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Small modular nuclear reactors in a regional clean energy transition strategy

A case study on SaskPower's selection of small modular reactors and conditions for successful implementation

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Abstract

Small modular nuclear reactors (SMRs) are a complex solution for Saskatchewan's energy transition from fossil fuels to low-carbon sources. As Saskatchewan predominantly relies on fossil fuels for its electricity needs, the consideration of SMRs by SaskPower is in hopes of decreasing carbon emissions and maintaining energy security. SMRs offer several advantages, including modularity, grid stability, and a minimal carbon footprint compared to renewable alternatives. However, challenges such as high capital costs, regulatory and licensing hurdles, technology uncertainty, and the potential negative effects of radiation pose significant barriers. The successful implementation of SMRs in Saskatchewan could have broader implications for the adoption of SMRs globally, positioning the province as a critical case study of the viability and impact of SMRs within the energy sector. There is little research on SMRs to date. Evaluating the rationale behind proposing SMRs in an energy strategy and the factors for their success can have a global impact in a world that requires clean energy transitions urgently. This project will use Saskatchewan as a case study and assess why SaskPower has chosen SMRs as an option (RQ1), whether their proposed timeline is realistic (RQ2), and the conditions that could lead to SMR implementation succeeding or failing (RQ3). Data was collected through reference cases, document analyses, and 6 interviews with different levels of stakeholders. The results reveal that emission reduction goals were the most obvious reasons for looking at SMRs in Saskatchewan, but economic incentives and strong social support motivated the decision as well. SaskPower's timeline is ambitious for a new-to-Canada technology and will likely face delays at both the regulatory and construction phases. SMRs will likely succeed if electricity prices from nuclear remain competitive, is social support remains strong, and if no major nuclear incidents happen geographically close to Canada. Those factors for success can easily be flipped and be the factors for SMR failure. It is recommended that social engagement and support be closely monitored, economic competitiveness of electricity prices must be maintained, and all of the safety precautions regarding potential negative effects be taken.

Keywords: Nuclear power, Small modular reactors, Clean energy transition, Saskatchewan, SaskPower

Executive Summary

Problem Definition

The release of harmful greenhouse gases through human activities such as burning fossil fuels have led to a degree of global warming that is increasingly threatening our ecosystems. The largest source of these emissions is from the energy sector: electricity, heat, and transport. Not only is it necessary to mitigate the existing emissions, it is also crucial to decarbonize the energy sector to prevent any more emission releases. As nuclear power has the lowest carbon footprint of low-carbon sources, it is a promising option for a clean energy transition. Although Canada produces its electricity, on average, from low-carbon sources, certain provinces, such as Saskatchewan, are highly dependent on fossil fuels for their energy needs. The electricity provider of Saskatchewan, SaskPower, has goals to transition their electricity generation away from fossil fuels and towards net-zero, and they have chosen small modular nuclear reactors (SMRs) as one of the components for this clean energy future. SMRs face both criticism and hope as they are a new-to-Canada technology and could aid in a clean energy transition, or have detrimental harmful effects on people, the environment, and the local economy. Investigating why SaskPower has chosen to look at SMRs and whether they would be successfully implemented in Saskatchewan could inform and steer the viability of SMRs on a global scale.

Aim and Research Questions

The aim of this research was to supply a deeper understanding of the process and factors by which an emerging nuclear technology, especially SMRs, are selected as an energy source and assess the subjective factors regional to Saskatchewan in whether SMRs will succeed through different stages of implementation. Moreover, this research aims to supply insight and provide a reference for academics studying energy transitions and climate mitigation, practitioners of nuclear and related industries, energy planners, and policy makers. The research questions I aim to answer are:

1. Why has nuclear power been selected as a potential low carbon energy source solution for Saskatchewan?
2. What is the realistic timeline for implementing nuclear energy and is it in line with SaskPower's foreseen timeline?
3. Under what conditions might nuclear power succeed or fail in Saskatchewan?

Research Design

This project was conducted in a mixed-methods strategy using both the PESTE and feasibility spaces frameworks as a guide for the approach of the research. The PESTE framework enabled a comprehensive approach to internal and external factors that can affect the success or failure of SaskPower's SMR project. The feasibility spaces framework divided the research approach into inside and outside views of causal evidence that allowed for holistic conclusions to the research questions. A mixed-methods design was chosen due to the newness of SMR technology. Documents for research are limited and much of what exists is based on projections, so obtaining expertise and responses from interviews is quite helpful. The research consisted of 6 interviews with varying levels of stakeholder as well as reference cases and document analysis. The semi-structured interviews provided valuable information that often was hard or impossible to find in documents and thus enriched the research results. The responses can now be published and used to help future researchers in their endeavors. The document analysis was used to corroborate or supplement information gaps in the interview responses. Some examples of this are specific construction dates and budgets, regulations, schematics, and reports. Reference cases were valuable because there is lots of data on conventional-sized nuclear reactors, but not much on SMRs, so comparing either conventional reactors or other energy projects to SMRs can help inform certain realistic expectations in terms of answering the research questions. Data was analyzed using either thematic analysis or content analysis. The mixed-methods approach was an appropriate choice as it enabled a comprehensive and thorough response to each research question.

Results

In investigating why SaskPower selected SMRs as a potential low-carbon energy source (RQ1), it was found that emission reduction goals, energy stability, and economic sustainability are the primary criteria. As a monopoly, SaskPower's revenue depends on maintaining a stable centralized grid, ensuring residents can confidently rely on them for electricity. Direct input from a SaskPower employee confirms their commitment to reducing carbon emissions by phasing out coal and eventually natural gas, with increased renewables and a baseload of SMRs as the potential energy strategy. A decision point in 2029 will determine whether SaskPower will go through with initiating SMR construction, or whether they will pivot to a different solution.

To research whether SaskPower's projected SMR Project Schedule Timeline was realistic (RQ2), interviews and reference cases were needed and showed that there would most likely be delays, and they could originate from Ontario Power Generation's (OPG) SMR process or from licensing and construction delays of SaskPower's own SMR. Some criticisms of SMRs highlighted that even without delays or setbacks, this project won't be operational for another decade which is unhelpful for the required clean energy transition. Because SMRs are new to Canada, the regulatory and construction process will first be taken on by OPG, then repeated or improved by SaskPower. A delay in OPG's process will lead to a delay in SaskPower's. The licensing and impact assessments will likely be delayed based on both interview responses and reference cases, and construction cannot begin without those processes being completed first. Construction is also a likely setback point, but Canada has a positive reputation for finishing their nuclear project within a reasonable period, so even if there are delays, it won't be for too long. 2035 is a bold estimate for when there could be an SMR in Saskatchewan.

The conditions for success of an SMR in Saskatchewan (RQ3) evaluated the research through three phases: decision, construction, and operation phase. Success in the decision phase is marked by SaskPower's initiation of site preparation and construction and is heavily influenced by the outcomes and experiences of OPG's SMR project. Timeline delays or significant budget overruns in OPG's project could derail SaskPower's plans early on. During the construction phase, key conditions include economics, public support, and nuclear incidents. Budget overruns or insufficient initial funding could halt construction, while waning public support or nuclear accidents, even internationally, could also lead to project abandonment. Additionally, environmental contamination or negative health effects during construction could cause failure. In the operation phase, electricity prices and nuclear impacts on health and the environment are critical. Electricity prices must remain affordable and competitive and the environment and people cannot experience any radiation effects.

Conclusions and Recommendations

The interconnectedness of public approval, economics, and nuclear incident risks is crucial in determining the success of an SMR project, especially for a public utility like SaskPower. Interviews revealed diverse perspectives on nuclear energy, highlighting both justified concerns and the industry's emphasis on safety. This research does not conclude whether SMRs are beneficial or harmful for Saskatchewan but instead aims to provide reference and insight that will encourage application to a wider context.

It is recommended that ongoing public engagement be pursued in order to ensure positive and transparent customer and Indigenous relations. This benefits both the public and SaskPower. It is recommended that transparency as to the funding strategy of the SMR project, and future SMR projects, be established in order to build trust and allow for feedback from the ratepayers who will be affected. It is recommended that international collaboration be taken and policies be formed for the most economically beneficial trade agreements regarding enriched uranium fuel. And lastly, it is recommended that green job transition programs and policies for employees in the coal and natural gas industry be established to foster the most beneficial and positive clean energy transition possible.

Several proposed benefits of SMRs beyond low-carbon electricity generation warrant future research. Given Saskatchewan's harsh winters, researching the technological and economic feasibility of using SMRs for heat generation could reduce the province's reliance of fossil fuels. Additionally, investigating the social benefits of SMRs for Indigenous communities could strengthen business partnerships and collaboration incentives. The impact of inflation and shipping disruptions on construction materials and enriched uranium, which would affect SMR construction costs, should also be examined due to the significant role economics play in SMR success. As a new technology in Canada, SMRs present a vast research opportunity to understand their attributes and effects, both positive and negative.

Abbreviations

AECL	Atomic Energy
BQ	Bloc Québécois Party
CAD	Canadian Dollar
CANDU	Canada Deuterium Uranium
CEA	Commissariat à l'Énergie Atomique
CEU	Central European University
CNSC	Canadian Nuclear Safety Commission
CO_2e	Carbon Dioxide Equivalent
COP28	28th Annual United Nations Conference of the Parties
CPC	Conservative Party of Canada
DGR	Deep Geological Repository
EDF	Électricité de France
ESBWR	Economic Simplified Boiling Water Reactor
FNPA	First Nation Power Authority
FOAK	First of a Kind
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GEH	General Energy Hitachi
GEI	World Bank Government Effectiveness Indicator
GHG	Greenhouse Gas
GPC	Green Party of Canada
GWe/h	Gigawatt electrical or Gigawatt hour
IAEA	International Atomic Energy Agency
IMSR	Integral Molten Salt Reactor
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
LPC	Liberal Party of Canada
LR	Large Reactor (used interchangeably with conventional reactor)
MOU	Memorandum of Understanding
Mt	Million tonnes
MWe	Megawatt electrical
NDP	New Democratic Party
NPP	Nuclear Power Plant
NPT	Treaty on the Non-Proliferation of Nuclear Weapons

NRCan	Natural Resources Canada
NWMO	National Waste Management Organization
OCC	Overnight Construction Cost
OPG	Ontario Power Generation
PSI	Political Stability Index
SBWR	Simplified Boiling Water Reactor
SMR	Small Modular (nuclear) Reactor
TCPS 2	Tri-Council Policy Statement: Ethical Conduct for Researching Humans
UNECE	United Nations Economic Commission for Europe
UO_2	Uranium Dioxide
US	United States
USD	United States Dollar
USNRC	United States Nuclear Regulatory Commission
WNA	World Nuclear Association
WNISR	World Nuclear Industry Status Report

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1 Introduction

1.1 Background

Climate change is one of the biggest problems facing society today. Global warming is a result of detrimental human activities, mainly, burning fossil fuels which in turn releases harmful greenhouse gases (Intergovernmental Panel on Climate Change [IPCC], 2021). Energy use for electricity, heat, and transport is the largest source contributing 73% of global greenhouse gas emissions (Ritchie, 2020). To tackle the increasing severity of climate change, rapid transitions to cleaner sources of energy are needed. Nuclear power has some of the lowest emissions among other energy technologies, but there are doubts that it can effectively contribute to climate mitigation due to concerns about its costs and slow deployment rates. Nevertheless, some countries, including Canada have pledged to increase the use of nuclear power as part of climate change mitigation efforts.

