, we can continually analyse our qualitative data and contrast it with secondary data gathered from previous research and thus generate the theory as the study progresses. The iterative nature of this way of analysing enables us to progressively work towards our final theoretical framework that is within our boundaries. Creswell (2013) brings up the discussions of Strauss and Corbin (1998), where they expand the model one step further by introducing the concept of "conditional matrix". This concept aims to help the researchers to connect aspects that affect the underlying phenomena. In our case this "conditional matrix" will be utilized to make the connections between the identified effects and visualize these through illustrations. When the framework is completed, we aim to illustrate relevant concepts/effects and how they relate to one another. Thus, answering our research questions in an understandable and illustrative way.

3.4.3 Criterion-based analysis

Three different criterions were defined and needed to be fulfilled for the identified concepts/effects to be included in the analysis and subsequent framework. It is important to highlight that these criterions are only in effect when analysing the data relevant to answer the second research question. The first research question aims to understand the theoretical perspective on innovative ideas in connection with SMRs specifically in our context. These multi-criterions are:

1. Relevance for our scope
    a. The identified concepts/ effects need to be able to answer the research questions with regards to scope of the study. For example, decreased electricity prices for the SE4 area are a concept/effect that will impact our specific region.
2. Sustainability implications
    a. The concept/effect needs to impact at least one of the three identified dimensions of sustainability.
    b. A grouping of different minor observations that together contribute to at least one sustainability implication can make the group abide by this criterion.
3. Validation of the data
    a. The identified concepts/effects need to be verified using a criterion based on primary data frequency among the interviewees or validation through secondary sources that suggest the same/ similar conclusions.

The use of criteria when determining the usefulness of a concept with the help of a grounded theory approach is important according to Bell et al. (2019). They suggest the use of a criterion that relates to the frequency of the observed concept in the data collection phase. By this they mean that if a concept is to be deemed appropriate or useful for the study, the concept needs to appear more than once. For our context this means that if a concept is to be included in the framework, the concept needs to be confirmed by more than one interviewee or by an external source of information that suggests the same concept.

3.4.4. Defining the criterions

The criteria are important for our analysis since the exploratory nature of the study could quickly lead us outside our specified scope. We also need a way to determine if the observations relate to our research question in any meaningful way. Lastly, a criterion-based approach to validate our qualitative data collection is an important step to obtain a more objective selection of the observations. Ambiguity also gets resolved in a more meaningful way. The following clarification or the three criterions being used to objectively compose our suggested framework and is the defined and definite criterions that need to be met.

In order to assess the sustainability implications of an identified effects, relevant theoretical definitions based on the literature review will be used to evaluate whether the effects fulfill the sustainability criteria. Because of the scattered interpretations of the term sustainability, we will use an argumentative approach where each effect is carefully evaluated. As the literature review states, the sustainable development assessment needs to adopt a system thinking approach, which we will use to derive the finalized farmwork. The reason why we have chosen to not define the criteria for the three sustainability dimensions is due to the interrelated relationships between them. This means that they need to be evaluated on separate terms.

1. Relevance for our scope
    a. The identified concept/effect is geographically attributed to the SE4 area.

        i. If it could be argued that the concept/effect is geographically attributed to a larger area than SE4, it is still a relevant concept/effect if we deem them to be significant enough for the SE4 area.
2. Sustainability implications
    a. Implications for the ecologic dimension
    b. Implications for the economic dimension
    c. Implications for the social dimension
3. Validation of the data collection
    a. At least two interviewees need to identify the same concept/effect
    b. If only one interviewee identifies a concept/effect, that concept/effect needs to be further validated through an objective secondary data source that draws a similar conclusion.
    c. If a concept/effect has not been brought up by the interviewees, but it still deemed to be significant, a secondary data source can validate that concept/effect if the source is soundly connected with the linkages and is important for answering the research question.

3.4.5 Criterion matrix structure

In order to evaluate each identified concept/effect in accordance with our constructed criteria, each part that discusses the empirical findings will end with a conditional matrix that lets us know if it abides by our criterions. Once again it is important to highlight that the validation criterion is verified if the data is presented in the empirical section and being used in the analysis chapter to gain an understanding of the first and second criterion. For criterion 2 and 3, the identified concept/effect only needs to fit at least one of the underlying parts of the criterions explained in 3.4.4. The structure of the conditional matrix is as follows:

Concept/Effect	**Relevance for our Scope (Yes/No)**	**Sustainability Implications (Ecologic/Economic/Social)**	**Validation of the Data (Yes/No)**
Identified concept/effect	Yes/No	Ecologic/Economic/Social	Yes/No

Figure 5: Multi-criterion matrix

3.5 Validity

According to Bell et al., (2019), validity refers to the extent of which the research at hand accurately represents the phenomenon being studied. The authors argue that several approaches could be used in order to enhance the validity. As this study and its design is built upon grounded theory, certain measures have been put in place to strengthen the validity. More specifically, we focus on the credibility, transferability, and finally the confirmability of our research finding. Another measure we used to enhance the validity of the constructed framework was to define a set of criterions that needed to be met by the used concepts within the framework.

3.5.1 Credibility

As this study is based on a grounded theory approach, credibility is crucial in ensuring the trustworthiness of our findings. To enhance the credibility, interviews were conducted with a carefully selected group of respondents who possess expertise within a specific area. These respondents were chosen to provide rich and in-depth insights into the research topic. One method employed to strengthen credibility is respondent validation, also known as member checking (Bell et al, 2019). A summary of the transcriptions was sent to the respective respondents post interview for their review. This process allowed the respondents to verify the accuracy of their contributions and interpretations. They had the opportunity to object to any misinterpretations or suggest necessary changes, ensuring that their perspectives were accurately represented in the final thesis. By incorporating respondent validation, the credibility of the findings is enhanced as the participants actively engage in validating the researcher's interpretations.

3.2 Transferability

Transferability refers to the extent to which the findings of a study can be applicable to other contexts or settings. In this study, the aim is not to generalize the findings to a larger population, but rather to provide rich and context-specific insights. However, efforts have been made to enhance transferability through the use of triangulation. Triangulation involves the utilization of multiple data sources, including interviews, articles, and reports (Creswell, 2013). By gathering data from various sources, we can capture different perspectives and experiences related to the research topic. This approach allows for a more comprehensive understanding of the phenomenon being studied and increases the transferability of the findings to similar contexts. By comparing and contrasting data from multiple sources, common themes and patterns can be identified, thereby strengthening the validity of the findings.

3.3 Confirmability

Confirmability is concerned with the integrity of the conclusions drawn through the research and aims to establish objectivity in the study (Bell et al, 2019). Several steps have been taken to enhance confirmability in this study. Firstly, the researcher engaged in regular discussions and consultations with supervisors, who are knowledgeable about the research topic. These discussions involved sharing the research process and findings along the way as well as asking questions to which we felt unfamiliar with. Peer debriefing provided an external perspective and acted as a form of peer review, contributing to the rigor and credibility of the study. Reflexivity is another aspect of confirmability. Here, we actively engaged in self-reflection and documented personal biases, assumptions, and any preconceptions that we might have. By acknowledging and addressing these potential influences, we aimed to minimize biases and increase the objectivity of the study.

4. Results

This section will include our primary data collection in the form of qualitative interview answers combined with secondary data to either verify or combat any given answer. The main objective is to give a holistic description of our scenario and what consequences that specific scenario could lead to.

Before moving on it is important to understand that since our proposed scenario is purely hypothetical in our specific context, we could use the real-world consequences of the opposite scenario that has been occurring for decades in Sweden. Since the dismantling of the Swedish nuclear fleet, we argue that the effects that we see right now in SE4 could be used to explain what would happen if the opposite were to occur. This way of using a juxtaposition to reason for the opposite event was used by many of our respondents and we find it to be a logical way of interpreting their answers when it comes to answering our research questions. However, we do acknowledge that there are many other parameters affecting the current situation than merely the dismantling of the nuclear fleet in southern Sweden, which is why we will be very careful when using the juxtaposition to argue for possible effects.

4.1 Effects on the energy system

4.1.1 More plannable and synchronous energy production

Henrik Svensson, CEO for Karlshamnsverket, explains that nuclear power does not only provide the energy system in southern Sweden with more plannable energy production, but also made the distinction of that specific energy source being synchronously connected, meaning that it provides an indirect attribute of generating a stabilizing effect on the frequency of the energy system in general. *"The obvious effect would be that we would have access to an additional 600 Mw of plannable, synchronously connected electricity production in SE4."* He further explains that this would affect the use of the reserve power [oil-fired power] in a negative trajectory.

Maja Lundbäck, political advisor for the government, explains that there is a distinct difference between Mw and Mwh. Mwh is the energy consumed during an interval of time while Mw is the amount consumed at any given time. She states that this difference is very important to understand when discussing how the energy system works. The need to maintain the correct frequency in the system is critical for its function and is primarily done through activating the power reserve, which are mainly production methods that utilize fossil fuels or natural gas in Southern Sweden. In order to maintain the frequency, you need to be able to supply enough Mw to the energy system at any given time to keep the frequency at 50 hertz. Carl Berglöf, senior nuclear power advisor at Energiföretagen, adds to this by stating that synchronous energy sources indirectly serve as a frequency regulator which reduces the risk of power outages and the use of reserve power.

Svensson extends his reasoning to the issues that southern Sweden is facing now with the need for planned maintenance of every energy producing technology, especially nuclear power plants. According to Svensson, *"If we were to go back 10 years in time, we would never see headlines about Oskarshamn 3 or Ringhals 4 being offline due to fuel damage that would take 6 months to repair in the newspapers. If even one nuclear reactor needs to be taken offline,* *there will be consequences for the electricity market."* Here he is referring to the discontinuation of the Swedish nuclear reactor fleet from 12 reactors to 6 reactors that are currently active. Svensson continues explaining that if you take away an energy producing unit with its unique attributes you also need to replace it with something similar, or at least make sure that the grid can handle that specific change. If you don't do this analysis, you risk compromising the stability, integrity, and robustness of the grid, which has previously happened in Sweden, according to Svensson.

Sofia Tanaka and Gustav Olsson published an article in DN 26th of April 2023 that suggest that the impact on the energy system and energy price is huge when one or more nuclear power plants goes offline. They say in their article that due to a power outage in Stockholm the 25th of April 2023 nuclear reactors Forsmark 1 and 2 were forced out of production. The result of this were reportedly close to double energy prices the following day. Kim Lundin, at Dagens Industri (2023) also reports that the price surge on electricity the day after the shutdown of Forsmark 1 and 2 are likely due to this event. This statement is backed by electricity market analyst Christian Holtz in the same article.

In a joint venture report by Fortum and Uniper called INET (2022), they highlight a number of attractive attributes that SMRs pertain for the future energy system that includes a large share of renewable energy sources. These attributes are baseload capacity, decentralization, cogeneration and grid stabilization. Namely baseload capacity and grid stabilization attributes make it possible for the share of renewable energy sources to increase without compromising the integrity of the energy system.

Staffan Qvist examines which combination of energy sources provides the most cost-effective energy system in his extensive scenario analysis, (kraftsamling elförsörjning) published in "Svenskt Näringsliv" 2020. His conclusions indicated that a distribution of 1 third retained hydro-power, 1 third wind power, 1 third retained and expanded nuclear power production is the most optimal. It is important to mention that this scenario had a neutral position towards what energy producing technologies that would ultimately lead to the most cost-effective system. He also concludes that an energy system that utilizes exclusively renewable energy sources was on average 40% more expensive than the optimal scenario.

Energiföretagen published a report in the beginning of 2023 which predicted the needed supply of electricity by the year 2045. They concluded that the energy need would amount to 330 TWh and the capacity at the highest load would be 49 GW. They also shed light on the fact that if no refurbishing efforts would be made on the existing energy supply, there would only exist around 40 TWh by year 2045 of existing infrastructure, highlighting the need for investment into new infrastructure to accommodate future needs.

4.1.2 Transmission of energy

Svensson sheds light on the fact that energy producing plants that have the attributes that nuclear power possesses, acts like pressure points within the energy system. Making it possible to transfer electricity between energy areas more efficiently. Most of the interviewees agreed with this fact but to different extents. The general consensus was that 600 Mw of nuclear power at the Barsebäck site would generate an additional 300 MW of transmission capacity between energy area SE3 and SE4, contributing with around 900 MW of capacity effectively in total. Berglöf states that as Sweden expanded their wind production in northern Sweden and decommissioned plannable energy in southern Sweden, it effectively created a lock in-effect of the produced energy in northern Sweden. This energy was not able to be transferred effectively between energy areas because of how the energy grid was constructed with these "pressure points" in the south in mind.