Canada makes up about 1.4% of global emissions, however, its per capita emissions are amongst the highest in the world (Ritchie et al., 2020b). Additionally, the energy sector is the highest emitter within Canada, topped by electricity and heat emissions (Ritchie et al., 2020a). Canada's electricity mix consists of approximately 80% low-carbon sources and 20% fossil fuel sources, however, there are large differences within the provinces and territories of Canada with respect to energy mix (Government of Canada, 2023). Some are reliant on hydropower and nuclear power while others use almost exclusively fossil fuels, such as Saskatchewan. Saskatchewan is not only a province that needs an energy transition, but it is also a unique case where almost all its electricity production and distribution is overseen by one company: The Saskatchewan Power Corporation, also known as SaskPower. SaskPower is a Crown Corporation which means it is an organization or company that is owned and overseen by the government, whether that be provincial or federal.

SaskPower and, more broadly, Canada have committed to several agreements that impact energy production and consumption at different levels. Fulfilling these commitments would require replacing coal power with other energy sources. One such source may be nuclear power, specifically small modular reactors (SMRs), which SaskPower is currently considering. However, nuclear power is associated with challenges. Globally, nuclear power has experienced stagnation (Markard et al., 2020). Experts express concerns over slow timelines, large costs of new plants, and potential health and environmental risks of nuclear power. The published timeline for decision-making regarding implementing nuclear power in Saskatchewan by SaskPower is both slow and aggressively confident. Whether nuclear power in Saskatchewan succeeds has large implications beyond the province, or even Canada, as it is crucial for the prospects of this technology worldwide.

1.2 Research Aim, Questions, and Scope

The aim of this research is to contribute to understanding the rationale and the process by which new nuclear power plants, especially small modular reactors (SMRs), are planned and evaluate the prospects of such plans to succeed using Saskatchewan as the case study. The research questions I aim to answer are:

1. Why has nuclear power been selected as a potential low carbon energy source solution for Saskatchewan? The alternatives will be explored as well as the selected small modular reactor technology. Answering this question will give insight into the technological barriers and opportunities that arise from different energy options in Saskatchewan, and how SMRs can benefit Saskatchewan.
2. What is the realistic timeline for implementing nuclear energy and is it in line with SaskPower's foreseen timeline? Answering this question will provide common delays to nuclear energy projects from an inside and outside view. SaskPower's timeline will be assessed as either ambitious, realistic, too slow.
3. Under what conditions might nuclear power succeed or fail in Saskatchewan? "Conditions" may touch upon political, environmental, social, technological, or economic aspects. Answering this question will set realistic expectations for the outcomes of SaskPower's SMR project proposal.

The scope of this research is energy transitions in the province of Saskatchewan, Canada, specifically the planned deployment of small modular nuclear reactors. The thesis will draw on and provide reference for nuclear power introduction in other provinces and countries.

1.3 Ethical Considerations

My research has been minorly funded by my educational institution, but this has not influenced the nature of the research or conclusions in any way. No one may be in a position to unduly influence my analysis and conclusions.

Participation for respondents is voluntary. There is no cause to believe that the participants may have suffered any disadvantage or damage from their participation in the study. Consent and confidentiality were secured and consent forms for interviews were provided. GDPR and Tri-Council Policy Statement: Ethical Conduct for Researching Humans (TCPS 2) guidelines were considered and followed. All interviewee data and results were collected and anonymized and stored in a backed up, password protected computer. No defining information except for profession or area of expertise will be shared.

1.4 Audience

The targeted audience of this research are academics studying energy transitions and climate mitigation, practitioners of nuclear and related industries, energy planners, and policy makers.

1.5 Thesis Structure

This thesis consists of six chapters. Chapter 1 provides background information on the research topic in both a broad and specific context and outlines the research questions, aims, and objectives. Chapter 2 consists of the literature review to provide the necessary knowledge that is foundational to the research thesis. It introduces literature relevant to the three research questions. Chapter 3 consists of an explanation of the theoretical framework that is used throughout the research as well as the methodology of the research used to collect data and come to conclusions. Chapter 4 is divided into the research questions and covers the collected data that is relevant for each RQ while making conclusions in order to answer each RQ. Chapter 5 is the discussion where the results will be discussed in a broader, more integrated context and interesting relationships between the data are fleshed out. Lastly, Chapter 6 will conclude the thesis where the results will be summarized and future research will be suggested.

2 Literature Review

2.1 Why has nuclear power been selected as a potential low-carbon energy source solution for Saskatchewan? (RQ1)

2.1.1 Political

Decisions to introduce nuclear power are often political because they touch upon many political objectives such as climate and energy security, affect political interests, and require state involvement (Stirling, 2014). More generically, the introduction of nuclear power requires government involvement to some capacity, whether that be purely regulatory or fully invested and financially overseeing the project (Brutschin et al., 2021). In order to achieve greenhouse gas emission reductions, fossil-fuel energy must be phased out and replaced with low-carbon energy sources. This is one of the motivators for choosing nuclear energy, specifically SMRs, as they would offer an alternative stable energy source to the decommissioned coal plants (Hamill, 2021). Achieving greenhouse gas emission reduction goals is a political reason as those goals are usually set by the government or internationally, and achieving the goals reflects positively on the government as a whole.

In terms of energy security, the region may want to diversify its energy sources to increase energy resilience, or there may be a desire to move away from imported energy dependence. Results showed that the less dependent a country became on foreign resources to meet their energy needs, the less likely they were to build nuclear power (Fuhrmann, 2012). In other words, the likelihood to build nuclear power was indicative of energy dependence. Major nuclear accidents are likely to persuade countries to not pursue nuclear power projects, whereas non-major accidents do not seem to have a significant effect. A smaller but noticeable relationship of post-nuclear accident decisions is that democracies are less likely to pursue nuclear power after a major accident whereas authoritarian states were less affected by the accident and more likely to pursue or continue pursuing a nuclear power project (Fuhrmann, 2012). Countries that already have established nuclear power programs are less influenced by a major nuclear accident than those without any established nuclear power programs (Fuhrmann, 2012).

As most national energy strategies come from government bodies, determining political priorities that guide the national strategies can help provide insight into what propels a government to choose nuclear power as an option. Gralla et al. (2016) show through their research that a nation is likely going to reference sustainability as a reason for including nuclear within their national energy strategy, regardless of whether 'sustainability' is defined or not. Governance and economy were recurring themes in relation to sustainability and nuclear energy (Gralla et al., 2016). "Interest in exchange and connection with other communities," guided the governance theme as energy often requires international cooperation. A government may choose nuclear power because of geopolitical considerations such as trade deals struck up with other nations that would be part of the supply chain or becoming a nuclear authority on the global market itself (Smith & Gieré, 2017). Nuclear power may also fit into a nation's energy strategy and military strategy. The uranium enrichment and reprocessing cycle can create nuclear weapons material, which might entice a country to implement nuclear power as an energy source and as a defence program (Smith & Gieré, 2017). This can have a poor effect on the government, on the other hand, if they have signed the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). Achieving governmental goals, international cooperation and influence, and a possibly greater experience for military defense are common reasons as to why a nation may choose to select nuclear power as an energy source.

2.1.2 Economic

Economic development and growth can help make nuclear power projects successful compared to other nations that don't necessarily have the economic capacity. Higher levels of gross domestic product (GDP) are correlated with increased likelihood of nuclear power plant (NPP) construction (Fuhrmann, 2012). The cost of nuclear power is a major consideration in all stages of its construction and operation (Lovering et al., 2016). Canada has already implemented nuclear power and therefore has reference for conventional-sized nuclear reactors. Canada's first reactor, built in 1957, was a demonstration Canadian Deuterium Uranium (CANDU) technology that operated at 17MWe (Lovering et al., 2016). The overnight construction cost (OCC) of CANDU was $11,000/kW Canadian Dollars (CAD). The OCC is a measure of the costs of direct engineering, procurement, and construction services and land, site preparation, project management, training, contingencies, and commissioning costs (Lovering et al., 2016). The OCC is highly variable between countries and timelines whereas other costs, such as Interest During Construction, are more predictable and constant. The commercial reactors ordered between 1960 and 1974 had OCCs between $2000 and $3000/kW and produced up to 500MWe. From there the cost of reactors gently increased to a maximum OCC of about $4000/kW. This incline in price is possibly explained by changes in builders or manufacturers, or the smaller size of the reactors compared to other reactors used internationally (Lovering et al., 2016). This trend of high upfront costs associated with pioneer technology with a drastic price decrease followed by a slow and slight price increase may be seen with small modular reactors.

There are various reasons as to why SMRs may be a desirable investment from an economic perspective. SMRs offer reduced risks and shorter timelines which means reduced economic risks. Mangena (2021) reviews the economic benefits of SMRs, including reduced construction, technology, regulatory, safety, operation, and societal risks which corresponds to reduced economic risks. As SMRs are somewhat of an emerging technology, there may be some associated high costs taken on by first mover investors however, it also opens the opportunity for dominating the global SMR market which includes knowledge, jobs, and technology (Mangena, 2021). The opportunity for cogeneration of district heating is also an economic benefit to be considered, especially in very cold regions. The concept of economy of multiples also comes into play with SMRs in contrast to the economies of scale. As SMRs are smaller and do not play into the economies of scale, the modularization and standardization aspects of SMRs can counteract this disadvantage. Lower operation and maintenance costs, fewer refuelling requirements, and simpler decommissioning are also factors of SMRs that would require lower costs than regular sized nuclear power plants (Mangena, 2021). There are clearly many economic opportunities and considerations that would lead to SMRs being chosen as an energy source.

2.1.3 Social

There are certain values that society may have, as Hecht (2001) exemplifies with France, that make it more accepting, or even a driver of, nuclear power. Nuclear power was marketed as a combination of modernity and technology, both of which are integral components that have, and continue to, shape France's identity. This portrayal draws intriguing parallels between the iconic "industrial grandeur" symbolized by the Eiffel Tower and the formidable presence of nuclear power plants (Hecht, 2001). The association between technology and national identity serves as a cornerstone for a political strategy among technologists, aiming to articulate and reinforce the significance of technological advancement in shaping the nation's trajectory and global standing (Hecht, 2001). National grandeur and military technological prowess influenced the selection of reactor types and the underlying strategy of nuclear hedging. The independent technopolitical regimes of the Commissariat à l'Énergie Atomique (CEA) and Électricité de France (EDF) wielded considerable influence over national policy, reversing the traditional hierarchical dynamic (Hecht, 2001). These reactors were touted as iconic French achievements, serving the nation. This narrative reinforced the deep-rooted association between nuclear prowess and the French identity, a strategic move by both technopolitical regimes. In contrast to the CEA's fear of Americanization, which would entail investing in an alternative reactor type, EDF exhibited a tendency towards embracing cheaper and more economically viable American technology (Hecht, 2001). The narrative of national identity was becoming linked to economic activity and emphasizing interdependence over independence. Thus, it became imperative to delineate technology from politics to adopt a new, more American and more economically feasible option. The new French national identity was moving towards being linked with economics and how to make technology French as opposed to making French technology. The French example shows how technological artifacts and adoption are inherently cultural and political (Hecht, 2001).

2.1.4 Technological

The selection of SMRs as a nuclear power option must consider both the advantages and concerns of the technology. Many SMRs are based off large-reactor designs and expectations for their regulations and performance are tailored accordingly, however, the research and development of the technology needs to continue to be strengthened so that investors can be better informed (Mangena, 2021). Some challenges that technology research and development face are testing of the components and fuel, first-of-a-kind (FOAK) design uncertainty, economy of scale, perceived risks, and regulation procedures (Mangena, 2021). Collaboration of technology stakeholders combined with different levels of government support and creation of research, experimental, and educational centres are two ways that technology obstacles can be overcome (Mangena, 2021). A common design goal of SMRs compared to large reactor designs is for the fuel to have a higher burnup value so that uranium resources are used more efficiently and for the refuelling cycles to be longer so that proliferation risks are reduced and there are less safety concerns with radiation escaping during refuelling (Mangena, 2021). SMR technology encompasses deliberate design features aimed at enhancing various technology aspects of nuclear power plant construction and operation. These features include modularity to streamline construction and decommissioning, improved thermal efficiency, shorter supply chains, and reduced maintenance and operation expenses (Mangena, 2021). The modularity of SMRs is a huge advantage for construction time and testing regulations. The ability to construct components in a factory in an almost-assembly-line fashion means that a consistent set of standards can be met and construction on site will be majorly more efficient (Mangena, 2021). In terms of waste and end-of-life technology disposal, extrapolations will have to be drawn from large-sized reactors, however, the assumption is that there will be less waste created from one SMR lifecycle at a similar lifespan compared to that of a large-sized reactor. Although there are some uncertainties due to the new technology of SMRs, there are already some expectations to the benefits of SMR technology compared to that of large reactor options.

One cannot discuss nuclear reactors without mentioning infamous nuclear accidents that gives the technology such a strong reputation. There have been four major memorable nuclear accidents, amongst others: SL-1 in Idaho in 1961, Three Mile Island in Pennsylvania in 1979, Chernobyl in Ukraine in 1986, and Fukushima Daiichi in Japan in 2011. SL-1 was a research reactor in Idaho Falls, Idaho and was undergoing routine preparations for restarting the reactor when the central control rod was pulled out too far (Siegel, 2004). The reactor exploded which resulted in the three-man crew all dying and the technology undergoing scrutiny for its flaws and weaknesses that needed to be improved upon (Siegel, 2004). It does not seem like there was significant radionuclide release which drastically decreases the effect of the accident on the surrounding environment and people (Wilson et al., 1985). In 1979, the Three Mile Island Unit 2 reactor partially melted down as a result of equipment malfunctions, design-related problems, and worker errors (United States Nuclear Regulatory Commission [USNRC], 2024). There were no detectable negative health effects on plant workers or the public after the accident even though there was a small offsite release of radioactivity (USNRC, 2024). Chernobyl, one of the most famous accidents, occurred in 1986 and claimed more lives than the two previously mentioned cases. In a case of poor reactor design and undertrained personnel, an equipment test with poor safety procedures created rapidly pressurizing steam that then exploded and destroyed the reactor and killed two plant workers (World Nuclear Association [WNA], 2024a). 28 people died shortly after due to acute radiation syndrome, about 5000 cases of thyroid cancer emerged, about 350,000 people were evacuated and displaced, and many radionuclides were deposited in parts of Europe (WNA, 2024a). Last, but not least, is the Fukushima Daiichi accident that was an unfortunate result of an earthquake and resulting 15-metre tsunami (WNA, 2024b). The power supply and cooling were disabled by the tsunami which led to the three cores melting, and the whole accident lasted approximately two weeks as the reactor released high radioactive releases and was slowly cooling down (WNA, 2024b). Of the 100,000 people that were evacuated, there were no recorded cases of radiation sickness or death but their were 2,313 disaster-related deaths from evacuating (WNA, 2024b). Nuclear accidents are terrible events with different levels of effects, but need to be prepared for, safeguarded, and avoided at all costs.

2.1.5 Environmental

Nuclear technology has low emissions compared to other electricity generation technologies (Liou, 2023). At COP28 there was a commitment to triple nuclear power globally by 2050 to contribute to solving climate issues (U.S. Department of Energy, 2023). However, Sovacool et al. (2020) measured renewable and nuclear electricity production in 123 countries to analyze the correlation between the technology and any corresponding carbon emission changes. They found that large-scale nuclear attachments are not significantly associated with carbon emission decreases over the studied timespan, whereas renewables are associated with emission decreases. There are emission decreases measured in countries with nuclear, but it was not enough to become statistically significant whereas the decreases measured with renewables were. The correlation versus causation differentiation becomes key in this article as there are various explanations as to why carbon emissions could be rising or falling in association with nuclear electricity production.

There was criticism of Sovacool et al.'s (2020) article, however, by Fell et al. (2022). They argued that the statistical size of 30 nuclear countries did not have enough power to properly represent that nuclear energy and renewables are both associated with decreasing carbon dioxide (CO_2) per capita emissions. Fell et al. (2022) also argue that the singular control variable of GDP per capita was not robust enough to account for the various other factors that affect the implementation of nuclear or renewables and any subsequent national carbon emission changes. The effect of outliers on an already small sample size were also identified and accounted for. The summary of the revised results is that there is a more significant level of correlation between nuclear generation shares and per capita CO_2 reductions, which extends to the conclusion that nuclear energy and renewables affect carbon emission reductions in a similar, and more importantly significant, way. The empirical methods employed by a study clearly change the impact of the conclusions of whether nuclear energy is effective at reducing carbon emissions.

Another environmental aspect of nuclear energy is the different types of waste that are produced. Low-, intermediate-, and high-level waste are all produced from nuclear energy construction, operation, and decommissioning, and therefore must be dealt with. Uranium mine and mill waste is another waste form from the uranium mining processes. Nuclear waste is typically more of a concern than the waste of other electricity sources because of its radioactive and harmful effects on humans and the environment, as well as its lifespan (Deschênes-Philion & Leduc, 2020). Low-level waste has the highest volume of the wastes and high-level waste has the lowest. As of the end of 2016, Canada had accumulated 2,395,385 m^3 of low-level waste and 11,089 m^3 of high-level waste (Deschênes-Philion & Leduc, 2020). Presently, the majority of Canada's radioactive waste is stored in interim facilities with the intention of creating a deep geological repository (DGR) to store the highest-level waste, such as spent nuclear fuel (Deschênes-Philion & Leduc, 2020). DGRs are not necessarily the solution as co-storing different levels of waste can create issues with DGR design and construction, which means that flexible and creative waste solutions must still be brainstormed (Deschênes-Philion & Leduc, 2020). The federal government of Canada created the Radioactive Waste Policy Framework in 1996 with a key management principle where the entity that creates the nuclear waste must handle its management, disposal, and funding (Deschênes-Philion & Leduc, 2020). This regulation adds a layer to the decision making process where implementing nuclear power will require logistics for the handling of its associated waste.

In order to choose SMRs as an energy option, there are environmental impacts that must be taken into account, which are well outlined by the International Atomic Energy Agency (IAEA) (2020) and are as follows: site footprint, refuelling, atmospheric environment, soil quality, aquatic environment, geology and hydrogeology, aquatic wildlife and habitat, terrestrial wildlife and habitat, human health, landscape and culture, transport and traffic, and socio-economic factors. The physical footprint of an SMR site is expected to be significantly smaller than that of large reactors (LRs) which means that SMRs may be more acceptable in certain environments due to their compactness (IAEA, 2020). It also means that emergency zones and construction resources can be reduced due to the size of SMRs. The refuelling interval of SMRs can be made just as long or longer than those of LRs which decreases any potential environmental damage from accidental radiation release (IAEA, 2020). The potential effects of SMRs on the atmospheric environment are combustion gases, dust and particulates, and possible controlled releases of radiological or non-radiological contaminants (IAEA, 2020). Soil quality and the aquatic environment can be affected by leaked contaminants that permeate the soil and possibly even surface and groundwater and change the soil quality or water quality (IAEA, 2020). Geological or hydrogeological effects could occur from the construction and presence of SMRs but are similar to the effects from LRs (IAEA, 2020). Aquatic and terrestrial wildlife and habitats can be affected through all processes of the SMR operation and lifecycle through physical disturbance, changes to air, soil, or water quality, noise, light, contaminants, or thermal discharges (IAEA, 2020). Human health risks are more accurately assessed through a Human Health Risk Assessment (HHRA) but can come from contaminants or physical operation risks (IAEA, 2020). Landscape and cultural effects are more effects on the visual or cultural/spiritual environment and require good relationships with stakeholders to assess the importance of this and minimize the effects (IAEA, 2020). Transport and traffic and socio-economic factors are not included in an environmental impact assessment except if new transport infrastructure is being built in association with the SMR and the perceived effect of SMRs on employment, revenue, living standards, and visual impacts of stakeholders (IAEA, 2020). SMRs offer smaller and reduced physical impacts on the environment compared to LRs, but a full analysis of the selected technology and the unique characteristics of where it will be constructed and operated should be assessed with an environmental impact assessment to get a more holistic picture.

2.2 What is the realistic timeline for implementing nuclear energy and is it in line with SaskPower's foreseen timeline? (RQ2)

There is often uncertainty with the ability for nuclear power to grow quickly enough to achieve climate goals due to its reputation of long construction times. Historical analysis shows, however, that nuclear energy has been built relatively quickly in terms of energy capacity when compared to wind and solar energy (Vinichenko et al., 2023). This has been measured by normalizing growth rates of each technology so that they are compared by the same standards. Wind and solar facilities are constructed and diffuse faster, but when comparing electricity capacity and generation, nuclear energy capacity and generation grows faster (Vinichenko et al., 2023). This means that although the physical construction time of nuclear power plants may be lengthy, the relative energy they produce is significant and therefore, they can meaningfully contribute to decarbonization goals. However, a new technology such as SMRs may not be as applicable to historical rates and construction projections so will have to be studied once it is more widespread.

Nuclear power is notorious for being slow-moving and exceeding projected timelines. Historical analysis of 600 nuclear projects over the past 70 years shows that 3% took longer than 15 years to complete (Rubio-Varas, 2022). However, further analysis shows that many delays and complications are not necessarily attributed to the inherent characteristics of nuclear power construction, rather the context of historical events and location. 88% of all reactor projects that started construction have been completed and connected to the grid (Rubio-Varas, 2022). The 3% of reactors that took longer to complete are the outliers – 19 of them, specifically. The largest component that lead to their delay was economic instability, which was often a result of extreme political changes. The US projects that took the longest all started construction before 1974 and were vulnerable to a macroeconomic crisis caused by political decisions, and the oil crisis (Rubio-Varas, 2022). The constructions of the slowest reactors in the Soviet bloc were started after 1981 and were greatly affected by the disaster in Chernobyl in 1986 and the collapse of the Soviet Union because of declining energy demand and economic instability (Rubio-Varas, 2022). The debt crisis of the 1980s in Latin America caused changes in economic stability and political systems, so the nuclear projects that were started in that region were severely delayed (Rubio-Varas, 2022). The construction and timeline of nuclear power projects is most greatly affected by events occurring at that time and location which often affect the economic viability of the projects.

Although SMRs are a new technology whose construction timelines are uncertain, there have been limited predictions and studies that have attempted to estimate what average construction lead times will look like. As in the analysis above, Rubio-Varas (2022) shows that for all regular-sized NPPs ever connected to the grid, 84% took less than 9 years to build, showing that long and unprecedented lead times are the outlier, not the norm. Stewart et al. (2022) summarize other studies that had conclusions related to factors that affected lead times and estimations for construction times of SMRs. Nuclear experience of the country pursuing construction, the regulatory environment, project management, supply chain maturity, labor productivity, and design maturity are all factors that can affect the lead time of regular-sized NPP construction and can realistically be translated onto SMR construction (Stewart et al., 2022). Modularization of SMRs have been predicted to reduce an estimated 7 year construction time down to 4 years, however the detailed justification for these estimates were not published (Stewart et al., 2022). Another study predicted that modularization of a generic SMR design could reduce an approximate 5.1-year lead time down to 3.5 years. One of the most detailed estimates was for a 100MWe SMR at a 29-month construction period and one study interviewed 16 experts who, on average, predicted approximately 3 years for SMR construction time (Stewart et al., 2022). Until there is enough data to properly assess the average construction time for SMRs, it is realistic to assume that SMR construction will take between 2.5 and 7 years, with a very low probability of exceeding 9 years.