Christian Sjölander, Co-founder of Kärnfull Next, adds that the current electricity grid is constructed according to where the consumption of electricity existed historically. This assumption that the consumption of energy will remain where it is for all eternity, is according to Sjölander, a foolish thing to do. Sjölander says *"If you build reactors, you will get the system services that allow you to move the energy better than we can today. Then we have the possibility to use the transmission in a different way."* He adds by stating that it is difficult and expensive to build additional transmission and poses the question, is it better to build new transmission or to invest in energy production geographically closer to the consumption?

Svensson does not think that building more powerlines will solve our problems because there is a lack of "pressure points" and power production in southern Sweden to accommodate the supposed new power lines. He argues that the grid is sufficient but currently lacks a well distributed production of energy compared to where the consumption is located. Berglöf argues that to maintain a stable, robust and competitive energy system you need to make changes in balance to gain the preferred attributes. Berglöf says, *"We usually talk about building it out in balance. You can imagine that only plannable energy sources are built. What happens then is that you get an unnecessarily expensive system, so you can imagine that instead you build with only weather-dependent power, that is the cheapest kilowatt hours, and then you get a system that will not be able to be operated and used in a good way."* Jacob Stedman and Janne Wallenius adds to this discussion in an article published on NyTeknik.se (2023), where they argue that if the focus is to have a reliable and cost-effective energy system, we need to have a balanced and neutral approach to every energy source. They reference a study conducted by Staffan Qvist previously mentioned called "kraftsamling" (2020) where they concluded that an energy system that is neutral with its preferences to energy production methods as well as have a relatively balanced approach. They argue that this approach has a less risk of creating a generally more expensive electricity market than it needs to be, and it will support the electrification of the society.

An explanation for why Svensson is arguing that the grid is sufficient enough if accompanied with the correct production methods in the correct locations is because of a criterion called N-1. Berglöf and Svensson explain that this criterion is about being able to handle the largest dimensioned fault in the system at any given moment in time. They explain what this means by an example; if Oskarshamn 3 goes offline, you need to be able to cover its share of capacity within 15 minutes of the fault occurring. Berglöf continues by explain how this is done today: *"In order to be able to handle a N-1 in southern Sweden, it is necessary to leave capacity over in the power lines from the north so that you can lead down the current in order to relieve power lines or where you have overloads in the event of an N-1 failure."* He continues to explain that before the decommissioning of the nuclear power plants in SE4, we could rely on those reactors or import electricity to cover the capacity loss during an N-1 fault. Whereas now SE4 can only rely on import from neighbouring areas.

Mats Rosen, Head of business development at Kävlinge municipality, explains that the closure of Barsebäck nuclear power plant led to that all plannable electricity production seized to exist in SE4 which in turn has led to increased discussions with the private industrial sectors that exists in southern Sweden regarding the future energy reliability within the area. Rosen continues to explain that the grid in SE4 is built with the presumption that Barsebäck exists and produces electricity, which creates issues for private expansions because it is difficult or impossible to provide these energy intensive investments with the guarantee of enough capacity to function.

One aspect that Christian Ekberg, professor at Chalmers, bring up when posed by the possibility of increased transmission capacity by around 50% of the introduced energy production capacity, is that this doesn't take the law of export of electricity within the European Union into consideration. He essentially means that if southern Sweden were to get access to 900 Mw of more electricity production, we are obligated to leave a percentage of this open for trade with the European Union.

In an article published on SVKs website (2021), where an interview is conducted with Niclas Damsgaard, Head of strategy related questions about the electricity market at SVK, he answers some questions regarding the interconnected electricity market in Europe and how it affects the pricing in Sweden. He says that the trade of electricity commodities has increased in recent years, which has affected the pricing of electricity in southern Sweden to have become increasingly dependent upon the electricity prices in northern Europe. Whereas the prices in northern Sweden are more determined upon the accessibility of hydropower and wind power. Damsgaard is asked a question if it is possible to change this dependability by investing in new transmission lines vertically within Sweden, and answers that it is possible within a longer timeframe. He adds that the need of more investments within plannable energy production, specifically in southern Sweden, is equally important.

In the same article there is a sub header that explains how the European Union regulatory laws says about the open electricity market. "*With the new electricity market regulation (binding EU legislation) from 2019, an explicit requirement was introduced that system operators – SVK in Sweden – must leave at least 70 percent of transmission capacity to the market for trading.".*

4.1.3 Price of electricity in SE4

The problem of transmitting electricity from North to South and the need to leave enough capacity in the power lines to secure the system during an N-1 fault with our current energy system is affecting the energy markets and how the electricity is priced, says Berglöf. The difference in electricity price between energy areas are a result of how the system is working and large price differences are according to Lundbäck a symptom of a dysfunctional system. Svensson, Berglöf and Lundbäck bring up the importance of revenues from congestion in the transmission network when we are discussing the current difference in energy price between the different zones in Sweden. This part of the electricity price goes to SVK and is added upon the electricity price determined by the market for each energy area. This part of the electricity price is working as a signal for when the physical grid needs attention in the form of expansion and investments, says Lundbäck. She continues by stating that the revenues generated from this discrepancy between energy areas are accumulated into a fund, which sole purpose is to be invested into the expansion of the grid and by doing so be a self-regulated entity so to say.

This means that if more plannable energy production would be introduced in southern Sweden, the electricity prices would decrease, according to all interviewees. The answers were however more nuanced. Christian Sjölander for example, brought up the importance of decreased fluctuations of the electricity price if our scenario were to occur. Sjölander has a background in finance and compared price fluctuations of electricity with volatility and risk. He states: *"In finance, we know what costs money. It is risk. The risk in the financial sector is defined by volatility. Here we have built an energy system where you try to sell in volatility as a feature in the system. We work with flexible usage. Flexible use is high volatility, high risk. Everyone will require higher returns in such a system than they have done before. That means that all energy production will be more expensive, and the return requirement will be much higher."* He essentially says that less price fluctuations of electricity would lead to lower risk for investments because of less volatility.

Uniper and Fortum presents a chart (Chart 5) in their INET- report (2022) where it becomes clear how the volatility has increased by analysing the number of hours the electricity price has been negative. They attribute this increase in volatility to the expansion of renewable energy sources that are weather dependent (intermittent). They also mention that this volatility could be reduced by integrating energy storage but contradict this, stating that energy storage as a solution is still very expensive, resource intensive and difficult to scale up to offer generalizable solutions that cover the entirety of the domestic energy system.

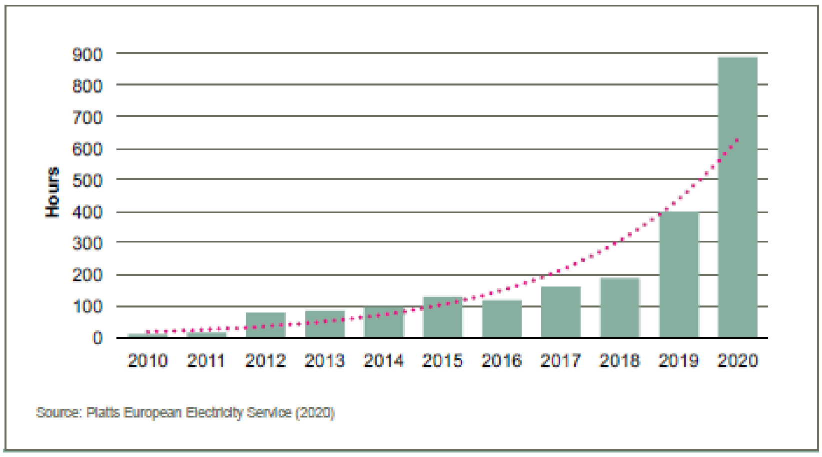

Chart 5: Number of hours with negatively electricity price in Europe. Source: INET (2022)

Eero Vesaoja, Senior manager of strategy and development at Fortum, states that the impact of added capacity usually means that electricity prices decrease. He also adds that nuclear power adds a smoothening effect to electricity prices. Vesaoja explains that he is not an expert in how the Swedish electricity system works but says that more nuclear power would offer a general decrease in electricity prices and an increase in price stability.

Svensson briefly talks about how more plannable energy in southern Sweden would affect the pricing because we become less dependent on the international energy market and the current price of fossil fuels. He references a study conducted by Wråke et al. (2022) that were published in Energiforsk, which concluded that additional electricity generation comparable to the decommissioned nuclear reactors Ringhals 1 and 2 in energy area SE3 in Sweden, would most likely lead to an average electricity price reduction of between 30-45% during September through November 2021 in energy area SE3. They also concluded that replacing Ringhals 1 and 2 with offshore wind would yield similar results but with more variation in price during the same period. Svensson noted that this study is comparable to our proposed scenario, which would mean that a similar effect could be anticipated. The main difference between this study and our scenario is that Ringhals nuclear power plant is located in SE3 and Ringhals 1 and 2 had a combined capacity of around 1785 MW as opposed to our scenario being an introduction of two 300 MW SMRs in Barsebäck, which is located in SE4. Why these are significant differences to our scenario is because the limitations in transmission capacity between SE3 and SE4. These restrictions limit the transmission of added capacity within SE3 according to the study (Energiforsk, 2022). They also highlight that if Ringhals 1 and 2 were to be restarted the difference in electricity price would be around 6% in SE4 because of the limitations of transmission between SE3 and SE4.

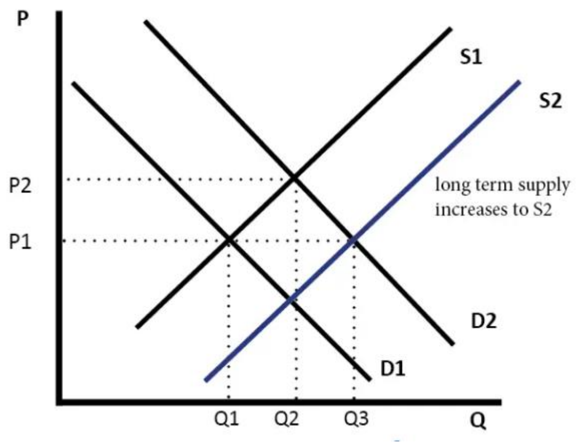

Chart 6: Alterations in supply or demand changes the price. Source: Economicshelp.org

Basic microeconomic theory also suggests that and increase in supply will change the intersection of supply and demand, thus lowering the general price of the affected commodity. (Chart 6)

4.2 Societal effects

In this section we highlight what our interviewees have insinuated about the societal effects, meaning the effects on the local society and private entities existing within SE4 or want to exist in SE4. What activities would more plannable electricity enable within SE4?

4.2.1 Effects of reduced electricity price and price fluctuations

Svensson starts of by stating: *"I believe predictability is always favourable. From the perspective that individuals should be able to plan their private finances. To enable industries to know whether it makes sense to invest in these areas or not... What industry is interested in investing x number of millions or even billions if you don't know what such an important input as electricity will cost. In my world, it actually has very negative consequences for the whole society with such volatility and these extreme energy costs that we have seen."* The importance of predictability has been expressed by the majority of the interviewees and as Sjölander stated previously, volatility is equal to risk, which affect the expected return on any investment.

Svensson also sheds light on the fact that it is the cost of the operation that determines the price and not the size of the initial investment. Nuclear power operates have a relative low operating cost, which means that the price of the electricity would be priced competitively compared to other sources of electricity. Sjölander adds to this by asking a question, *"What is cheap electricity?"* The term "cheap electricity" needs to be replaced by "competitive electricity" according to Sjölander. Sjölander explains that in order to compare the price of electricity you need to take everything that goes into the construction and adequate function into account. He says, "*It doesn't matter how much Germany says that renewables are cheap. When you look at their money being spent, it's not cheap. When you look at what it costs on the margin in kilowatt hours to produce, then it looks like it's cheap. But then I don't take into account that they're not even capable of moving electricity from north to south in Germany. They have been building transmissions since I was young, and nothing happens."* He concludes this by stating that the holistic perspective is not being used as it should be when discussing what energy producing sources should be utilized. The questions surrounding this topic is equally important.

Rosen argues that a reduction of electricity price would be very beneficial for everyone in southern Sweden. He argues that if and when someone announces new nuclear power in southern Sweden that will have a stabilizing effect on the society in Southern Sweden and it would also bring simplified planning conditions for the businesses and for future investments.

4.2.2 Increased investments

Svensson starts of this argument by stating, *"Electricity is something that the whole society is made up of. We cannot live without electricity at all. Our dependence will only grow if we look forward."* Ekberg adds that with a more stable electricity price comes predictability, which is an important factor for private corporations when they make investment decisions. Svensson continues to ask the question, *"[Which industry would be interested to invest x-amounts of millions if they don't have a reliable prediction of what the important input of energy into their production will cost?]"*

Berglöf adds to what Rosen said about how the intentions of leaders within energy production might directly affect the investment decision making process. He states that the very notion of the intention of building new nuclear power in southern Sweden will affect the investment decisions from that very moment. Berglöf says, *"This is how the market works, when you feel confident that there will be enough electricity when and where it is needed, then you can start investing in your electrolytes or whatever it may be."*

Lundbäck states: *“[It's important to have access to cost-effective, clean electricity. Electricity doesn't always have to be the most affordable alternative, but it should be both affordable and dependable. People may be willing to pay a little bit more for the assurance and convenience that secure access to energy brings to their daily life. Negative prices may not always have positive socioeconomic effects, so it is crucial to strike a balance within the community. Although providing consumers with the cheapest electricity may seem alluring, it may not always offer the best overall value or quality, as one can understand*.]” Sjölander adds to this statement by saying that the people who don’t believe in nuclear power say that increasing the share of intermittent renewable energy is that it increases the electricity price fluctuations that could subsequently be taken advantage of by all entities. He disagrees with this argument because of his previous statement that volatility is equal to risk. He also believes that everyone would rather have an electricity price of 70 öre with a volatility of 10% than an electricity price of 40 öre with 200% volatility.

Sjölander also brings forward that they have had discussions with a dozen municipalities in Sweden that believe that nuclear energy production in their region could lead to a competitive advantage compared to other municipalities because they become more attractive for new industry to invest in their region, thus creating many positive effects. He continues by stating that southern Sweden is one of the fastest growing regions in Sweden and is being neglected in terms of energy security. By introducing new nuclear power in southern Sweden, Sjölander means that it creates competitive advantages for the region and by not introducing more plannable electricity generation the policy makers are neglecting this opportunity to harness the potential that exists in this region.

Lundbäck adds another dimension to this discussion by introducing the problem with limitations in capacity once again. There is currently an issue with new expansions of electricity intensive investments in southern Sweden, which is more crucial than the predictability of electricity price. Private investment plans have been declined due to a lack of capacity within that area, according to Lundbäck. She explains that this is a more pressing problem for the society because it destroys the reputation of the affected area, and it could lead to significant losses in developments within southern Sweden. She explains that reliability of the energy supply has been one of Sweden's strongest competitive advantages but is no longer the case.

Rosén, which is head of business development in Kävlinge municipality, observes that businesses operate within very short time perspectives, but investment decisions are made with very long-term perspectives. With this in mind Rosen says that there is currently no trust in that the electricity supply will be sufficient for businesses to invest large amounts, because the planned contribution of energy supply might be occupied by the general electrification that is ongoing instead of enabling energy intensive industry.

The Swedish public service tv-station SVT published an article written by Lärka and Ekhem in 2019 titled “Brist på el gör att skånska företag flyttar investeringar” where they essentially say that private companies in Skåne can´t invest in expansions due to a lack of capacity in the grid. Ola Ringdahl, CEO at Lindab, expresses that because of the shortage of capacity, Sweden risks losing investments for several years. He also says that because of this, Sweden in general has gained a heightened level of risk premium associated with proposed investments. Ringdahl also calls for expansion of the regional electricity production in SE4 to alleviate this problem for the industry. Additionally, Pågen, which is a large producer of bread, also got their plan for expansion denied due to the local grid not being able to guarantee enough capacity for the expansion to be approved.

4.2.3 Increase of disposable income

Berglöf draws conclusions to that if new nuclear power was being built in SE4, it will have an effect on the employment rate and employment opportunities. He states that it creates jobs directly connected to the nuclear power plant but also indirectly through the increased investments from the private sector. Lundbäck develops her reasoning to about how the electricity prices affect the general public by bringing up the situation during 2021 and 2022, where the electricity prices increased dramatically. She explains that this was horrible for the general public with inflated electricity bills. She states that if we solve the issue with capacity shortages, it will result in a reduction in electricity price, which in turn will help to alleviate the current inflation rate.

SCB and the central bank in Sweden have synthesized a report (2022) that compares the inflation with increases in price of energy commodities. They state that the electricity price contributed to the inflation rate by 1,9 percentage points.They also gave examples for why these price increases might affect the inflation rate from various industries, quote *"... where higher electricity prices affect the total spending for farmers who have to compensate by raising food prices or where higher costs of operating and heating of buildings result in higher rents."*

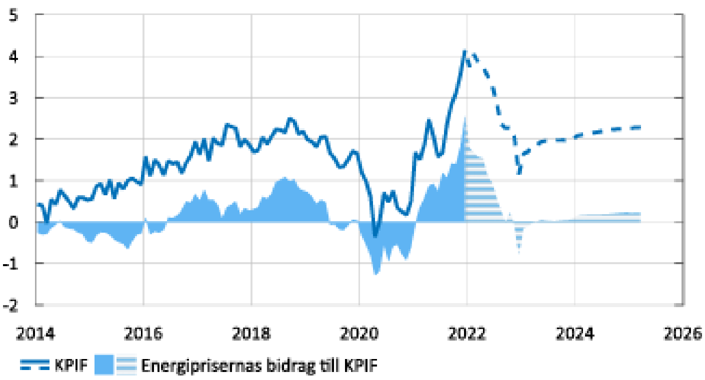

Chart 7: How energy prices affect inflation rates. Source; SCB and the Swedish Central bank (2022)

In the same report they also clearly conclude that the monetary policy needs to act to reduce the inflation rate in Sweden by raising interest rates. They continue by stating that by raising the interest rate, the expectations from the households and corporations adjust to a more conservative monetary policy, which will ultimately lead to a reduction of the inflation rate due to less spending. They do however recognize that the households and private corporations are heavily indebted, which could lead to more insolvencies when increasing interest rates. In an article published by SCB (2020), they refer to ECB and Macrobond (Chart 8), which shows the debt per capita in selected European countries in 2020.

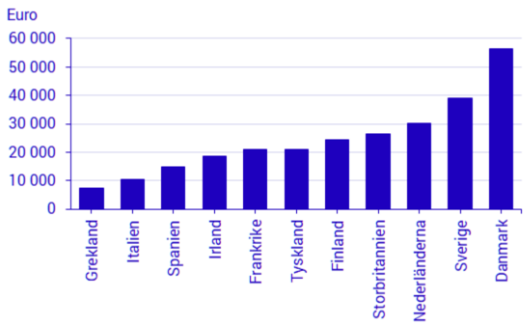

Chart 8: Indebtedness Source: ECB and Macrobond, published by SCB (2020)

Afry published a report in April of 2023 for Balanskommissionen where they concluded that for each billion SEK not invested in the Swedish electricity grid, there would be a predicted 8 billion SEK not realized increase in GDP. Alluding to an 8-time leverage on GDP increase for investments into the electricity grid.

4.2.4 Increased interest of the nuclear power market and public perception

According to an article written by Torbjörn Sjöström, published on novus.se, which is one of the leading analysis and research companies in Sweden, 56 % of swedes believe that nuclear power is the best way to solve the energy shortage. Novus conducted a survey with 1,027 randomly selected interviewees in a nationally representative sample of individuals between the ages 18 to 79 years from February 10th to 15th, 2022. Berglöf provides insight into the public opinion in Sweden regarding nuclear power. According to Berglöf, there has been a significant upward trend in public opinion in recent years favouring the construction of new nuclear power plants and acknowledges that approximately 60 percent of the population now holds a positive stance towards it. Furthermore, he argues that the construction of new nuclear power plants is unlikely to lead to a negative public opinion, but rather only increase the positive perceptions. Berglöf also suggest that the construction of new nuclear power plants may contribute to the "*normalization*" of nuclear power, leading to a decrease in the perceived controversy surrounding it. He mentions the role of the government and draws a parallel to Finland, stating that the issue of nuclear power is not a political debate in Finland, as no political party opposes its use. He says, *"I see that it may become similar in Sweden as well, and we can already observe this trend."*.

Christian Ekberg, who has previously stated that he used to be an opponent and had a negative perception of nuclear power, when asked why he had changed his view he answered, *"I educated myself"*. Ekberg claims that there is a lot of misinformation circling, referring to it as *"fearmongering"*. By educating himself and learning more about the industry, Ekberg say that instead of reacting with feelings, he began understanding the reality and came to the conclusion that nuclear power is the best alternative right now. While acknowledging that nuclear power might not necessarily be the most optimal solution, due to the question around handling the waste, it is still the best one right now he says, *"If we can find other alternatives* [energy sources] *then great, but I don't see any other viable options today"*. Ekberg further implies that there is a stigma attached to the nuclear power industry that is based on outdated data and data created to suit a certain narrative, and that this may be the reason for certain politicians and regulators having the views that they have.

Rosén build on this and shed light on certain factors influencing the public perception and general acceptance of nuclear power. Rosén make the argument that the acceptance of nuclear power is generally very high in municipalities where nuclear power plants are located. He states that the presence of a nuclear power plant seems to contribute to the understanding what is happening thereby heightening the resident's awareness. *"The knowledge that one's neighbour works and goes there [nuclear power plant] everyday means that it must be quite safe" says Rosén.* This awareness amongst the residents tends to spread out throughout the community according to Rosén and says that this is made evident by the yearly polls that measure resident's attitudes towards nuclear power. He states that the five municipalities in Sweden that have nuclear power today, consistently rank high when it comes to their positive attitudes to nuclear power. It is however noted by Rosén that the positive attitude seems to begin to erode in municipalities such as Kävlinge and Nyköping. The reasoning behind this according to Rosén is because the active nuclear reactors that once stood there have now been decommissioned and that the municipality has since then received residents who have not familiarised themselves with nuclear power. While Rosén does acknowledge that numbers are stagnating in these areas, the attitudes are still high compared to other municipalities because "*there are so many who still work within this sector but with different companies"*.

Additionally, Pettersson makes the argument that the residents of Kävlinge municipality have become accustomed to having a nuclear power plant in close proximity, implying that their attitudes towards nuclear power is more favourable because of this. She does however acknowledge that there has been an influx of new residents in Kävlinge since the decommissioning of the plant, and that these newcomers may have a different attitude compared to the long-term residents. When asked what the primary differences between the older and newer inhabitants in Kävlinge are with regards to their attitudes towards nuclear power, Pettersson replied, *"Previously, you just had to accept the situation. Now, maybe people are thinking more about solving this* [the energy crisis] *with other types of energy sources that are not nuclear power."*

Looking closer into the public opinion on nuclear power, Danaki & Hemmingsson (2022) present in their report, *Socioeconomic analysis of nuclear power in Sweden,* the Swedish public opinion on nuclear power over the last two decades. As can be seen in chart 9, they report a drastic decrease in the alternative "phase out when close" since the late 90s. The authors imply that respondents who previously stated that they wished to see a halt in nuclear development have shifted their opinions and begun projecting alternatives such as "develop and build more" and "continue using as today".

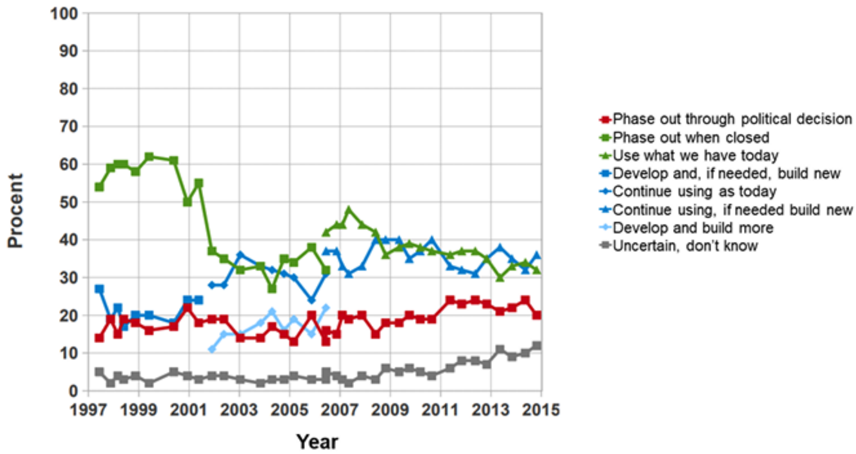

Chart 9: Evolution of public opinion in Sweden on the future of nuclear power. Source: Danaki and Hemmingsson (2022)

Furthermore, comparative conclusions could be drawn from public opinion polls on nuclear power in a similar nuclear municipality. Danaki and Hemmingsson (2022) additionally look into the local populations trust in nuclear power in Oskarshamn municipality. Oskarshamn is located on the east coast of Sweden and houses one of the oldest commercial nuclear sites in Sweden, initiating its first reactor in the early 70s. Interviews were conducted in Oskarshamn in 2018, 2019 and 2020, with the aim to report how much the local population trusts the power plants. The results can be seen in chart 10. The authors comment on the results stating, *"The reader might expect that proximity to a nuclear power plant would cause fear for problems and accidents. In reality it seems to be the opposite".* The authors argue that the support and trust for nuclear power is bigger in municipalities where there is a nuclear power plant compared to the rest of the country. They explain that the major differences and reasons for the is access to information, and employment in the plant. It is clear through the diagram below the overall trust for nuclear power withing these municipalises has gone up, further indicating the relationship between awareness and positive attitude.