2.3 Under what conditions might nuclear power succeed or fail in Saskatchewan? (RQ3)

The rate of nuclear power diffusion has been critically analyzed and tends to depend on various distinct factors. A historical analysis of first sizable commercial nuclear power reactors in 79 countries by Brutschin et al. (2021) found that the introduction and diffusion of nuclear power is strongly affected by the ease of diffusion, the size of the economy, electricity demand growth, and energy import dependence. The analyzed timeframe was between 1950 and 2018. The ease of diffusion and market attractiveness favoured several nuclear pioneering countries, including Canada. Once nuclear power was spreading to less industrialized countries outside of Europe, the size of the country and its economy, and therefore its market attractiveness was a major factor that shaped the trend of distribution (Brutschin et al., 2021). Significant increases in energy demand is a strong indicator for the likelihood of a country introducing nuclear energy. Being aligned with a key supplier like the US in agreements or foreign policy can indicate an increase in the chances of implementing nuclear energy (Brutschin et al., 2021). Lastly, energy market liberalization can hurt the chances of introducing nuclear energy.

The success of nuclear power programs has shown to be highly dependent on various external factors that are intrinsic to the states that are developing them. Jewell (2011) compares newcomer countries that are interested in developing a nuclear energy program and analyzes their capacities and motivations. In doing so, key criteria for nuclear program success are identified. Size, wealth, political stability, electricity consumption growth, grid connections, and fuel supply stability are all conditions that may affect the success of a nuclear energy program. It is assumed that in the case of the newcomer countries, their nuclear energy program will consist of regular sized reactors assumedly at greater than 1 GWe of energy whereas Saskatchewan is planning on SMRs of 300 MWe. One of the first aspects is a technological one: it is recommended by the IAEA that a single power plant should not provide more than 5-10% of the electricity grid (Liou, 2023). The electricity grid of the proposed country should be at least 10 times larger than the electricity output of the proposed reactor type. Another technical aspect of nuclear power is energy demand growth that will support the usefulness of nuclear power. The more energy demand growth there is, the more likely nuclear power will be successfully implemented. The financial capacity of the region must be taken into consideration when considering the success of nuclear power implementation. Two ways to measure financial capacity is with GDP and GDP per capita. The region must have enough investment to establish regulatory, legislative, and physical infrastructure as well as the construction of the actual power plant (Jewell, 2011). In the case of countries new to nuclear power, an indicator called The World Bank Government Effectiveness Indicator (GEI) was used to estimate the "amount of confidence that government policies are effectively and fairly designed, implemented and enforced over time" (Jewell, 2011). This manifests in two main ways: the ability of the government to manage and maintain public services, such as transport infrastructure, and the perception of the degree of independence from political pressures which can ensure commitment to policies and projects. Political stability is another factor that can affect the success of nuclear implementation through investor interest and international cooperation and can be measured by using the World Bank Political Stability Index (PSI). The implication is that a more stable government, country, or region will have a better chance at successfully implementing and maintaining nuclear power. Lastly, the motivation for implementing nuclear power, such as energy security or reduction of greenhouse gas emissions, is a factor to be considered but is harder to measure and correlate with the success of nuclear power implementation. Similarly to Brutschin et al. (2021) and Rubio-Varas (2022), it is not the inherent factors of nuclear power that affect its implementation, success, and timeliness but that of the contextual factors around it.

2.4 Limitations

Most of the literature that exists currently on nuclear energy is about large-sized nuclear reactors as they are the established form of technology and have widespread historical data. Many of the conclusions regarding SMRs must be extrapolated or inferred from their LR counterparts which introduces uncertainty and weaknesses. Because SMR technology is new and barely implemented in the world yet, this is a limitation of the literature review and even some of the subsequent research. Literature takes on more of a predictive lens as opposed to reporting on collected data. Nevertheless, there must be pioneering reports and predictions on a pioneering technology in order to start the accumulation of relevant data for the future.

3 Methodology and Theory

3.1 Theory

3.1.1 PESTE(L) Framework

The process of researching the transition of certain energy systems to nuclear power, specifically SMR technology that is not widely used yet and is thus an emerging and new technology, requires a framework that encompasses both the aspects of an energy transition and that of a project that is being assessed for factors of success or failure. Energy transitions traditionally incorporate 3 perspectives: techno-economic, socio-technical, and political (Cherp et al., 2018). These perspectives must be considered when dealing with an initiative with chances of success or failure that have yet to be implemented. The political, economic, social, technological, environment, and legal (PESTEL) framework is commonly used to assess external factors that affect the success or failure of an organization or project (Mullerbeck, 2015). As SaskPower has not made an official decision on implementing SMRs, assessing the external factors of the project and the opportunity it poses for an energy transition means the PESTEL framework is useful to guide research. It incorporates aspects from the 3 perspectives on energy transitions and anticipates macro-environmental factors for SMRs in Saskatchewan that have yet to be constructed. For the purpose of this research, however, the political and legal aspects overlap frequently and I have chosen to remove the separate legal aspect from the framework, thus leaving a PESTE framework.

Research Question 1 and 3 will be directly guided by the PESTE framework whereas Research Question 2 will include the PESTE framework to organize the inside and outside view data and results and make sure nothing is missed. Figure 1 represents how all the aspects come into play and what macro-environmental considerations fall under each aspect. The political aspect now generally covers any policies, impacts of politic power, political stability, legislative considerations, and government resource allocations that would affect the decision-making, timeline, and success of SMRs. The economic aspect generally covers investments, economic capacities, infrastructural costs, employment rate effects, and effect on the market that SMRs may require in the holistic planning and implementation process. The social aspect generally covers public perceptions, health effects, and any negative or positive impacts on the public that the SMR implementation process may produce. The technological aspect generally covers technology readiness, waste streams, supply chain, innovation, and development trends that affect the selection, timeline, and success of SMRs in Saskatchewan. And finally, the environmental aspect generally covers environmental costs, environment and pollution risks, and any benefits to the environment that the SMR process might elicit.

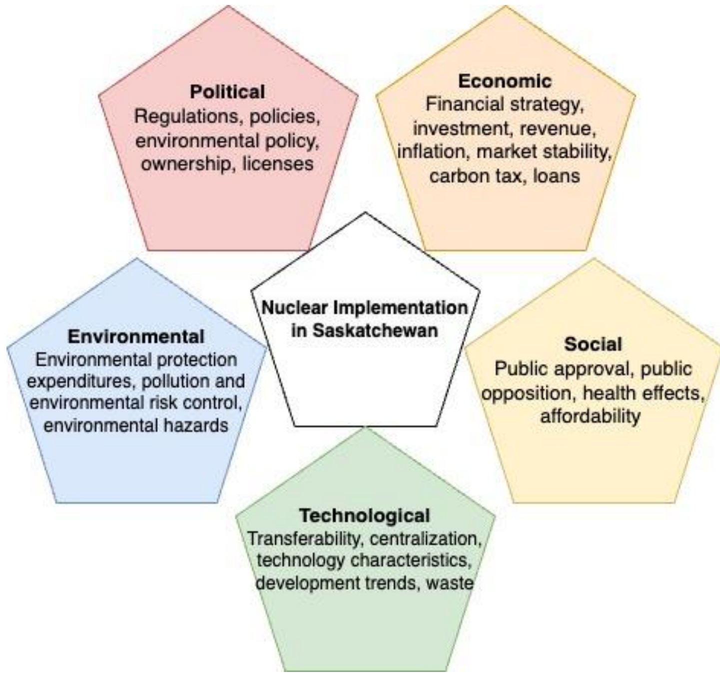

Figure 1. PESTE Framework for analysis

3.1.2 Feasibility Spaces

When regarding Research Question 2, these research endeavors touch upon the scope of feasibility. The Intergovernmental Panel on Climate Change (IPCC) (2022) defines feasibility as the "potential for a mitigation or adaptation option to be implemented." In this case, mitigation or adaptation options would be the SMR option. Jewell and Cherp (2023) posit that causal evidence should inform discussions about feasibility with an inside and outside view and reflective consideration of agency. The inside view will be obtained through interviews and internal documents and looked at through a PESTE framework lens. The outside view will be obtained through literature research and similar reference cases, and also looked at through a PESTE framework lens.

Feasibility spaces harmonize the different approaches to feasibility assessment such as reference cases and endogenous efforts (Jewell & Cherp, 2023). The theory of feasibility spaces helps inform the research of specifically Research Question 2 in how they will be methodologically approached. In order to assess the achievability of an SMR implementation timeline and the success of such implementation, both endogenous efforts and exogenous cases will have to be analyzed. Reference cases will be identified based on similar situations where similar things were proposed and happened, either successfully or not. These reference cases will then be comparatively assessed, and agency of solutions will be designated. Within this feasibility space theory, Research Question 2 will be properly investigated and answered.

3.2 Methodology

The methods of this research were selected to best answer the research questions: (1) why has nuclear power been selected as a potential low carbon energy source solution for Saskatchewan, (2) what is the realistic timeline for implementing nuclear energy and is it in line with SaskPower's foreseen timeline, and (3) under what conditions might nuclear power succeed or fail in Saskatchewan? As the research deals with the macroenvironment of Saskatchewan energy and the potential for nuclear power, various sources of information must be collected and analyzed. Figure 1 visualizes how the framework has guided the methods in terms of the external factors that are researched. The PESTE(L) framework has yet to be applied to the potential energy transition in Saskatchewan, especially regarding nuclear power. The framework by nature assesses external factors and environmental tensions in the macroenvironment to better understand and inform the long term goals of an organization, in this case SaskPower and the Government of Saskatchewan, and advise in investments and actions in the near and distant future (Song et al., 2017). As the framework has five main aspects in this case, the research incorporates various methods and approaches. Interviews of relevant stakeholders, analysis of comparable reference cases, and analysis of documents will be conducted to best answer the research questions in a mixed-methods approach.

3.2.1 Interviews

In order to get a better understanding of the research scope as well as obtain information from professionals and relevant stakeholders, interviews were conducted. The interview process represented the qualitative aspect of the mixed-methods approach. Experts and industry professionals can provide insight that may not be readily available in published documents or reference cases. Interviews were constructed in a semi-structured format which included questions I had curated beforehand and questions that arose in the moment to better understand the interviewee's responses and point of view. Interview questions aimed to answer my research questions and were loosely grouped into the research question(s) that they could answer, and a subgrouping of whether they fit into the political, economic, social, technological, or environmental aspect(s). Different interviewees had different areas of expertise and so didn't always warrant receiving questions for which their expertise did not cover. The interview protocol can be found in Appendix 1.

Interviews were conducted with different levels of stakeholders and professionals and represented both neutral, pro-, and anti-nuclear sentiments. 6 semi–structured interviews were conducted, each lasting 30 – 60 minutes. The semi-structured format was chosen as different interviewees had different experiences and perspectives on the research scope and this meant I could delve deeper into certain topics depending on who I was interviewing. The selection of interviewees was based on expertise and knowledge and relevance to the research scope. To ensure sampling diversity in such a small sample pool, there was an equal gender balance and different perspectives of nuclear power were accounted for. Two of the interviewees were distinct in their relevant experience so I labeled them as [SaskPower employee] and [Civilian]. Four of the interviewees are involved in academia so I have changed their names to [Willow], [Annie], [Alex], and [Nick] in order to differentiate them but maintain anonymity. A table with the anonymized interviewees code names and relevant information can be found in Appendix 2.

3.2.2 Reference Cases

Reference cases are situational analogies that can be historical or more present and used to compare to the case that is presently being studied, or the target case (Jewell and Cherp, 2023). Using reference case analysis as a research tool requires certain similarities between the reference case(s) and the target case to ensure there are applicable results. Reference cases were used to answer Research Question 2 as a part of the outside view of the feasibility space framework. Nuclear projects within Canada were looked at for their construction period and budget in order to give perspective to SMRs, and the commonalities were the energy generation type and country. These reference cases were found through Google searches and within websites that published information on Canadian nuclear reactors. Some nuclear projects were looked at outside of Canada for construction time and power capacity, and these were found through the World Nuclear Industry Status Report (WNISR) database and had commonalities of power capacity and energy generation type. Reference cases for Saskatchewan energy projects were used to assess construction times in a regional setting with commonalities of province and power capacity, but the energy generation type differed. These were found on the SaskPower (2024b) System Map.

3.2.3 Document Analysis

Reviewing relevant documents is an important research avenue and does not depend on stakeholder schedules but can be hindered by the transparency or availability of certain documents or information. All documents used for this research were found online on varying websites, databases, and repositories. Many of the documents regarding SaskPower were available on their website, including reports, engagement sessions, and information of power facilities, to name a few. Research articles were found through Google Scholar or the CEU library Ebsco database through the search criteria of key words and a data range of usually 2015-2024. The data range was expanded as needed. The Regina Leader-Post and Saskatoon Star-Phoenix newspapers provided historical data on energy projects in Saskatchewan before 2000, and were found through Newspapers.com by Ancestry.ca. Other schematics, reports, and general documents or news articles were found through Google Search and were open access.

3.3 Data Analysis

Each interview was recorded and afterwards transcribed using manual transcription on Microsoft Word Version 16.84. Editing was done to remove redundant words and to ensure punctuation best emphasized the interviewee's meaning. As questions were asked for specific correlating research questions, the coding used for the data was simple, but thematic analysis was also conducted to detect common themes and data points. Thematic analysis is "a method for identifying, analysing and reporting patterns within data" (Braun & Clarke, 2006). The process of thematic analysis is familiarizing yourself with the data, generating initial codes, searching for and then reviewing themes, defining and naming those themes, and finally, producing the report (Braun & Clarke, 2006). In the interview protocol in Appendix 1, it can be seen that questions are grouped by research question, and by the PESTE framework. Interview answers were also accordingly coded. Once the interview data was coded for research questions and PESTE, common themes were identified and emphasized in the results.

During the coding process, inductive reasoning was used to classify the interviewee as pro-, neutral, or anti-nuclear based on their responses and language they used. I did not ask the interviewees up front because I wanted the questions to remain neutral as this research does not take a stance on SMRs. The value of assessing the general stance of the interviewees was simply for diversity and balance purposes to ensure that many points of view were being heard.

Content analysis was used for the relevant research documents to discover answers to the research questions or relevant information. Words, themes, and concepts were looked for and catalogued. Data within documents that pertained to the interview coding structure, so research questions and PESTE framework, was utilized in the results. Deductive conclusions were often made in this research from interviews and document analysis to answer the research questions.

4 Results

4.1 Nuclear power history in Saskatchewan

4.1.1 Nuclear Power in Canada

Nuclear power developed as an energy source in Canada when the first small–scale CANDU reactor began supplying power to the Ontario grid in 1962 (IAEA, 2022). The first commercial reactor was connected to the grid in 1971 in Pickering, Ontario, and the last was in 1993 (IAEA, 2022). There are now 19 operating CANDU reactors in Canada which supply approximately 15% of Canada's electricity (IAEA, 2022). Canada is characterized as a Tier 1 nuclear nation due to its experience and complete supply chain; Canada mines its own uranium, converts it to fuel, powers our own reactors, has research reactors, produces isotopes, and manages waste and transportation within Canada (IAEA, 2022). Currently there are 18 reactors in Ontario and 1 in New Brunswick (IAEA, 2022).

Nuclear power in Canada incorporates all levels of stakeholders and governance and has unique dynamics that come into play. In terms of energy and jurisdiction, there are clear responsibilities of the federal and provincial governments, and then there are some shared responsibilities and independent regulatory bodies that have influence as well. The provincial governments are responsible for the energy management of their province and for most of the natural resources within their province as well (IAEA, 2022). The federal government is responsible for energy infrastructure, energy management on federal Crown land, offshore energy and energy within the territories (Yukon, Northwest Territories, and Nunavut), interprovincial and international trade, and the regulation of nuclear materials, transportation, research, and development (IAEA, 2022). Environmental monitoring and regulation and research and development in non-nuclear energy projects is a shared responsibility between the federal and provincial governments (IAEA, 2022).

The four innovation and regulatory bodies that are most closely associated with nuclear power are Natural Resources Canada (NRCan) (or the Department of Natural Resources which directly reports to the Minister of Natural Resources), the Canadian Nuclear Safety Commission (CNSC), Atomic Energy of Canada Limited (AECL), and the National Waste Management Organization (NWMO). The CNSC and AECL report to Parliament through the Minister of Natural Resources (IAEA, 2022). NRCan is a department which, "develops policies and programs that enhance the contribution of the natural resources sector to the economy, improve the quality of life for all Canadians and conducts innovative science in facilities across Canada to generate ideas and transfer technologies" (Natural Resources Canada [NRCan], 2023). Essentially, NRCan is the branch of the federal government that develops policies on Canadian energy, including nuclear, and works with the Uranium and Radioactive Waste Division to regulate nuclear materials, research and development, and activities (NRCan, 2017). The CNSC is the nuclear regulatory organization that is an independent agency of the government but reports to the Parliament of Canada (NRCan, 2017). The CNSC's mission is to "regulate the use of nuclear energy and materials to protect health, safety, security and the environment to respect Canada's international commitments on the peaceful use of nuclear energy" (NRCan, 2017). The AECL is a Crown Corporation in charge of establishing peaceful uses of nuclear energy and the waste and decommissioning responsibilities of the

Government (NRCan, 2017). The NWMO is a non-profit organization responsible for "the safe, long-term management of Canada's used nuclear fuel," that is run by an advisory council, member organizations, and a board of directors, and is subject to regulations by the CNSC (Nuclear Waste Management Organization [NWMO], n.d.). Additionally, there are 4 main guiding legislations regarding nuclear energy: The Nuclear Safety and Control Act (which deals with regulations), the Nuclear Energy Act (which deals with research and development), the Nuclear Fuel Waste Act (which deals with nuclear waste), and the Nuclear Liability and Compensation Act (which deals with liabilities) (NRCan, 2017).

In 2018, the federal government and interested provinces, territories, Indigenous communities, companies, and civil society stakeholders worked together to create a plan for SMR development in Canada which was called Canada's SMR Roadmap (IAEA, 2022). A Memorandum of Understanding (MOU) was signed by the premiers of Saskatchewan, Alberta, New Brunswick, and Ontario which acknowledges the potential of SMRs to provide economic and technological research and development opportunities, a solution for regional energy demand, and a potential solution for climate change concerns in Canada (IAEA, 2022). In 2020, Canada's SMR Action Plan was launched which addresses recommendations from the SMR Roadmap and provides actions for pursuing SMR development (IAEA, 2022). Since then, Ontario Power Generation (OPG), the crown utility that provides about half of the electricity in Ontario, has selected an SMR technology and a site to build 4 SMRs and has broken ground on the project (Office of the Premier of Ontario, 2022).

4.1.2 Background on SaskPower

SaskPower is the foremost energy supplier in the province of Saskatchewan as it supplies almost all of Saskatchewan with electricity. The Power Corporation Act in 1949 granted SaskPower with exclusive franchise to supply, transmit, and distribute electricity within the whole province except for the municipalities of the City of Saskatoon and the City of Swift Current (SaskPower, 2023). The president and Chief Executive Officer of SaskPower reports to the Board of Directors which in turn report to the Minister Responsible for SaskPower (SaskPower, 2023). This creates a link between the company and the provincial cabinet and the Saskatchewan Legislative Assembly (SaskPower, 2023). SaskPower's mission is to ensure "reliable, sustainable and cost-effective power for our customers and the communities we serve" (SaskPower, 2023).

SaskPower now supplies over 550,000 customer accounts over Saskatchewan's approximate 652,000 square kilometres and has grown since its establishment in 1929 to having a generation capacity of 5,437 MWe (SaskPower, 2023). SaskPower's energy production is dominated by coal and natural gas facilities that supply 70-90% of daily energy system demand, depending on the day and season (SaskPower, 2024c). The generation capacity of 5,437 MWe consists of 3,968 MWe from power production facilities that are owned and operated by SaskPower, 1,380 MWe from power purchase agreements with independent power producers, and customer-generated solar accounts for 53 MWe and customer-generated wind for 2 MWe (SaskPower, 2023). Of the total generation capacity, 40% is from gas, 25% from coal, 21% from hydroelectric, 11% from wind, 2% from solar, and 1% from other sources (SaskPower, 2023).

4.1.3 SaskPower and the road towards SMRs

Canada signed the Paris Agreement and has committed to reducing its greenhouse emissions by 45% below 2005 levels by 2030 (Leach et al., n.d.). Canada has also committed to achieving net-zero emissions by 2050 in a law called the Canadian Net-Zero Emissions Accountability Act, as well as phasing out coal by 2030, although it is not a law (Electricity Canada, 2022). SaskPower has expressed a desire to advance towards a lower-emitting and more sustainable future and has committed to reducing their greenhouse gas emissions by at least 50% of their 2005 levels by 2030, similarly to what is implied globally in the Paris Agreement (SaskPower, 2023). All of these commitments indicate that Canada, including Saskatchewan, will be or should be moving towards low-carbon alternatives in every sector, energy included. The combination of phasing out coal-fueled energy while also finding low-carbon alternatives is a tactic to reduce the energy sector emissions. In 2005, SaskPower produced approximately 14.2 million tonnes (Mt) of CO_2e and had produced 13.8 Mt of CO_2e in the 2022 calendar year (SaskPower, 2023). Their emissions reduction goal was missed by 14.9 percentage points and was explained by an additional 635 GWh in demand and a low water season that affected hydroelectric capacity that had to be met by baseload sources of coal and natural gas (SaskPower, 2023). In order to help SaskPower meet their emission reduction targets they have implemented a carbon capture and storage facility and have several renewable energy projects in the works as well as a proposed SMR project.

SaskPower has received approval from the Government of Saskatchewan to add an additional 700 MWe to their generation capacity from solar and wind sources which will hopefully be completed by 2027 (SaskPower, 2023). Their carbon capture and storage facility has captured 5 Mt of carbon dioxide since its start-up, and an agreement with Manitoba Hydro was signed which will provide 190 MWe of imported electricity from a renewable energy source (SaskPower, 2023). Lastly, SaskPower is pursuing SMRs as an additional potential power source. They acknowledge that a reliable and sustainable energy future needs diversity and a balance of different power sources (SaskPower, 2023).