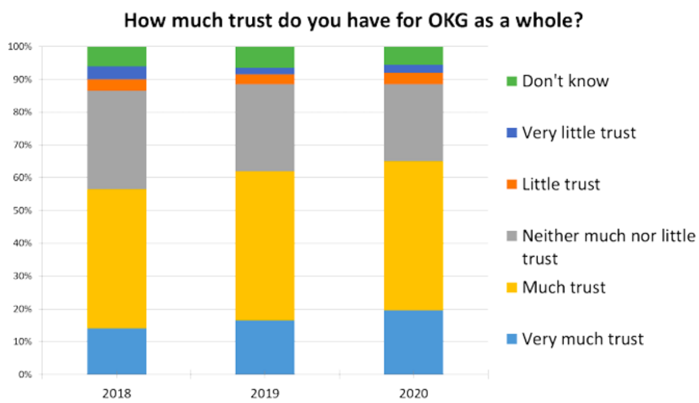

Chart 10: Evolution of public trust towards nuclear power plant in Oskarshamn. Source: Danaki and Hemmingsson (2022)

4.2.4.1 Public perceptions and opinions could affect the political decision-making process

As the general opinions about nuclear power have strengthen over time, the regulatory institutions have adapted to this situation. The current Swedish government have put forward a memorandum with the purpose of easing the regulatory policies of the national nuclear power fleet. (Dnr KN2023/01921) The memorandum (2023) essentially states that the current nuclear policy that restricts any new nuclear activities to a geographical location that is currently hosting permanently closed nuclear reactor will be removed, enabling the introduction of nuclear reactors in locations that historically have not had any nuclear activity. The described reason for this decision is based on the predicted increase in energy consumption linked to the electrification of transportation and industrial processes. (Dnr KN2023/01921) Another reason for this memorandum was to provide further grounds for creating a stable and cost-efficient energy system with regards to where the electricity production is placed in the future. In the same memorandum, the government openly state that this decision creates opportunities for private corporations to invest in nuclear facilities for their own operations, but also states that this comes with certain implications for the corporations to take into account, such as disassemble and handling of nuclear waste.

4.2.5 Increased competence development

Knowledge transfer within the nuclear industry has long been appreciated and fostered. Christian Ekberg, Head of the division of Energy and Materials at Chalmers explains that the nuclear competence in Sweden has gone into retirement and does not believe that we will return to that level again. Ekberg does acknowledge that the theoretical knowledge and competence, although not improved, is still in available today. However, he argues that just the theoretical knowledge is not enough when it comes to practically constructing the nuclear power plant. *"We have quite a few highly skilled nuclear physicists in Sweden who can calculate how it should look here. But from that to actually building a nuclear power plant is a huge leap."*. Ekberg elaborates by stating that the systems that are in place today are more complicated than they were in the 80s, meaning that that there is a need for more nuclear competence today. When ask if it is possible to have a more centrally controlled automatic system, Ekberg answered both yes and no;

"You still need to have the same system as you had before. So even though electronics are involved, the electrical control reduces the need for extensive pneumatic knowledge. However, there is also a risk in this. And I have mentioned this a few times, expressing my slight concern about upgrading all the current nuclear reactors to electrical systems because they were not built for that. This would mix pneumatic systems and analog gauges, resulting in a completely new system."

Christian Sjölander expressed his belief that Sweden possesses a strong foundation of well-educated individuals, particularly in the field of engineering. He emphasized the country's extensive history as an engineering nation, indicating that this expertise serves as a fundamental advantage. The academic sector also places significant emphasis on relevant topics, contributing to the availability of competent professionals in the field. Sjölander stated that future developments in the energy sector require more than just engineering programs. *"We need to bring in other skill developments as well. We need a significant presence of economists. We need a considerable amount of financial expertise in the future. This is to transform it into* *a comprehensive solution when it comes to energy."* He acknowledged that resource allocation is a crucial factor to consider. In addition to engineering expertise, other areas of competence must be incorporated to address future challenges effectively. By integrating diverse skill sets, such as economics and finance, into the energy sector, Sjölander believes that a more holistic approach can be achieved. This approach acknowledges the multidimensional nature of energy-related issues and aims to develop comprehensive solutions that address not only technical aspects but also economic and financial considerations.

Berglöf emphasized the different starting point in the 1970s and 1980s when nuclear power was being built in Sweden. At that time, Sweden had already been involved in nuclear power development since the 1950s, accumulating decades of experience in the form of heavy water reactors and other technologies that were not commercially pursued he says. Despite this, Sweden had developed expertise, test facilities, and infrastructure that facilitated the rapid establishment of its nuclear power program. Berglöf did point out that Sweden was unique as a relatively small country that developed its own reactors and built its nuclear power program using predominantly Swedish technology and expertise and the majority of the program was built with domestic resources.

Moreover, Berglöf expressed that if a new nuclear power program were to be initiated, it would naturally generate more interest among individuals to pursue studies in nuclear power technology at universities. He also anticipated that there would be an emergence of nuclear power consulting firms as the interest increases. However, the extent of these developments would depend on the approach taken in implementing the construction of new nuclear power plants. With regards to the educational systems, Berglöf claims that students are sensitive to trends. This means according to him that when we as a society begin to shed more light on nuclear energy, it automatically impacts the programs the students choose to apply to. *"This year [2023], there is a record-high applications and admissions for certain programs, such as the one mentioned [nuclear technical educations]."*

Lundbäck also acknowledge that further development and new construction of nuclear power will definitely contribute to increased competence in Sweden, however, she, just as Sjölander, pointed out that just focusing on the technical aspect of nuclear power is not enough. She explains that once the power plant is built, someone still needs to take care of it and be able to identify any potential issues that may arise. Therefore, Lundbäck says that along with the technical aspect and competence revolving nuclear power, we must also evolve the safety and competences around handling and running nuclear power plants. This does however tend to come naturally within the nuclear industry according to Lundbäck as there is a certain level of safety standard that permeates up the chain and even "*... elevates the universities in both mechanical, nuclear, and control engineering."*

When asked if there is a possibility of eventually creating a new market for Sweden exporting nuclear energy competence, Lundbäck answered that it is a question that has already been raised with the minister of energy. She explains the fact that Sweden today has a strong nuclear industry and that exporting services in the form of plant designs and other valuable competences is possible. This however is according to Lundbäck not viable in the near future and says, *"We have to learn to crawl before we start walking, and especially before we start* *running a marathon. A marathon in this case is when we begin exporting our own reactors, and I believe we should start with the foundation first. We excel in cutting-edge expertise in Sweden, and that's probably where we should focus.".* Carl Berglöf was asked the same question regarding a new market for nuclear power export to which he responded, "*Yes, absolutely. That could be the case. It would be more long-term. It will take time to reach that point, but it can be done"*.

4.3 Innovation and Small Modular Reactors

There are currently over 90 SMR designs in different stages of development globally according to INET (2022). The majority are however primarily in the early or advanced development stage and are therefore not viable options until at least 2025. Although numerous improvements and advances have been made with regards to the safety and efficiency of SMRs, the basic technological principles are the same today as they were 50 years ago. Small modular reactors do however bring with them a set of innovative and distinct features that further advance the industry and create better possibilities for societal improvements. OECD (2021) thoroughly analysed the challenges and opportunities of SMRs and have thereby identified key design features of SMRs that are believed to be advantageous. They argue that their smaller size relative to traditional reactors offers several advantages. Liu & Fan (2014), explain that the objectives of the SMR designs are rooted in progressive and significant innovation. They call this a *"balance of tradition and innovation",* as the concept of SMR goes back the 1960s and that the current designs absorb the advantages of the already existing technology resulting in, lower power generation, smaller configuration size, lower generation cost and an overall decreased operation risk.

The development around nuclear innovation has been focusing on improving safety, reducing costs, and optimizing waste. According to the INET report (2022), SMRs are characterized by their size and modularity. With the capabilities of being factory-made with standardized series production, an onsite assembly becomes the most optimal solution when it comes to construction. These factors ultimately lead to the overall reduction in complexity, time and upfront costs. Beautiful nuclear (2022) also highlights the potential for repurposing coal or oil powered electricity generating units. Utilizing the infrastructure with a nuclear-powered energy production method would be advantages for surrounding environment through the decrease of emissions and utilization of existing land footprints.

4.3.1 New packaging of the technology

Sjölander, Rosén and Ekberg all acknowledged that the core technology revolving around SMRs is nothing new. *"SMRs are the same thing, just boiled down"* says Rosén when comparing an SMR with a traditional nuclear reactor. Ekberg builds on this and says that the technology itself remains unchanged, *"I can't see that the technology itself will change at all".* He emphasized that SMRs are fundamentally nuclear reactors designed to generate electricity continuously, without significant fluctuations in power output. According to Ekberg, the core function of an SMR is to connect to a generator and produce a steady amount of electricity. The reactor does not like to vary its power output or operate at different speeds, making it a predictable and stable energy source he says. However, Ekberg acknowledged that the potential for changes lies in the surrounding business models and strategies for selling the electricity.

Sjölander emphasized that SMR is not a specific reactor type but rather an approach to industrialize nuclear power. According to Sjölander, SMRs offer several advantages, including mass production and the ability to incorporate interchangeable components. Instead of focusing solely on building large reactors and supplying electricity to the grid, SMRs allow for the construction of purpose-built systems. Furthermore, SMRs can be designed in different sizes to cater to various applications, making them versatile in their usage. One notable advantage highlighted by Sjölander is the utilization of the thermal power produced by SMRs. He suggested that this thermal energy can be harnessed for other purposes, such as the production of hydrogen or ammonia. Essentially, any energy-dependent process can be facilitated by SMRs, enabling a wide range of potential applications.

The small size of an SMR plays a key role and is arguably the most distinct feature. As noted by energy.gov (2020), SMRs are *"extremely flexible",* indicating that they have the ability to either increase or decrease their scale in order to meet energy demands as well as assist in areas where large nuclear reactors are not optimal. Locatelli et al. (2011) discuss that because of the smaller size, SMRs create many different opportunities, such as lower up-front costs, I.e lower initial investment. The size in combination with its modularity makes it an ideal candidate for the sequential construction of multiple reactors followed by an amplification in energy production over time as the project develops. Subsequently meaning that sequential evaluation is possible, allowing for rejection of continuing the project further if the results were to be deemed undesirable.

4.3.2 Safety, standardisation and modularity

Liu and Fan (2014) discuss the fact that SMRs employ various safety features to prevent accidents and minimize their consequences. These features are designed to enhance the safety of the reactor, prevent radiation release, and ensure the integrity of the containment system. The design of SMRs, particularly the integral pressurized water reactor design, reduces the number and size of penetrations and welding links through the reactor pressure vessel, eliminating the high-consequence accident scenario of a large pipe-break LOCA. SMRs also have increased relative coolant inventory, relative heat transfer area, and passive cooling capability, making them more resistant to thermal transients and other upset conditions. Liu and Fan (2014) and Boarin et al. (2011) agrees regarding that SMRs have a smaller radionuclide inventory and are often built underground, making them more resistant to external impacts and natural disasters. Overall, the safety features of SMRs are designed to ensure that they operate safely in remote areas, making them an attractive option for many countries seeking to expand their nuclear energy capacity. The safety of SMRs is critical in building public trust and support for nuclear energy, and therefore, safety will continue to be a significant focus in the design, construction, and operation of SMRs.