SaskPower is one of the interested participants that contributed to the SMR Roadmap and the SMR Action Plan. SMRs were selected as a possible power source because of greenhouse gas (GHG) emissions goals that would be difficult to meet with its previous long-term energy supply plan that did not include SMRs (NRCan, 2022). Although the technology has been selected, SaskPower has not committed to implementing nuclear power. They have evaluated the feasibility of nuclear power and identified that they are currently in the planning stage and won't decide whether to build an SMR until 2029 (SaskPower, 2023).

4.2 Why has nuclear power been selected as a potential low carbon energy source solution for Saskatchewan? (RQ1)

4.2.1 Political

The five parties represented in the House of Commons in Canada are the Liberal Party of Canada (LPC), the Conservative Party of Canada (CPC), the Bloc Québécois (BQ), the New Democratic

Party (NDP), and the Green Party of Canada (GPC) (Parliament of Canada, n.d.). The elected parliaments in Canada have always been either the Liberal Party or the Conservative Party, with one exception from 1918-1921 (Parliament of Canada, n.d.). In Saskatchewan, the election history has not always been as consistent, but for the last 30 years the two viable major political parties have been the NDP and the Saskatchewan Party, which is a conservative party in Saskatchewan (Provincial Archives of Saskatchewan, 2019). Currently, the LPC and CPC support nuclear power, the NDP doesn't have a strong stance, and the BQ and GPC do not support nuclear (O'Donnell & Edwards, 2021). Historically speaking, there is a very small chance that the GPC or BQ parties will come into enough power on either the Saskatchewan provincial or federal level to oppose nuclear power. The Saskatchewan Party holds similar ideals to the CPC and is therefore in favour of nuclear in sentiment, but the process of choosing to go forward with nuclear implementation is another thing. A table of the political parties of Canada and their ideals regarding nuclear and fossil fuels is included in Appendix 3.

Small modular reactor development in Saskatchewan can be seen as a highly political decision. This decision is by and large made by SaskPower, which is a crown corporation, meaning it is overseen by the Government of Saskatchewan and therefore, its decisions are inherently tied to a government body. Initially there was not a lot of support for nuclear power as an option, as stated by [Alex], "transitioning away from fossil fuels was a really threatening thing to do so we had no support for that from the Government of Saskatchewan...The Government of Saskatchewan was able to make changes to the leadership of SaskPower and now they have a leadership that is at least more open to thinking about nuclear power options." There are now federal, provincial, and internal reasons for SaskPower to look at SMRs as a potential low carbon energy source. Federally, Canada has certain commitments and alliances that dictate what direction energy should be headed in. Canada's commitment to the Paris Agreement and the Canadian Net-Zero Accountability Act as well as their active founding role in the Powering Past Coal Alliance creates an impetus for the country to move towards low-carbon energy sources or risk public and political backlash (Powering Past Coal Alliance, n.d.). The province of Saskatchewan and SaskPower also have decarbonization and climate commitments that motivate their choices and actions. [SaskPower employee] has stated the decision of looking at nuclear power "comes down to greenhouse gas emissions and managing a target of net-zero." This can be seen as a political motivation because a successful implementation of SMRs and reduction of GHG emissions would positively reflect on the company and the province. An additional political factor that influences SaskPower is the longevity and financial sustainability of the company. SMRs would provide a centralized energy source that would help sustain the market that SaskPower monopolizes. Other options that decentralize the energy grid would not be as profitable for SaskPower and therefore they are likely looking at something that maintains their influence (Dolter, 2021).

The combination of phasing out coal plants and building more renewable energy and exploring the viability of SMRs is a type of clean energy transition. SMRs are also a more expensive energy source than existing fossil fuel sources at the moment, and this requires political coalitions that are willing to support new, more expensive technologies in order to transition to commercialized cleaner energy sources (Breetz et al., 2018). SaskPower and OPG are working together in a sense of a pseudo-political coalition. OPG is building the initial BWRX-300 SMR and after it is built and successful, SaskPower will then decide whether to pursue it based on the example that OPG demonstrated. This coalition that allows SaskPower to learn by example is a reason for selecting the specific BWRX-300 and SMRs as an option. [SaskPower employee] stated that "We wanted to see SMRs in the vendor design review process with the...CNSC," and the "timing is starting to get right" as US utilities, New Brunswick Power, and OPG are all starting to look at SMRs. [Nick] said, "SaskPower went, in my view, in the right direction by letting Ontario Power Generation, first choosing the same reactor type as OPG, and let them go first so it won't be the first of its kind." Commercialization of SMRs will likely lead them to becoming economically competitive which means that typically, they would be contested by incumbent technologies like coal and natural gas (Breetz et al., 2018). But if the voice of the incumbent technology is turning away from fossil fuels and towards emerging technologies, then that reduces the political or industrial opposition to the new technology, such as in the case of SMRs and SaskPower. From a political perspective, the lack of a liberalized electricity market in Saskatchewan makes it much easier to integrate new transformative technologies that challenge the pre-existing technologies. The monopoly of SaskPower which is politically granted means that it can choose to turn to nuclear energy without major opposition or competition, at least more than they have likely accounted for.

Nuclear waste is often a contested aspect of nuclear power that requires a lot of planning and attention. This is no different in Saskatchewan's case. The political aspect of nuclear waste include regulations for infrastructure, protocols, and transportation if necessary. SaskPower seems to have a plan for their projected nuclear waste (if they pursue nuclear power), with [SaskPower employee] stating that nuclear waste "is very intricately planned for and regulated... [our] decommissioning plan and waste products will be reviewed and made sure its technically sound by the CNSC... Canada does have a national strategy to centralize these materials and that's what the NWMO is looking after." The presence of a provincial and national plan for nuclear waste provided one less obstacle for SaskPower to consider when choosing to look at nuclear power as a possible low-carbon electricity solution.

Energy generation is a provincial jurisdiction and many of the provinces attempt to create all their energy in their own province instead of widespread collaboration and trade of energy within Canada. This habit creates a political incentive for Saskatchewan to pursue technologies that not everyone is 100% confident in instead of decreasing their energy emissions by importing energy from existing hydro or solar from other provinces. It certainly happens and may expand in the future, especially with SaskPower's plans to import 190MWe from Manitoba Hydro, but it seems to be considered a backup source. This sentiment is echoed by [Willow], "in some ways it's, you know, really unfortunate that energy generation is [a] provincial issue right...you know I'd love to see transmission lines going across the country with branches off, like we should have cross-Canada transmission, we should have all of those things, but it's not going to happen because provinces generally want to generate the power in their own provinces." [Alex] said much of the same, "The problem with hydro is simply interprovincial jealousy. It would mean giving up control of electrical power generation and the Government of Saskatchewan isn't ready to do that." Clearly, tackling energy projects within the province is presenting as a higher priority than increasing imports from already established technologies, which is one of the reasons SaskPower may be looking at nuclear as a possible energy source for the future.

There were also negative sentiments towards the political reasons for looking at SMRs as a possible energy technology, including lobbying from the construction industry, stubbornness against federal carbon emission goals, and political and industry will versus feedback and community will. [Alex] stated that, "you don't get very far in this research without encountering the construction industry, which is surprisingly powerful as a lobby group. And they were clearly thinking about what a major nuclear build would for construction in the province and jockeying to make sure they got their share." A nuclear project that takes multiple years and will require manpower, maintenance, and eventual refurbishment and decommissioning is a huge opportunity for the construction industry. The extrapolation of this observation is that if the construction industry is a huge lobbying group with influence, then they could have had a hand in turning Saskatchewan's heads to SMRs as an option.

Saskatchewan and the federal government of Canada have publicly butted heads in recent years over carbon emission reduction goals and tactics. One example of this is the most recent refusal to collect and remit carbon tax on natural gas by Premier Scott Moe which has exacerbated tensions between the Government of Saskatchewan and Canada (Zimonjic, 2024). [Willow] believes that this dynamic has permeated the decision-making of the province and SaskPower in terms of looking at SMRs, "they're not at all interested in cutting down their carbon emissions at the level that the federal government is asking them to, and so the nice thing about SMRs is it's a wonderful delaying tactic for any province that wants to keep with their oil [and] keep basically burning fossil fuels... it's a way of putting off actually doing anything by saying oh yeah we're gonna buy an SMR down the road." As the decision will only occur in 2029, the road to connecting an SMR is long and technically uncertain. If the province is indeed looking for a way to stall a clean energy transition and fossil-fuel phase out, then SMRs may be the ideal wild goose chase.

Lastly, the power imbalance favouring government bodies over civil society members or communities could be another explanation for SMR consideration. When discussing the dynamics between the government and community interests in energy, [Annie] stated, "there is a power imbalance between who makes a decision. So, for example, if you're a community and you want to develop a project, there's always this power imbalance of how much you can actually do like as a community and then how much power, for example, SaskPower or the government has." SMRs may not benefit all Saskatchewan communities, especially remote and Indigenous communities. They may view other options such as decentralized grids or community-powered energy projects as a more inclusive option. However, with a monopolizing force such as SaskPower, such projects may never be initiated. Another sentiment expressed was the absolute authoritative presence of advocates of the nuclear industry and political will in general. When asked about why they thought SaskPower has been looking at SMRs as an option, [Civilian] answered, "I think what has become very, very good is the sales pitch...and if I put over the length of time that I heard them and there were people like me on each one, who question various steps in the process, and there was absolutely no change... so there's no feedback. Are they not accepting feedback or [don't they] believe what anybody else says? The only one who says so, only person who knows it, is who?" In this instance it sounds like a decision had already been made and concerns and criticisms and feedback are of no concern or consideration. [Civilian] went on to elaborate, "The members of the nuclear industry have a... club-like tenor to them. You can't question the certain basic beliefs that this is a good system and we have to have it and we need it for a baseline." [Civilian] wasn't alone in these sentiments, [Annie] also made a point of mentioning, "With SMRs...there's a lot of political will [and] so if there's a political will there is definitely going to be a lot of nudging or like pushing their agenda where like government and industry are especially the ones that are more involved in the energy sector, in like the renewable nuclear sector, [so] they're going to be pushing a lot their agenda." The political significance of this is that there is a possibility that SaskPower has begun to look at SMRs for a variety of the aforementioned reasons, and their reasons may tend to be more political and less considerate of what civil society members have concerns about.

4.2.2 Economic

The economic side of SMRs can be quite uncertain, but there are several reasons as to why SaskPower may have turned to SMRs as a low-carbon energy option from an economic standpoint. Usual construction, operation, maintenance, and decommissioning costs commonly associated with conventional reactors are projected to be lower with SMRs. Saskatchewan is also projecting SMR contributions to affect GDP increases, wages, and tax revenues in the order of billions. SaskPower also seems confident in their funding strategy, one reason is because of their unique position as a crown utility. There are, however, skeptical views regarding these assumptions as they are based on assessments and projections and not yet from real world data or examples.

Because of their smaller size and somewhat simpler design, SMRs are projected to require less economic investment throughout their life cycle compared to conventional reactors (Mangena, 2021). Section 2.1.2 reviews some of the literature that researches predictions into the economic benefits of SMRs. SaskPower could be looking at possible reduced construction times, regulated and tested technology, simpler regulatory protocol, a safer facility, and simpler operation which all contribute to less economic commitment throughout the SMRs lifetime (Mangena, 2021). Commercialization of the technology can also lead to the economy of multiples where modularization and standardization can lead to price decreases. This is expressed by [SaskPower employee], "Nuclear are very capital intensive projects and any capital intense project requires a lot of planning to be successful. Mega projects have a tendency to be delayed, to have cost overruns, and we feel that with SMRs, they're small enough [and] the modular aspect of how they're designed is meant to help mitigate some of that construction risk that has plagued big nuclear projects in the past...the more we standardize, and the more we limit the number of technologies that we implement, the cheaper they will become and the easier they are to produce. But if you standardize, costs will come down [and that will] make smaller jurisdictions easier to just roll them out." [Nick] corroborated the sentiment, "The theory is it will become more competitive, because you are not committing large capital up front. So they call it economy of multiples. If you need 1200 MWe, build four, you can add 300 you can add another 300, you don't need a mega project and end up with a tremendous amount of power that you don't need." As OPG is building the BWRX-300 model first, they hypothetically will work out any kinks or regulatory issues that may arise which means they will likely bear the brunt of the costs associated with a pioneer investor. SaskPower can then learn from OPG's experience and may have slightly reduced costs because of the lesson. That said, SaskPower will still have a large bill to pay as they too will be a pioneer and SMR technology will not have spread enough to reduce costs.

The projected cost of the initial SaskPower SMR of roughly 5 billion Canadian Dollars (CAD) is more than the cost of the four Pickering A units that each produce(d) 508 MWe (Hunter, 2022; WNA, 2024c). Pickering 2 & 3 have been shut down and have not been refurbished. The four Pickering A reactors cost CAD 716 million (in 1973 dollars) to construct which adjusted for inflation is approximately CAD 4.8 billion (Ontario Hydro, 1988). For significantly less produced power, one SMR is projected to cost more than 4 conventional-sized reactors, at least in construction. Two of the most recent nuclear reactors constructed and connected to a grid are the Nuclear Power Corporation of India's Kakrapar atomic power station Unit 3 (KAPS3) and Unit 4 (KAPS4) (World Nuclear Industry Status Report [WNISR], 2024). Each unit has a capacity of 700 MWe and together their construction cost approximately $2.71 billion (assumedly in USD) which by today's exchange rates converts to approximately CAD 3.72 billion (Tharayil, 2024). There are likely many different explaining factors as to the price differences between the projected SMR costs and other technology examples, but if SaskPower is looking at SMRs because they are supposed to cost less than conventional reactors, it may be more accurate down the line when the technology is commercialized enough, because it seems there are cheaper alternatives available that produce more power in the present. [Willow] commented on both the price tag of SMRs and SMR commercialization, "You have to look at the cost of [SMRs]…Yes, nuclear is orders of magnitude more expensive to construct, but if it works, OK. The cost of operating it would likely come down, right? And so it could be closer [in cost] to potentially wind and solar and storage... but the problem is by the time things actually work, if they do in say 2035, the cost of wind, solar, and storage is going to be so low that the nuclear reactors are going to be generating the most expensive costs, the most expensive electricity on the grid….and the problem with the small reactors is there they just don't make any sense financially. They're not going to be a proportion of the cost of a big reactor, they're going to basically cost the same as a big reactor but you get less energy from it." SMRs may not be the cheapest option at present but could gradually get cheaper. The issue, however, is whether the decrease in cost will be as competitive as other energy options. It seems that SaskPower is looking at SMRs as an option because it *could* be cost-competitive because it is not certain that SMRs *will* be cost-competitive.

In the various feasibility and viability assessments that the Government of Saskatchewan and SaskPower have performed, they have concluded that SMR implementation would bring billions of dollars to the province in GDP growth, wages, and tax revenues. In an executive summary by the Conference Board of Canada (2021), Saskatchewan's economic potential in a scenario where a fleet of 4 BWRX-300 SMRs would become operational one at a time from 2032-2041 would be estimated at CAD 8.8 billion in GDP, CAD 5.6 billion in wages, and CAD 2.9 billion in taxes which would go to the province. The project would also affect Canada with 30-34% of the economic benefits exiting Saskatchewan (Conference Board of Canada, 2021). SMR project development, manufacturing, construction, operation, and decommissioning is projected to provide 9,321 jobs in Saskatchewan or for Saskatchewan's economy, and 13,490 jobs created throughout Canada (Conference Board of Canada, 2021). The economic benefit prospects and job creation potential are enticing reasons to look at SMRs as a possible low-carbon energy source. The GDP in Saskatchewan is currently just under CAD 78 billion, so an energy project that could provide over 10% of that is a compelling offer (Government of Saskatchewan, 2024a). [Willow] also notes that much of the wages from SMR implementation is what will make it expensive, "Part of the reason that nuclear is so expensive to operate is because of all the people involved right?... it does create those high paying jobs which are expensive." So a fleet of four SMRs may generate CAD 5.6 billion in wages, but it may actually be a hidden cost. The total amount of projected economic benefits to Saskatchewan is CAD 17.3 billion, but if one SMR is projected to cost at least CAD 5 billion, then the following three must reduce their costs significantly in order for the economic benefits to outweigh the costs of four SMRs.

Uranium is an abundant natural resource in Saskatchewan and the uranium mining industry in Saskatchewan accounts for all of Canada's uranium production and approximately 22% of the world's supply of uranium as of 2016 (WNA, 2024c). The export of uranium accounts for approximately CAD 2 billion in revenue (WNA, 2024c). [Alex] made the observation that, "Saskatchewan, of course, has a certain amount of natural resources, it's always been, I think, a source of regret to the government of Saskatchewan that it can't do more with the uranium... it just kind of breaks their hearts that they're essentially just [mining] it and sending it in this semi-processed form to Ontario or to the United States where value is added. So this idea of moving up the value chain, whatever it would look like, so the uranium would become a more valuable resource is very important." The opportunity to add more value to uranium within Saskatchewan instead of exporting all of it to Ontario, New Brunswick, or internationally is a benefit of implementing nuclear power, which is shown in the formation of the Uranium Development Partnership (the Partnership) by the Government of Saskatchewan. The Partnership's mandate is to "identify, evaluate, and make recommendations on Saskatchewan-based value added opportunities to further develop our uranium industry" (Uranium Development Partnership, 2009). The Partnership was comprised of a wide panel of expertise, professions, and company representatives and eventually recommended that Saskatchewan construct nuclear energy sources of up to 3000 MWe with the added benefit of possibly exporting excess energy to Alberta (Uranium Development Partnership, 2009). The opportunity to grow GDP and capitalize on a local resource are factors that lead to nuclear energy being seen as a possible low carbon energy source.

Another reason that SaskPower may be looking at SMRs as a possible low-carbon energy source is because of their position as a crown utility and subsequent funding strategy. SaskPower has the ability, and one might say, privilege in this case, to be aligned with the Government of Saskatchewan instead of operating as a private utility. This allows them to secure funding from the provincial, and sometimes federal government, which can help them afford to implement such an expensive project. In August of 2023, the federal government approved up to CAD 74 million for the SMR development project in Saskatchewan (WNA, 2024c). The Government of Saskatchewan also has the ability to lend money for the development of SMRs and subsequent lifetime costs. This is verified by [SaskPower employee], "Nuclear projects in general have high upfront costs and what makes the energy affordable is if you can spread that cost over a long life of reliable power. At SaskPower with our mandate as a crown utility we have the luxury...of not requiring a return on the investment in year 10 or 20, right...so we can spread that upfront cost over a long life, which makes the cost of electricity a lot more affordable...we are the crown entity and so our primary financing vehicle is the provincial Government of Saskatchewan who has pretty secure lending capabilities." The CNSC also has regulations in place which assure that decommissioning and waste management are not left out of budgeting considerations. [SaskPower employee] said, "Before they let us build, [the CNSC] will make sure we have the money in the bank to deal with [nuclear waste management] and that [the] money is accessible if we should somehow end up going away or the CNSC needs to come in and, you know, take over certain things. So you have to have the plan and you have to have the money in the bank available to fund decommissioning and waste management." The confidence in the ability to secure funding and in the CNSC to make sure certain amounts of money are already saved makes SMRs a more viable and affordable option for SaskPower in considering them as a low-carbon power source.

Despite SaskPower's projections and funding strategies, there is speculation about the economic reasoning for interest in SMRs. [SaskPower employee] stated the that, "SaskPower is not a nuclear company and so there's a risk profile with ... nuclear that requires a lot of investment." Some believe that the amount of investment required should deter SaskPower from choosing to implement SMRs at the 2029 decision point. [Willow] observed, "Basically it's not a viable industry because of the cost of it. So they're in a heavy, heavy promotion mode and because the big reactors are so expensive, they decided to pivot to small reactors with the idea that somehow they would be less expensive. So a province like Saskatchewan that doesn't have the same level of, say hydro resources [or] offshore wind, ...something like a small modular reactor, the way it's being promoted by the industry, is very appealing." SaskPower may have been sold on SMRs through good marketing, but it does not mean that they are truly economically viable. Instead, [Willow] says, "Is the federal government really going to give $5 billion to Saskatchewan to, you know, to put in an SMR that generates 300 megawatts of energy when for $5 billion you could get a lot more from wind and solar?" Federal funding may not be the financing plan for a Saskatchewan SMR, but based on the power output that CAD 5 billion could buy from either an SMR or solar or wind, not everyone can justify the SMR option. Similarly, [Alex] discussed other energy options such as better trans-Canada transmission lines, "Even between provinces like Alberta, Saskatchewan, and Manitoba there are links, but the old fashioned ones lose a lot of power so that would require upgrading and that's the excuse - that their view is it's too expensive to upgrade it so we'll just have to generate our own." Similarly, [Nick] also said, "It's a disgrace when we have a Trans-Canada Highway but we don't have a Trans-Canada grid." Reflecting upon SaskPower's mission to ensure "reliable, sustainable and cost-effective power for our customers and the communities we serve," requires critique of whether SMRs will actually provide cost-effective power for their customers (SaskPower, 2023). As [Willow] states, "it's the ratepayers who are going to have to pay for this, right? So why would you force them to pay for a more expensive electricity? And if they do build an SMR and they do hook it up to the grid and then there was other renewables with storage that are producing electricity a lot cheaper, well they're going to have to force SaskPower to buy it because they've spent billions of dollars on it. It just doesn't make any sense to me why they would do that - why they would force ratepayers to pay for more expensive electricity?" The implementation of an SMR, let alone four, requires huge investment. If the price tag on energy bills after are too high compared to other options, then SMRs should not be looked at as a low-carbon energy solution for Saskatchewan. That said, commercialization may reduce costs, and as discussed above, the funding strategy may be stable and consistent enough to allow for those associated energy bills to not be grossly overpriced compared to alternatives. If projections show competitive energy prices for customers, then SaskPower would understandably look at SMRs as an option and would fulfill their mission.

4.2.3 Social

Nuclear power has been part of Canada's identity for decades but implementation in Saskatchewan requires a societal shift from fossil fuels to low-carbon sources of energy. Electricity production and local natural resources are part of the Saskatchewan provincial identity which has impacted public perceptions and likely the decision-making of SaskPower. The opportunity for job creation is a benefit for residents of Saskatchewan and can be a source of enticement but can also cause issues because of experience gaps in the workforce. Intensive public surveys, consultations, and workshops conclude that the majority of Saskatchewan residents support nuclear power with a trend of increasing support over time. SaskPower has also led many engagement initiatives to assess public, municipal, and Indigenous perspectives and concerns regarding nuclear power. There are, however, concerns held by certain social groups that SaskPower has had to, and will continue to have to, navigate in pursuing SMRs. Indigenous relations must also be considered when historical interactions between Indigenous groups and industry or government leaders have had such a negative effect on the trust between the two.