OECD (2021) argue that standardization and modularization provide SMRs with some major competitive advantages. Standardization of SMR designs results in additional cost savings because it encourages "economies of scale" at the development and production stages, which in turn allows a supply chain to be established. OECD (2021) continues by stating that this could be accomplished by establishing that all SMR units that make use of the standardized design technology have access to the same global architecture, requirements for the design and construction of the nuclear steam supply system, and related safety measures. By breaking the plant up into pieces that can be manufactured in a factory, transported, and then put together on-site, modularization simplifies construction. It enables cost savings from building and/or preassembling modules in a dedicated facility away from the construction site. Construction times should be shorter and more predictable as a result of improved labour productivity, tighter quality control, and reduced project management risks. The SMR market prospects may be favourably impacted by the indirect benefits of modular construction, such as faster time to market.

Vesaoja expresses that standardization in SMRs offers benefits by reducing rework and design modifications caused by local regulations. Standardized units improve economics by minimizing alterations between countries. However, achieving 100% similarity is impractical due to site-specific factors, such as seismicity, which require some customization. Balancing standardization and flexibility are crucial for cost-effective and efficient SMR deployment, addressing local requirements while maintaining uniformity. The goal of SMR vendors, according to Vesaoja, is to have standardized units that are as similar as possible, regardless of the country in which they are built. By achieving standardization, vendors can minimize the need for significant alterations due to local regulations, resulting in cost savings and improved efficiency. This standardization ensures that the design and construction processes can be replicated more easily across different locations, reducing the risk of errors and delays associated with adapting the reactor design to specific local requirements.

NEA (2020) calculates that modular construction is already used in about 30% of nuclear reactors, and that number could go up to 60%–80% if more ambitious plans are made possible by the smaller sizes of the parts. OECD (2021) discusses some potential drawbacks and clear disadvantages to modular building, such as the need for additional up-front engineering work to identify and properly design the various modules in order to lower construction risks during their assembly. Before starting construction, it is also necessary to purchase the materials and parts for the various modules, which increases the upfront investment requirements and reduces some of the financial advantages. Mignacca and Locatelli (2019) conclude by adding that the unique characteristics of SMRs such as factory fabrication, learning, shorter constructions times and co-sitting economies etc should theoretically be enough to compensate for the economy of scale and therefore make SMRs an attractive investment. However, a few papers have gone on to counter argue or even deny the attractiveness of SMRs based on the characteristics mentioned above. Ramana & Mian (2014) express that each SMR design has a few distinctive qualities, but none of these designs encompasses all the elements required to make up for a lack of economies of scale. They argue that while it is possible that SMRs will be less expensive to build than LRs, it is unlikely that SMRs would be able to produce electricity at a lower cost per unit than LRs. They conclude by adding that SMRs are even less competitive than other energy sources like coal and natural gas-based thermal power. Cooper (2014) goes on to say that the predicted cost savings from factory fabrication are unduly optimistic because "mass manufacturing" can experience difficulties when working with pricey equipment in small quantities. He also points out that building a large production line is a difficult and unjustifiably expensive operation. Taking this into account, this strategy could also hinder competition, which would otherwise spur innovation and reduced costs. Finally, Cooper points out that the introduction of new technologies will greatly increase costs, which is another crucial factor to consider when assessing the economic competitiveness of SMRs.

4.4 Effects on environmental sustainability

Discussions were held with both Svensson and Berglöf regarding the role of the oil-fired power station, Karlshamnsverket. According to uniper.energy.se. Karlshamnsverket is an oil-fired peak and reserve power plant located in the SE4 electricity region in southern Sweden. This power plant produces a portion of the power reserve, which is later procured by SVK for the winter periods.

When discussing the scenario regarding what effects would occur if two, 300 megawatt SMRs became active in SE4 tomorrow, Svensson says that the Karlshamn power station would not need to be used as much. However, Svensson does state that Karlshamn would not become entirely redundant, acknowledging that there will always be days when specific conditions arise. These conditions may include extremely cold weather, minimal wind, or technical failures in other power generation facilities, making it necessary to have reserves for such occasions. Svensson emphasizes that he speaks in general terms, indicating that his comments apply to the broader context. Berglöf, while acknowledging that he does not possess an in-depth understanding of the specific services delivered by Karlshamsverket, says that these types of services could essentially be provided by another fossil-free power plant. He argues that the introduction of a new fossil free power plant, i.e. SMR, would likely result in reduced need for Karlshamsverket. He implies that, Karlshamsverket would be utilized to a lesser extent, particularly when it comes to electricity supply and demand on the market stating, *"If you have more power available in SE4, it makes sense that you won't need to utilize the reserve power as much"*.

When considering the environmental aspect, Svensson suggests that the conclusion would be that the less Karlshamn operates, the better it would be for the environment. Implying that a reduction in the plant's activities will minimize its environmental impact. *"If we are talking through an environmental viewpoint then the less we run the oil-fired power station, the better"*. Svensson further explains that despite Karlshamn's significant operational activity in previous years, it still represents a relatively small portion of their overall capacity. The plant typically operates intermittently, starting and running for a day before being shut down again. Svensson describes Karlshamn as a relatively small facility.

According to Wennbergs article published on energinyheterna.se (2023), the Karlshamn power station doubled its production in 2022 from the previous year. Over 1000 production hours and 221 gigawatts of produced electricity, leading more producing in 2022 that the previous 10 years combined. According to details retrieved from uniper.energy.se, a total of 54 300 tons of oil was used to power the station, resulting in 171 tons of CO_2 emissions (chart 11). Svensson acknowledges the increase in oil-fired production in 2022 and explain that the reason that Karlshamn is being used more frequently is a direct result of Sweden closing down plannable energy production in southern Sweden. Svensson refers to Sweden and Germany, where over 20 nuclear reactors have been decommissioned in the last 20 years. He states, "*To some extent, these reactors have been replaced with intermittent, that is, weather-dependent, electricity* *production from wind and solar. When conditions are favourable, there is abundant electricity supply with low prices. However, it becomes quite expensive when the weather is less favourable for electricity production*".

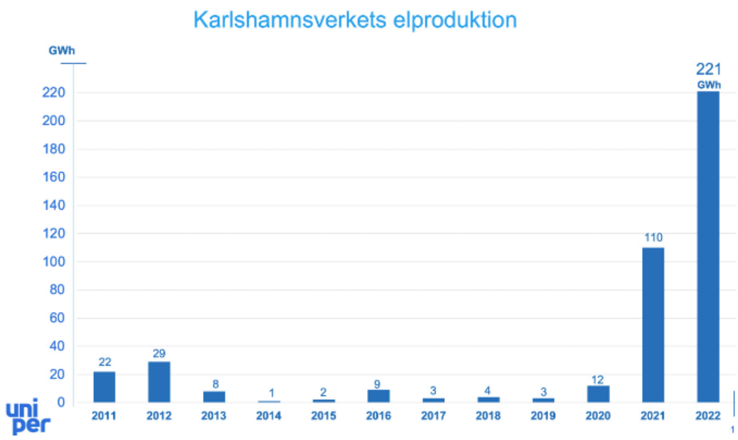

Chart 11: Karlshamn power station electricity production. Source: Uniper, gathered on energinyheter.se (2023).

Lundbäck further empathises the importance of clean and affordable energy in accordance with SDG 7 and she provides insight into the relationship between reducing fossil fuel dependency and nuclear power. She highlights the significance of sustainable energy systems and says that it is these types of systems that develop a society, *"it is the access to affordable and fossil free electricity that has built this country* [Sweden]*"*, she says. Furthermore, Lundbäck states that there is a direct correlation between counties that have implemented nuclear power and countries that have successfully reduced their fossil fuel consumption.

Ekberg states that Sweden is a relatively small country when it comes to CO2 emissions, *"We practically have a CO2 neutral energy production today"* he says. He thereafter draws the conclusion that it would not have an impact for Sweden to make efforts to reduce its emissions even more in the larger context. Rather, the benefits would be in the technology and competence that Sweden exports to other countries to help reduce their emissions.

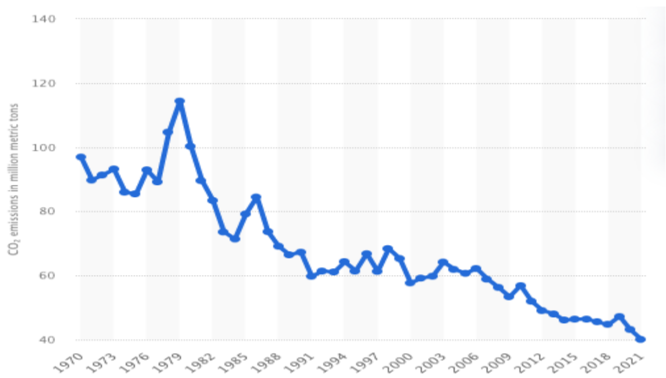

Chart 12: Sweden's CO2 emissions since 1970. Source: Statista

CO2 emissions in Sweden have reduced by upward of 70% since peaking in 1979 according to Tiseo (Statista, 2023). As of 2019, the country has held the lowest greenhouse gas emissions per capital in Europe, landing at 5.2 metrics tons of CO2. It can also be noted that Sweden ranks as the ninth highest country for generation most electricity per capita globally (Data Commons, 2021), meaning that although it produces a relatively large amount of electricity, it still does it in the cleanest and most efficient way.

5. Analysis

The analysis of the empirical result aims to discuss the primary and secondary data and the included concepts/effects have been verified with our proposed criterions before they are included in the analysis. The connection between the innovative theories and the development of a new technology concept that is SMRs will also be thoroughly analysed and does not abide by our criterions.

5.1 Eco-innovations influence on SMR implementation

It has been established that the role of innovation plays an important role in the furthered development and implementation of new nuclear solutions such as SMRs. Sweden, once holding its place in the forefront of nuclear development and having a key position in the race for a fossil free energy production is now close to reclaiming that position. The development of eco-efficient technologies that either directly or indirectly aim to enhance the environment is more important than ever as climate concerns are rising. It has been shown throughout this research that small modular reactors could be considered an innovative solution that aim to enhance the environment, while simultaneously creating value for society. Going by Kemp and Foxons (2007) definition of eco-innovation, SMR is an application that throughout its life cycle will result in reduced environmental risk and pollutions. The authors also specify that reduced negative impacts on resource utilization, which includes energy, is a part of the eco-innovation criteria. It has been discovered that a rise of oil-fired energy production has occurred in the SE4 electricity region in the last few years. While it cannot be determined that this is due to the lack of SMRs, we can conclude that an introduction of an SMR would have implications on the reduced use of Karlshamn power station. It has been identified that industries today are transitioning and aiming to use hydrogen instead of oil and coal as an energy source within their production processes. The synergetic effects ascribed to SMRs have the potential to increase hydrogen production when the electricity grid is satisfied. This means that even when it is not economically viable to produce and sell electricity, the capacity can be maintained at a sustained level but produce hydrogen or other forms of energy. This flexibility enables this type of investment to diversify its output and not be totally dependent on the electricity market conditions in order to stay profitable.

The International Atomic Energy Agency (2022), who has closely been monitoring the efforts of its member states developing SMRs, recognize their potential and describe them as being *"a viable solution to meet clean energy demand, both in expanding and embarking countries".* In their report, Small Modular Reactors: A New Nuclear Paradigm (2022), The IAEA identifies SMRs as a driver of innovation and the creator of new opportunities across various industries. Vujic et al., (2012) agrees and says that small modular reactors represent a promising new approach to nuclear energy generation, offering a smaller, more flexible, and potentially more cost-effective alternative to traditional large-scale nuclear reactors. SMRs are positioned to play a crucial role in the regional transitioning to clean energy. Furthermore, it has been discovered through this research and the empirical findings that the nuclear community is actively pursuing innovation in technology, market design, financing, regulation, and project delivery to advance the development.

Maja Lundbäck argues that Sweden is in a unique position when it comes to fostering innovation. She emphasized that because we have achieved the foundational level of Maslows Pyramid, we have created a sense of security that now allows us to focus on other matters. She argues that by providing a solid foundation that addresses basic needs, our society can afford to explore and invest in emission-reducing technologies and states, *"We can afford to have a mindset strong enough to power innovation".* With a certain level of standard of living, individuals possess the capacity to think innovatively rather than constantly fighting fires and dealing with immediate crises according to Lundbäck. Sjölander also acknowledges the value of innovation and the importance of keeping innovation at the forefront while maintaining an ongoing debate in the field [Nuclear industry]. He stresses the need for continuous development, arguing that failing to move forward may prevent innovation and impede progress. Sjölander did however argue that nuclear power has advanced to a high level of maturity. He claimed that the technologies already in use can satisfy our present energy requirements and hinted that addressing current issues may not require more nuclear power innovation. He did, however, note the need for various nuclear technologies, particularly generation 4 reactors, such as high-temperature reactors, in the future, specifically when seeking to solve the current issues. Sjölander highlighted that while the prerequisites for initiating the transition to generation 4 nuclear power already exist, it is not quite enough, drawing upon the analogy, *"To get to iPhone 24, someone first needs to buy an iPhone 14".* Similarly, in the context of nuclear power, building on current generation reactors is a necessary step to eventually progress to the new generation reactors.

5.1.1 SMR adoption and acceptance

With the current climate issues at hand, no disagreements are presented over the importance of speeding up the development and implementation of new energy producing technologies that address the harmful impacts of the current energy system. Our examination of secondary and primary data reveals that public perception regarding nuclear power in Sweden is on a significant upward trend. As highlighted by Berglöf and others, this positive trend can be attributed to the growing awareness and understanding of the benefits and safety measures associated with nuclear power. However, it is important to note that this perception of awareness works both ways. If people are aware of how safe and impactful small modular reactors (SMRs) are, their interest will increase, and they will demand more. Consequently, if there are incidents or issues with SMRs that pose risks and do more harm than good, public perception will decline, leading to significant backlash.

Regulations are said to serve as a key driver of innovation as we have discovered in chapter 2. The current Swedish government proposed in January 2023 that the limit on the amount of active nuclear reactors be removed. Together with this, the proposal simultaneously votes to remove the restrictions on building nuclear reactors in locations where no nuclear power has previously existed. Raising these factors on a regulatory level reflects a shift in energy policy moving towards meeting the increasing demand. By allowing the construction of more nuclear power plants in multiple sites around Sweden, the government aims to augment the capacity for generating clean electricity. This decision acknowledges the crucial role of nuclear power in providing a reliable and abundant energy supply while reducing greenhouse gas emissions.

Moreover, it signifies a departure from the previous policy framework, which limited nuclear power expansion to existing sites, thereby fostering innovation and development.

Within the discussions of innovation, Vesaoja makes remarks as to the role that the EU plays when it comes to determining how a country should operate and develop its energy sources. Vesaoja agrees that the EU should rightfully set goals that align with decarbonation, but it should not be selecting technologies that a country might deem suitable for them. By doing so, he argues that the EU is selecting the winners ahead of time, stating that *"nobody has the skills for that".* Vesaoja goes on to state that the most optimal way to foster innovation withing the energy sector is through a bottom-up approach, where the bottom represents the level of investments and the current instrumental support.

The rationale behind this proposal lies in the recognition that the country requires a diverse portfolio of fossil-free energy sources to successfully achieve its ambitious sustainability goals. Electrifying industries and transportation demand a substantial increase in clean electricity production. While renewable energy sources such as wind and solar power contribute significantly, nuclear power presents a viable option due to its high energy density and reliability. These types of proposals are of course likely to spark debates and discussions regarding the advantages and disadvantages of nuclear power, including concerns about safety, waste management, and the potential impact on local communities and the environment. The analysis and evaluation of these aspects will be essential in determining the feasibility and long-term implications of expanding nuclear power generation in the country.

In addition to the discussion of reduced regulatory control of the expansion of nuclear reactors, the private investments would increase in these solutions for private use, as it becomes legal to do so. Through the way that SMRs are packaged, as argued in this study, we can conclude that they present an array of opportunities that are simply not obtainable through traditional nuclear reactors. Effectively, this creates opportunities for this type of technology to be adopted by a wider range of actors, more specifically the industrial sector. This leads to the industrial sector being given, through innovation, an opportunity to utilize the nuclear technology for their private processes. Effectively meaning that they are provided the opportunity to diversify their energy portfolios, leading to a possibility to decrease their dependency on both fossil fuels and the regional energy grid with it its limitation. Kärnfull Next is currently working with many interested private organizations that are interested in these solutions to improve their own energy reliability and stability.

5.2 Increased energy security

The empirical findings have identified a few concepts/effects that are jointly contributing to sustainability implications for the SE4 region by increasing energy security within the specified boundaries. These effects include increased plannable energy production, increased synchronous energy producing technologies, decreased dependency on import of electricity from neighbouring areas and a decreased use of frequency regulating reserves.

Stability, reliability, and robustness of the energy supply is arguably closely connected with energy security as the society heavily relies on energy to function, which we argue is a direct effect of the introduction of SMRs at Barsebäck. These factors are closely connected with all three sustainability dimensions outlined in the literature review. Turkson et al. (2020) put forward a framework (Figure 3) that helps to understand the interconnectivity between the different aspects of sustainability and our framework will follow this structure to a large degree as we have found evidence for its importance during our empirical data collection. Turkson et al. (2020) reference to Khan (2015) is closely connected with our proposed scenario. By introducing nuclear power with its discussed attributes, the energy security in southern Sweden will increase, which will be a step towards the holistic sustainable development within SE4 because of the importance of energy in our current society. We argue that by creating a wider portfolio of energy sources with different attributes within an area will result in a holistic sustainable development and thus affect all three dimensions. An increase in predictable regional electricity production mitigates the use of CO_2 heavy processes to establish reliability of regional energy supply in combination with a decreased dependability of importation of energy supply that must abide by strict physical and policy driven restrictions that precede transmission of the electricity commodity would arguably affect the regional energy security within SE4.

5.2.1 Discussing the concepts/effects that jointly increases energy security

When analysing the empirical findings of this study, we find that the first and most prominent effect of introducing SMRs at the site of Barsebäck is an increase in plannable electricity production in the energy area SE4 in Sweden. This increase in plannable electricity production can be attributed to the improved reliability and predictability that nuclear power offers in general compared to renewable energy sources, which allow for better planning and management of the energy production. This prediction is derived both from answers and comments from our interviewees and from analysing the juxtaposition of our proposed scenario. The effects that transpired recently in Stockholm on the 25th of April, when the Forsmark nuclear power plant, more specifically reactors Forsmark 1 and 2, went offline due to a power outage in the area, became obvious when the electricity price for SE3 and SE4 doubled the following day. Market analysts attribute this price increase to the shutdown of Forsmark 1 and 2, which shows how important these energy producing units are to the reliability of the entire ecosystem that is the energy system. Another aspect of existing nuclear powerplants going offline is the fact that regular maintenance is required. If you cannot temporarily replace power production because of known, annual maintenance being planned ahead of time without having severe consequences affecting the electricity price or the activation of reserve power, there is something wrong.

There are distinctions between factors that are important to understand when we discuss how the energy system would be affected by the introduction of nuclear power. A lack of aggregated energy production (MWh) compared to energy demand is not the same thing as a lack of capacity (MW) as Lundbäck explained. If the aggregated energy consumption in an area is equal to 100 MWh over a period of time, but the needed capacity fluctuates during that specific period. This is important to understand since you can claim that the energy production during that time period is equal to the consumption and therefore have a functioning system. But this argument misses one crucial aspect that the supply of enough capacity needs to be equal the demanded capacity at any point in time. For example, during our specific period in time there were an instance where the demanded capacity reached 20 MW, but the supplied capacity could only reach 15 MW within that area. This scenario means that there would be a lack of capacity, which result in either import of capacity, or activation of the power reserve would have to happen to keep the system in balance.

Furthermore, the Swedish energy grid is dependent on the stability of the frequency around 50 Hz, which is maintained through a flexible approach where the supply of energy gets altered to fit the demand within certain boundaries of frequency deviation. As explained by Svensson and seen in chart 11, the use of Karlshamnsverket has increased dramatically over the last few years. Karlshamnsverket is acting as a frequency regulator, which means that it is not used as a main mode of baseload power generation but is simply one of the flexible energy sources that works as a frequency regulator.

With this in mind, we can derive another effect that is less discussed. Namely, the attribute of nuclear power being synchronous, meaning it possesses the passive ability to regulate the frequency merely by how it functions. This in turn means that reserve power would need fewer activations in SE4 to maintain the correct frequency, resulting in cost saving efforts by SVK (the Swedish TCO). Another aspect that is outlined by our interviewees is that the current structure of the Swedish grid is not optimal based on where the energy producing units are located currently, brought up by Sjölander.

When we connect what Svensson said about the grid structure and what nuclear power offers in terms of being like a "pressure point", effectively adding around 150% of the added capacity, and what Sjölander says about the structure of the grid, we can derive that by adding synchronous energy production to SE4 would yield results that would immediately alleviate some of the unwanted consequences that we see right now. The importance of the N-1 criteria cannot be understated as it immediately affects the transmission capabilities between energy areas. By introducing our proposed scenario, the transmission between SE3 and SE4 would not need to be as restricted as it is today because of the N-1 criteria, resulting in this additional 50% transmission capacity into SE4 from SE3.

Concept/Effect	**Relevance for our Scope (Yes/No)**	**Sustainability Implications (Ecologic/Economic/Social)**	**Validation of the Data (Yes/No)**
Increased plannable energy production	Yes	N/A	Yes
Increased synchronous energy production	Yes	N/A	Yes
Decreased dependency for import of electricity	Yes	Economic/Social	Yes
Decreased use of the power reserve	Yes	Ecologic	Yes
Energy security	**Yes**	**Ecologic/Economic/Social**	**Yes**

Table 4: Criterion validation

5.2.2 Effects on electricity price in SE4

Increased nuclear energy production, with the discussed practical implications, will in turn lead to a reduction of the electricity price in SE4 on both the aggregate level and the volatility aspect. The limited transmission capacity between energy areas in Sweden as explained by Lundbäck, Svensson and Berglöf indirectly increases the electricity price and price fluctuations in the affected areas during times when demand is high. SE4 would also become less dependent on international electricity markets as the availability of regional domestic production increases. The reason for why the electricity becomes expensive in SE4 is the same reason for why our scenario would induct the opposite reaction of the electricity prices. By introducing a reliable energy producing unit within the most affected area (SE4), we circumvent these restrictions in transmission with the nominal power production being located within the geographical boundaries.

Additionally, the balance between energy sources will ultimately increase, creating a more cost effective and reliable structure within SE4. According to a majority of the interviewees, an optimal energy system in a general sense should include an evenly distributed mix of different energy sources in order to gain the most cost-effective and competitive energy system. This mix should include baseload power production, intermittent sources and flexible power production, where the baseload acts as the fundamental energy producing unit with small fluctuations in output. The intermittent energy source is responsible for reducing the general electricity price and the flexible energy source acts as a regulator when the supply and demand is out of sync. To strengthen this reasoning, Svensson refers to a study conducted by Qvist (2020) where his conclusions also suggest a more balanced and technology-neutral approach to the future decision-making process in regard to the evolution of the energy system. These effects will ultimately lead to a reduced electricity price in SE4. The mere fact that an added energy supply will, based on common micro economic theories (Chart 6), reduce the intersection between demand and supply resulting in a general decrease in price of the commodity.

Cost-effective energy prices should not be associated with the cheapest energy prices. As stated by Sjölander, Lundbäck and Svensson, who stresses the importance of competitive electricity prices instead of “cheap electricity”. Their explanations determine that competitive electricity implies more factors than just the price. As explained above the reliability factor and stability factor are equally important when determining if an energy system as a whole is competitive. Sjölander also stresses the importance of assessing the energy system holistically, not only focusing on the actual production of energy, but also how the energy grid is structured. His example of Germany, investing in renewable energy and the marginal price associated with these energy sources being extremely low, does not take into account how this energy will be distributed effectively. Resulting in cheap electricity, but an expensive transmission of that electricity. This conclusion connects back with the term “energy security” as affordability also is a factor to consider as a part of this term according to Turkson et al (2020).

Energy security and the price of electricity has a close relationship as the literature also points out that affordability is a large factor for increasing energy security. The availability factor, reliability factor and affordability factor are therefore a system of factors that together contribute to the energy security situation within a region. Concluding that an introduction of new nuclear power would achieve all of these factors combined, resulting in a considerable sustainability development within SE4. This in turn is directly linked to Turkson et al (2020) and Finkbeiner et al. (2010), which proposes that an energy system needs to be assessed with a holistic approach instead of only focusing on the environmental aspect. By reducing the electricity price, you enable households to gain more access to the affordability aspect of energy security, thus this suggests a connection with economic sustainability.

Concept/Effect	Relevance for our Scope (Yes/No)	Sustainability Implications (Ecologic/Economic/Social)	Validation of the Data (Yes/No)
Decreased electricity prices	Yes	Economic/Social	Yes
Decreased electricity price fluctuations	Yes	Economic/Social	Yes

Table 5: Criterion validation

5.2.3 Increase in regional investments

By analysing what would happen as the energy prices are reduced, we would find that the regional investments in different markets would increase. Especially energy intensive industries would be more willing to invest within SE4. If we examine the example of Pågen and Boliden being denied of investing in their expansion in the city of Malmö due to the specific reason of the local grid operator not being able to guarantee the expected electricity capacity, it becomes obvious that a direct effect of introducing more capacity within the region of SE4 would alleviate these symptoms, thus creating space for additional expansions for energy intensive activities and thus reducing risks for both investment opportunities and risks associated with the entity that is the energy system, as Axon and Darton (2021) suggested.

Additionally, we can derive an increase in interest for investing within this area because of the effect of lower electricity prices and electricity price fluctuations. Fluctuations are equal to variability or volatility, which is equal to risk in the financial sector. We can therefore claim that the probability of increased investments due to a decrease in electricity price fluctuations is likely to be higher than it is currently. Also as explained above, the “risk” of any investment would decrease, which decreases the return requirement thus affecting pricing of goods. Which in turn would help to decelerate the inflation rate. Another aspect that would affect the inflation rate is the operating cost of existing production within SE4. Less fluctuations also helps current corporations to plan their production, while not being as dependent on the current electricity price to function.

The predictability aspect has become apparently important for the future of SE4 when it comes to electricity price. When we examine the answers from both Sjölander and Lundbäck regarding the combination between stable electricity price and “low” electricity price. An aggregated higher electricity price with less fluctuation is argued for being more attractive than an aggregated lower electricity price with more fluctuations. As mentioned, the stability and reliability of the electricity price would directly affect future investments. An interesting aspect that emphasizes this effect, mentioned by several interviewees is that just the announcement of increasing the plannable capacity in SE4 would directly increase the interest for the area in terms of investments.

When we discuss the increase in stability of the electricity price, we can derive that the economic viability of investing in any project that are dependent on the electricity prices in their operations will increase, resulting in an increase of economic sustainability for projects on average. Alluding to what Abu-Rayash (2019) concluded, this relationship will increase not only the economic sustainability of renewable energy production projects, but also increase the general availability of energy for the society. Additionally, the literature review suggested that social sustainability implies that an increase in human well-being, equity and equality are to be established. By increasing the opportunity and incentive for investments, you increase the social inclusion of the residents by creating employment opportunities and attracting various functions that an equitable society brings to the general public. For example, if there are employment opportunities within an area, it will attract external individuals that collectively increase the likelihood of an improved welfare are to be developed within that region, in turn affecting the social dimension of sustainability.

Concept/Effect	**Relevance for our Scope (Yes/No)**	**Sustainability Implications (Ecologic/Economic/Social)**	**Validation of the Data (Yes/No)**
Increased regional investments	Yes	Ecologic/Economic/Social	Yes

Table 6: Criterion validation

5.2.4 Increased disposable income

The increase in regional investments would in turn lead to both direct effects and indirect effects of the disposable income in the area. The direct impacts would be the number of employment opportunities created in relation to the actual power plant. These opportunities would however not come close to the opportunities that would be generated though investments into other industries. As explained above, the investment interest within SE4 and all connected municipalities would increase, leading to an influx of highly skilled workers that would contribute to the public welfare and economic growth of the region. As mentioned by Sjölander, the municipalities already acknowledged the competitive advantage that nuclear power entails for a region, making several, previously non-nuclear, interested in that prospect.

Additionally, the inflation rate is affected to a large extent by the energy prices, which, if lowered, would cause the inflation rate to decelerate. This in turn aids the public by indirectly increasing their disposable income by alleviating the inflation of goods. An additional effect that would occur if inflation rate was lowered is the fact that the interest rate would also be decreased, resulting in an additional factor that increases disposable income for the general household. As the disposable income increases, there will be a larger possibility for the society to increase their living standards by gaining a stronger purchasing power, thus affecting the economic and social dimension of sustainability. You could also argue that this increase in purchasing power might lead to more consumption, which has a negative impact on the ecological dimension. Although this might be the case, the increase in purchasing power might also lead to an increase in consumption of "sustainable" goods, which are more expensive than "non-sustainable" goods, which would mean that the consumption stays at a sustained level but with less environmental impact.

However, it is also important to note that a general increase in disposable income would in turn affect the inflation rate in the upward trajectory as the general public has the capability to spend this income, thus once again according to basic microeconomic theory, move the intersection of supply and demand, resulting in a general increase in price. It is important to note that even though electricity price has an impact on the inflation rate, the inflation rate is a national factor and thus not only attributed to the SE4 area. However, since the rate of inflation is important for the societal implications of the SE4 area as well, it do fulfil the first criterion. The same relationship is true for the interest rate, which is a national factor and not specifically tied to SE4.

Concept/Effect	**Relevance for our Scope (Yes/No)**	**Sustainability Implications (Ecologic/Economic/Social)**	**Validation of the Data (Yes/No)**
Increased disposable income	Yes	Economic/Social	Yes
Decreased inflation rate	Yes	Economic/Social	Yes
Decreased interest rate	Yes	Economic/Social	Yes

Table 7: Criterion validation

Before moving on we want to stress both the positive and negative relationship between these three concepts/effects as the macroeconomic theory suggests. But as explained above, if the increase in disposable income is used to consume higher quality goods and services that has less ecological consequences, the negative relationship between spending and inflation rate, ultimately leading to an interest rate increase will diminish. This will also provide producers of ecologically sustainable goods and services with an influx of income, increasing their market share and thus further developing the regional economy into a holistically sustainable improvement by increasing economic strength and growth of the community and regional corporations.

In the light of analysing future investments and disposable income we can turn towards how the GDP of the region might react to these improvements. Komarova et al. (2022) and Szustak et al. (2021) found no GDP growth in relation to an increase in either energy production or energy consumption in developed countries, which suggest that an increase in GDP wouldn't be an effect of introducing SMRs. But if we examine the conclusions being made in the report made by AFRY (2023), that is concretely linked to the Swedish situation, we find an eight-time leverage between invested capital and GDP increase in Sweden. These conclusions suggest different outcomes of increasing consumption or production, which may be a result of the former conclusion not taking the predicted increase in energy demand, that is currently present in Sweden as the electrification of transportation and industrial processes accelerates, into consideration.

5.3 Increased “green” energy production

Not only will an introduction of nuclear in SE4 directly increase the green energy production due to EU declaring nuclear as green in 2022. It also safely increases the renewable adoption rate without compromising the energy grid. It will also reduce the use of reserve power which are mainly fueld by fossil fuels, contributing the greenhouse gas emissions.

It has been established that an implementation of two 300 Mw SMRs in SE4 would ultimately increase the overall production of green energy. Although this is a positive effect, especially as the demand for clean energy rises. However, while acknowledging that the move towards increased green energy production is positive, it is still important to note that Sweden already is one of the best performing countries when it comes to limiting greenhouse gas emissions. The main contributor to Sweden's low emissions levels is due to the already existing reliance on clean energy sources, the majority coming from hydroelectric and nuclear power. This in mind, it can be argued that it is not relevant for Sweden to add efforts to reduce their emissions even more. Rather, Sweden is in a position to contribute to the global effort to combat climate change by increasing its domestic competence and expertise in the area. This will enable Sweden to play a more significant role in reducing global emissions, which is essential in the fight against climate change.

Thereby contributing to the reductions of the emissions on a global scale. To truly understand how the competence development in Sweden can in a meaningful way contribute to reducing the CO2 emission, we need to extend our reasoning to the global context. An additional effect of the implementation of nuclear is the direct increase in green energy production. Nuclear power is classified under the EU taxonomy as green, essentially enabling investors to label and market these types of investments as green.

Concept/Effect	Relevance for our Scope (Yes/No)	Sustainability Implications (Ecologic/Economic/Social)	Validation of the Data (Yes/No)
Increased "green" energy production	Yes	Ecologic	Yes

Table 8: Criterion validation

5.3.1 Increased possibilities to invest in renewable energy

When we examine what the implications of increasing the plannable and synchronous energy production are for renewable energy sources, we have found that it provides manoeuvrability to expand these investments further without either compromising the stability of the energy system or the need for complementary investments in strengthening the grid or expensive additional infrastructure that support the unwanted side-effects of renewable energy production, such as energy storage systems. By introducing nuclear power once again within SE4 we also gain the advantage of being able to build more renewable energy production sources without risking the integrity of the energy system. Svensson, Berglöf, Stedman and Wallenius argued that a balanced approach to developing the energy system would yield the most satisfying results in terms of stability, reliability and robustness. Moreover, an additional effect of having a balanced and integrated energy system is according to Svensson, that you would gain the positive attributes from all energy sources, effectively resulting in the most cost-effective and reliable energy system possible. Thus, energy security is easier to retain while simultaneously increasing the renewable energy production fleet.

We also find that by reducing the risk of future investments in energy producing technologies, such as renewable energy, with the help of a more stable and predictable electricity price. We can reduce the return-on-investment requirement and subsequently attain a more cost-effective energy system indirectly. As Qvist (2020) concluded in his study, the most cost-effective energy system needs renewable energy sources as well, effectively concluding that additional nuclear power would generate a need for renewable energy sources to achieve his concluded energy producing structure. These factors are effectively working in unison to facilitate investments into renewable energy sources as a consequence of increased nuclear power generation.

This concept/effect is also related to increasing employment opportunities within the renewable energy sector and thus closely related with the concept/effect of increasing the general investment incentives in other sectors, as discussed above. Creating a more socially inclusive regional society with more equity among its citizens since there will be an increase in general opportunity within SE4.

Concept/Effect	Relevance for our Scope (Yes/No)	Sustainability Implications (Ecologic/Economic/Social)	Validation of the Data (Yes/No)
Increased investment incentives for renewable energy sources	Yes	Ecologic/Economic/Social	Yes

Table 9: Criterion validation

5.3.2 Decreased use of reserve power

The power reserve Karlshamnsverket has been discussed quite a bit in this study. What has become apparent through the empirical findings is that an introduction of nuclear power production in SE4 would circumvent the existing limitations of interarea transmission, effectively meaning that the increased activation of Karlshamnsverket would be affected negatively. Replacing this synchronous energy reserve with "green" energy production would in turn decrease the CO2 emission further in Sweden. However, as explained above the main positive attribute of decreasing the use of Karlshamnsverket is not the reduction of CO2 emissions, but rather the economic effect of reducing costly reserve contracts between SVK and private corporations. By reducing dependency on reserve power, SVK will attain a larger budget to invest in infrastructure instead of spending resources to acquiring stabilization contracts.

Concept/Effect	Relevance for our Scope (Yes/No)	Sustainability Implications (Ecologic/Economic/Social)	Validation of the Data (Yes/No)
Decreased use of the power reserve	Yes	Ecologic/Economic	Yes

Table 10: Criterion validation

5.4 Increased interest in nuclear power

The empirical findings, which include public opinion polls, strongly indicate a significant level of public support for nuclear power in Sweden today (Chart 9 and 10). It has been established that there is a direct correlation between awareness of nuclear power and the resulting opinion on the matter. Individuals who have higher awareness are more likely to hold a positive opinion (Danaki & Hemmingsson, Berglöf, Rosén). Insights provided by Berglöf suggest that the construction of new nuclear power plants may contribute to the normalization of nuclear power in general. This normalization can lead to a decrease in the perceived controversy surrounding the subject. As the public becomes more familiar with nuclear power and its benefits, scepticism and fear might diminish. This notion is supported by Rosén, who states that acceptance of nuclear power is typically high in municipalities with nuclear power plants in close proximity. For example, Rosén highlights that when people have neighbours working at a nuclear power plant and see them going there every day, it alleviates their concerns regarding its safety. Empirical findings also show that the five municipalities housing a nuclear reactor currently rank among the highest in public opinion polls, further reinforcing the importance of awareness. Similarly, based on Rosén's statements, there has been a slight decline in positivity towards nuclear power in regions where reactors have been decommissioned.

However, it is important to consider the aspects highlighted by Pettersson, who states that residents of nuclear communities have become accustomed to having nuclear facilities in their vicinity. Ekberg's statement about changing his perception of nuclear power after educating himself sheds light on the importance of accurate information in shaping public opinion. He emphasizes the prevalence of misinformation and fearmongering within the industry, raising questions about the information available to the public. It is noteworthy, however, that reasons behind this have not been discussed enough. What we have discovered is that awareness plays an important role when it comes to the opinion one holds on to nuclear power. This can be seen in the yearly polls that show that residents living in close proximity to a nuclear power plant hold the most positive attitudes and have the highest trust towards nuclear power than residents living further away.

Moreover, the normalization of nuclear power is a key factor in shaping public opinion. As nuclear power becomes more integrated into society, it gradually loses its status as a controversial subject. Increased familiarity with nuclear power plants, their operation, and their benefits contributes to the normalization process. This normalization can alleviate public concerns and diminish the perceived controversy associated with nuclear power. Furthermore, education and information play a crucial role in influencing public opinion on nuclear power as noted by Ekberg. Our analysis demonstrates that the implementation of small modular reactors in southern Sweden has the potential to positively influence public perception of nuclear power. Increased awareness, coupled with the normalization of nuclear power and the dissemination of accurate information, can contribute to a shift in public opinion towards greater acceptance and support for nuclear energy.

The growing interest in nuclear power can be seen effecting and expanding educational opportunities, training programs, and the overall enhancement of expertise in the industry. As interest in nuclear power grows, there is a corresponding increase in applications to nuclear power programs at the universities. This trend contributes to the development of expertise and competence within the field, ensuring a knowledgeable workforce for the nuclear power industry. The development of nuclear competence has been discussed thoroughly with the interviewees. All agree that Sweden was once in the forefront of nuclear power development and that we have since stagnated and “lost our touch”. However, many see a bright possibility of regaining this competence that we once had, but that a prerequisite for this is getting students into the right programs at the universities. For this to be possible, linkage is made back to the general interest and public opinion on nuclear power and that by creating a trust in the long-term applications of nuclear power, more students will apply to these programs.

Concept/Effect	Relevance for our Scope (Yes/No)	Sustainability Implications (Ecologic/Economic/Social)	Validation of the Data (Yes/No)
Increased interest in nuclear power	Yes	Economic/Social	Yes

Table 11: Criterion validation

5.4.1 Creation of a new product to export

Even though the possible creation of a new export commodity adheres a lot to the continued sustainable development on a global stage, it does not pertain to the scope of this study. It is worth mentioning however, since many of the interviewees agreed with this statement. The potential implications for the economic growth of a new industry within the Swedish borders and ultimately the inherent contribution to societal development in other less developed countries could be affected by this implication. How might Sweden as a relatively small country be able to contribute to the sustainable development on the global context? We argue that both adhering to the philosophy that decisions need to make sense from a holistic sustainable perspective within our own borders but also maximise the utility of our competence to help others achieve the same thing. Helping to develop energy systems in other countries to help achieve energy security as a whole, might be the most important thing for the future of the Swedish contributions to the global sustainable development. Increasing and expediating the opportunities for innovative thinking within the energy industry in Sweden at the same time.

Concept/Effect	**Relevance for our Scope (Yes/No)**	**Sustainability Implications (Ecologic/Economic/Social)**	**Validation of the Data (Yes/No)**
Export of competence	No	Ecological/Economic/Social	Yes

6. Conclusion

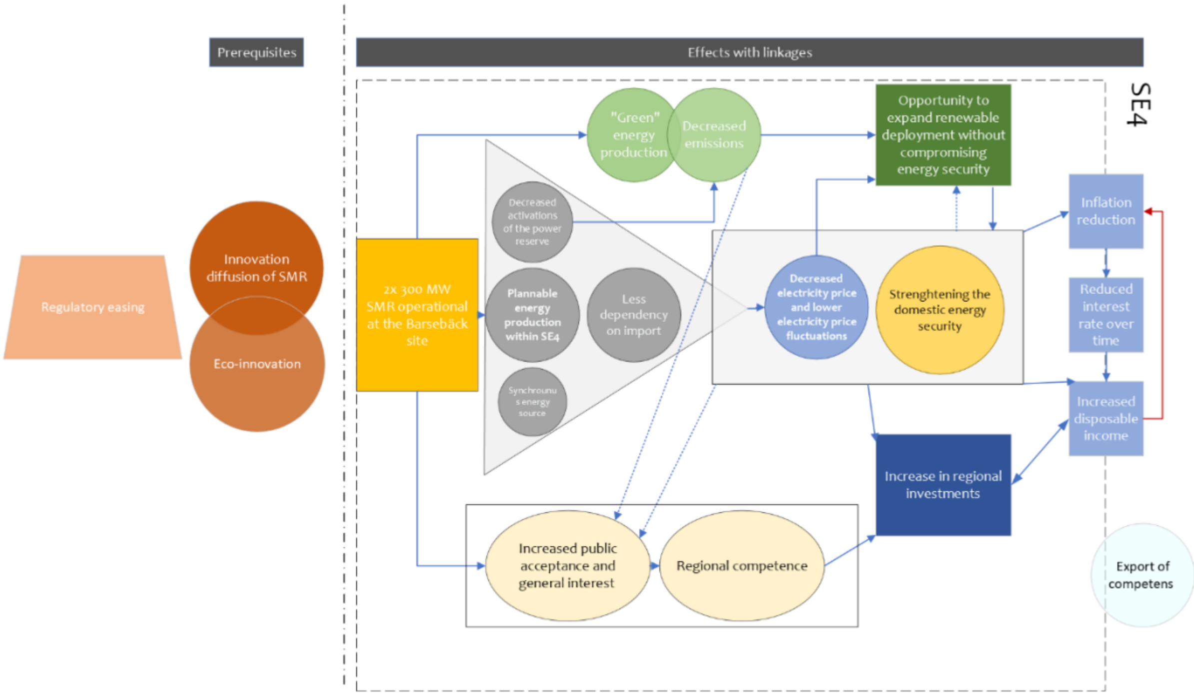

Figure 6: Synthesized framework based on the analysis. *A visual representation of the analysis chapter to provide a clearer overview of the identified concepts/effects. The prerequisite section aims to clarify how regulatory easing plays a significant role in fostering and enabling innovation. It simultaneously shows how eco-innovation and ultimately innovation diffusion together influences the rate of development and implementation of SMRs. Looking at the concepts/effects with linkages section we see the identified effects of implementing two, 300 MW SMRs at the Barsebäck site in the SE4 electricity region in Sweden.*

This master thesis has examined the concept of small modular reactors and their ultimate implications towards ecological, economical, and social sustainability. It has through this research become evident that SMRs are a product of eco-innovation and represent a significant potential to addressing the current challenges in the energy sector. This study has highlighted the importance of innovation diffusion as well as regulations when it comes to determining the development and implementation rate of SMRs. Equally as important, it has become clear that the rate at which SMRs are adopted is closely linked to the public's perception and interest in nuclear power. By increasing the awareness and knowledge about SMRs and nuclear power in general, we can determine that an enhanced acceptance and interest will arise among the general public.

While it is acknowledged that the core technology used in SMRs is similar to that used in traditional nuclear reactors, arguments have been presented for the packaging, standardization, modularity and safety features of SMRs is what ultimately makes them innovative. Through embracing the technological enhancements of nuclear reactors along with the innovative packaging of SMRs, countries and more specifically regions such as southern Sweden can reap the many benefits that this study has identified. By introducing two 300 MW SMRs in the SE4 electricity region in Sweden, the first and most powerful implication is the increased energy security within that region. Specifically, in the context of Sweden, the increased energy security achieved through SMRs would contribute to a stable and reliable energy supply, reducing the vulnerability associated with external energy sources. This enhanced energy security can pave the way for economic growth, as businesses and industries in the region can operate with increased confidence that the availability of energy as a regional commodity will be increased. Creating incentives for additional investments into this region is also highlighted and would have a large impact on all three dimensions of sustainability within the region. The establishment of these innovative nuclear technologies would create new job opportunities, drive infrastructure development, and foster collaborations with various stakeholders. The increased investments can have a ripple effect on the local economy, generating additional economic activities and further stimulating national growth.

In order to verify our results with evidential discoveries, we suggest that each effect should be an item for quantitative analysis. We also realize that many of the proposed effects are difficult to measure and collect data from, before or after the actual scenario has been implemented. Effects that are located far away from the scenario could be affected by many other factors along the way and are therefore difficult to ascribe to the original scenario. The findings in this study are an item for the scientific community to build upon to achieve a broader understanding of what energy producing technologies brings with it from a system thinking perspective, having as many perspectives as possible in mind when examining the actual impacts on a region. We have also contributed to the innovative literature by examining and implementing relevant theory to the specific context that is SMRs. Ultimately finding concrete connections between SMRs and the suggested theories. Through our widened sustainability perspective, we can conclude that we have contributed to the scientific literature revolving eco-innovation. By analysing additional dimensions of sustainability that is currently not reflected in the literature, such as the economic and social dimension in correlation with sustainability.

7. Recommendations for future research

This thesis should act as preliminary investigation, identifying various branches of which should be further researched. As this is a qualitative study that aims to simply identify effects in sequence of an SMR implementation in southern Sweden, we recommend further investigation of the identified effects and their interrelationships using quantitative methodologies to substantiate the preliminary conclusions. Accordingly, a multivariate analysis and correlation study should be undertaken to delineate the ways in which these effects interact with each other. This rigorous quantitative data analysis needs to be aimed to establish and clarify concrete linkages between variables, thereby strengthening the evidence base for our findings. Additionally, we recommend that a comparative study be conducted between SMRs and other forms of innovative energy production to examine the differences of sustainability implications to contribute to the efforts of finding solutions for the current problems of the Swedish energy system.

Another important topic we suggest would be further researched is how the private industrial investments might affect the total energy system within an area. As their own interest in diversifying their energy portfolios expands to their own energy producing processes, it would be interesting to find out how this might affect the society in terms of energy security and price action.

8. References

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9. Appendices

Interview guide

Please note that the full interview transcript can be provided upon request.

Purpose - The purpose of this interview is to gain a broader understanding from a working professional on how SMRs can effect a local region directly and indirectly. What aspects of the society will improve or decline as a result of the deployment of SMRs? The interview is set to be semi-structured with an inclination towards unstructured and the interviewees will lift topics/areas that the respondent will get to talk freely about. Simultaneously, the interviewees will listen actively and address any points deemed appropriate to dig deeper into.

Introduction - The interview will begin by introducing ourselves as well as the subject of the master thesis. Thereafter, we will explain why we have asked the particular participate in this interview and discuss which topics we wish to address. As the aim is to have a relatively unstructured interview, the key will be to create a good environment as quickly as possible so that he feels comfortable enough to talk openly. We will also ask for the respondent's permission to record the interview.

General interview guid. As the interviews were semi-to completely unstructured, topics and certain questions were discussed amongst the interviewees beforehand (see chapter 3 for reasoning).

Topics/questions

What are the main opportunities that an SMR can provide for a region?

- What are the main benefits?

Public opinion on nuclear power?

Plannable energy production

- What is plannable energy production and why is it important?
- What are some examples of energy sources that are more plannable than others?
- How do you balance the need for plannable energy production with the need for flexibility in energy systems?
- How can technology help to improve the plannability of energy production?

Energy system reactions to different types of energy sources

- How do energy systems react to different types of energy sources?
- Are there any energy sources that are particularly challenging for energy systems to handle?
- How can energy systems be designed to better handle different types of energy sources?
- What are some of the benefits of having a diverse mix of energy sources in an energy system?

Nuclear power as a solution

- Do you think nuclear power is the solution to a more balanced and sustainable energy system?
- What are some of the advantages of using nuclear power in an energy system?
- What are some of the disadvantages of using nuclear power in an energy system?
- How can the risks associated with nuclear power be mitigated?

Synergetic effects of SMRs

- How can SMRs be used to improve energy systems?
- What are some of the synergetic effects of using SMRs?
- What are some of the challenges associated with using SMRs?
- Selling points for nuclear power or SMRs

Nuclear power and lower CO2 emissions

- How can the usage of nuclear power lead to lower CO2 emissions?
- How does the carbon footprint of nuclear power compare to other energy sources?
- What are some of the challenges associated with using nuclear power to reduce CO2 emissions?

Sustainable energy demand

- What are some of the factors driving this trend?
- How can energy providers meet this demand?

Responsibility for UN SDGs

- What are your responsibilities as a national energy provider for reaching the UN SDGs on a regional and global scale?
- What are some of the challenges associated with meeting these goals?
- How can energy providers collaborate with other stakeholders to achieve these goals?