As was mentioned previously, Saskatchewan is territorial about their ability to produce electricity within the borders of the province, and this permeates into the abundant natural resources that fuel the electricity. Having a complete supply chain for coal and natural gas is a benefit as the workforce and economic benefits reside within Saskatchewan. This creates a loyalty to these resources and modes of operation, however, when a large portion of local residents are highly involved and invested, either monetarily or emotionally, in the generation of electricity by fossil fuels. It becomes a provincial identity. 65% of SaskPower's generation capacity comes from fossil fuels so transitioning such a large percentage requires capitalizing on provincial identity, or changing it (SaskPower, 2023). Because Saskatchewan produces all of Canada's uranium, this is another materialization of provincial identity that guided SaskPower's decision-making process. Section 4.2.2 covers how implementing SMRs would increase the value of the uranium supply chain in Saskatchewan which is one of the reasons why SaskPower is looking at SMRs. The other aspect of looking at SMRs for the sake of the uranium supply chain is that there will be social support for the project because it appeals to a pre-existing workforce and strong provincial support for local natural resources. As of a 2021 report by the Centre for Future Work, Saskatchewan had the second highest employment shares in fossil fuels at 2.3% of total provincial employment which accounts for 13,300 jobs whereas the average provincial fossil fuel employment shares is 1.2% (Stanford, 2021). The uranium industry in Saskatchewan in 2021 employed 1,842 people and has been actively mining and milling since 1953 (Government of Saskatchewan, 2023; AMEC Americas Limited, 2014). Although fossil fuel jobs are at risk because of the federal mandate for a coal-generated electricity phase out by 2030, transitioning to an energy source that doubles down on investing in Saskatchewan's mined natural resources while creating jobs for Saskatchewan residents appears like a good alternative. The Government of Saskatchewan can capitalize on a local resource and generally avoid public dissent by investing in an industry that already has strong ties to Saskatchewan through mining, but was just missing the energy creation component. A provincial identity linked to mining and capitalizing natural resources is preserved with implementation of SMRs.

The region of Estevan, Saskatchewan is being looked at strongly as a potential site for SMRs, and not-so-coincidentally, the Estevan region has the second highest fossil fuel dependence for employment in Canada, after Wood Buffalo, Alberta (Stanford, 2021). Approximately 20.7% of total employment in the Estevan region is in the fossil-fuel industry, which is the top industry for employment in the region (Stanford, 2021). With the federal mandate and accompanying SaskPower initiative to phase out coal-generated electricity by 2030, the Estevan workforce will be particularly affected by this because Estevan houses 2 of the 3 functioning coal plants and none of the functioning natural gas plants. Very generally speaking, a coal phase-out, will threaten most, if not all, of the fossil-fuel workforce in the Estevan region. Implementing SMRs in that specific region is a way for the workforce to recuperate and take advantage of pre-existing infrastructure and ownership of sites. Through engagement sessions with both the public and municipal leaders of the Estevan, job generation and economic opportunities were prioritized, especially regarding coal workers (SaskPower, 2023). It seems that fossil-fuel industry employees recognize the inevitable clean energy transition and are looking towards SMRs to fill the employment gap. That said, residents in southern Saskatchewan, where all 3 coal plants and some coal mines are, were significantly less likely to agree with SMRs replacing coal energy generation compared to the other regions of Saskatchewan (Rozwadowski et al., 2021). SMRs would provide jobs regardless of a coal phase-out, however, which is a major driver for SaskPower to look at them as an option. [SaskPower employee] stated, "SMRs require a lot of investment in people... so there is a lot of opportunity with deploying this new technology in Saskatchewan in terms of creating a new industry, creating a nuclear supply chain, [and] a workforce that can safely and securely operate and maintain the technology. All of that is investment in Saskatchewan and comes with some economic benefits for the province and the people of Saskatchewan." SaskPower is likely looking for an energy option that can help re-employ employees that previously had fossil-fuel jobs and through training, SMRs can be that option.

SaskPower and other research bodies have conducted many public surveys and hosted workshops, forums, and consultations to assess the social feasibility of implementing SMRs and ongoing thoughts, questions, and concerns regarding SMRs. SaskPower is transparent about the fact that there are people who do not agree with nuclear power in any form, let alone SMRs, and have general concerns about nuclear power and SMRs. That said, there have been wide public surveys showing that the majority of Saskatchewan residents, or at least those that participated in the surveys, support the option of nuclear power generation (Rozwadowski et al., 2021). A Saskatchewan Election Survey in 2020 showed that 53.7% of respondents strongly or somewhat agreed with the statement that "Saskatchewan should use small modular reactors to replace coal energy generation on the provincial electrical grid," whereas 15.8% of respondents somewhat or strongly disagreed (Rozwadowski et al., 2021). A 2021 Viewpoint Saskatchewan survey found that 51.5% of respondents somewhat or strongly agreed with the aforementioned statement while only 13.5% expressed disagreement (Rozwadowski et al., 2021). The number of respondents in the "Neither agree nor disagree" category increased between 2020 and 2021 (Rozwadowski et al., 2021). In the municipal information sessions held by SaskPower at Elbow and Estevan, the two potential sites for SMRs, there were concerns but also optimistic responses (SaskPower, 2022). The presence of positive responses towards SMRs in each community is good for SaskPower and their ability to effectively implement SMRs which means that they can look at SMRs as an option.

The potential SMR project will likely impact Treaty and Aboriginal Rights which means that SaskPower has a duty to consult with First Nations and Métis stakeholders that may be impacted. The Canadian Constitution upholds the Métis duty-to-consult rights (First Nations Power Authority [FNPA], 2021). SaskPower has engaged in several Indigenous engagement sessions where it seems the concerns are similar to other engagement sessions but include topics of Indigenous involvement in projects and supply chain, consideration and protection of Mother Earth, resource sharing and participation equity, and treaty relationships and obligations (FNPA, 2021). There does not seem to be much reported opposition to the prospect of SMRs, however, [Alex] mentioned, "What I've seen with the uranium industry is that it opens up really damaging splits in Indigenous communities between traditional governance authorities and the Indian Act authorities. Now, often the traditional authorities are very much in favor of retaining traditional ways of life and are very concerned about anything that might further damage them, whereas the Indian act authorities, the band council and so on, are looking for any kind of economic opportunity that will increase their resource base." [Annie] also said regarding Indigenous opinions on SMRs, "I cannot speak on that part, I cannot be the words of the community, but I did ask about SMRs from a few [Indigenous] people and their responses were that we don't know anything about SMRs. So basically there's not enough information but... they have a different perspective on energy projects so they see value sometimes in SMRs... [it] is a technology that could potentially bring energy security to the communities." It may be the case that there is only a certain group of Indigenous voices being represented in these engagement sessions, or perhaps there is hesitancy to report anti-SMR sentiments from a demographic group which could greatly impact the 2029 decision of whether to implement SMRs in Saskatchewan. As it stands, it seems that there is some vocal support from Indigenous and Métis voices which bolsters SaskPower's reasoning to look at SMRs as a low-carbon energy source because of the minimized chances of social dissent regarding the project.

Although I was not able to secure an interview with an Indigenous or Métis representative, there were some concerns about the mishandling of Indigenous relations from some of the people I did interview. [Willow] commented, "I understand that the Indigenous communities near the mine sites have come to arrangements mostly because they had no choice with the government around compensation or, you know, basically being turned into nuclear waste dumps, which is the way they are now with the mine tailings. But you know, presumably there's going to have to be some kind of consent from the Indigenous nations whose traditional land the reactors are being proposed for." This comment touches upon the long-standing damage caused to Canada's Indigenous peoples by colonial settlers that is both historic and systemically present. It is why the duty to consult is required and so important today. [Annie] elaborates, "There is a misalignment in how government industry sees the development of the projects or the Indigenous engagement in energy projects and how communities see it," which is why ongoing engagement with Indigenous communities, and communities in general is so important. The opportunity for job creation in a sector that is closely related with a provincial identity combined with vocal and statistical social support for SMRs as an option for replacing coal-generated power are highly compelling reasons for SaskPower to investigate SMRs as a possible low-carbon energy solution.

4.2.4 Technological

SMRs are not necessarily new technology systems, but the scale and applicability are new domains. Canada has decades-long experience in nuclear energy, but on a larger scale and with their own CANDU technology. CANDU reactors are pressurized heavy water reactors (WNA, 2024c). Small modular reactors (SMRs) are nuclear fission reactors smaller than conventional reactors and can typically be assembled in a factory and transported to a desired location, and are scalable (Liou, 2023). SaskPower has selected the GE Hitachi BWRX-300 (BWRX-300) technology of SMRs which differs from CANDU reactors in their size and fuel type, amongst other features. CANDU reactors currently supply about 500-881 MWe per reactor and use unenriched uranium fuel, which is easily sourced from uranium mines in Canada (WNA, 2024c). A BWRX-300 reactor produces 300 MWe of power and requires enriched uranium fuel which means that Canadian uranium will have to be exported for enrichment before being brought back to Canada to be used as fuel for the SMR (General Electric Hitachi [GEH] Nuclear Energy Americas, 2022). The choice to go with an SMR over a conventional CANDU reactor was because of the size of the power grid in Saskatchewan. The IAEA recommends that a singular nuclear reactor not supply more than 10% of the region's grid as refuelling periods or unforeseen shutdowns can cause a large gap in power production that other power sources will struggle to cover (Liou, 2023). Accordingly, [SaskPower interviewee] stated that SMRs were selected as to "not put too many eggs in one basket," and corroborated by [Alex] stating "Saskatchewan always felt that [having a conventional CANDU reactor in Saskatchewan was] too big of a risk to have one big reactor which would produce 1/3 to half of all power generation ... appearance of SMRs there makes it possible [and] changes the conversation." The grid must remain reliable and stable which is what a smaller model of reactor provides. The specific BWRX-300 model was selected as OPG also selected the BWRX-300 as their model to construct and implement. In observing their construction, assessments, regulations, and grid connection process, SaskPower can learn from their experience and implement the same model just as or more smoothly.

The BWRX-300 reactor is a light-water boiling reactor developed by General Electric Hitachi (GEH) Nuclear Energy in Japan which also created a safety analysis report for the Ontario Power

Generation company in 2022 to assess site requirements, different technological aspects of the reactor, and certain processes that will take place (GEH Nuclear Energy Americas, 2022). The approximate size of the plant apparatus and buildings will be 9,800 m^2 and the approximate size of the entire site within fences will be 30,000 m^2 (GEH Nuclear Energy Americas, 2022). A diagram of an example BWRX-300 plant layout is included in Appendix 4. The technology's power output will be 300 MWe and is designed to have a lifetime of about 60 years (GEH Nuclear Energy Americas, 2022). The fuel type will be uranium dioxide (UO_2) pellets with a fuel enrichment of <5% U-235 (GEH Nuclear Energy Americas, 2022). When uranium is mined, it consists of 3 main isotopes in varying ratios: uranium-238 (U-238) at approximately 99.3%, uranium-235 (U-235) at approximately 0.7%, and <0.01% of uranium-234 (U-234) (USNRC, 2020). Enrichment of uranium increases the U-235 ratio to between 3 and 5% from its original 0.7% so that the uranium can be used as fuel in light-water reactors (USNRC, 2020). The nuclear plant will also contain spent fuel pools that can accommodate 8 years of full-power worth of spent nuclear waste (GEH Nuclear Energy Americas, 2022). The reactor design will have a refueling cycle every 12-24 months and refueling will take approximately 10-20 days (GEH Nuclear Energy Americas, 2022). Natural water circulation from an external water source is the mechanism to remove excess plant heat and isolation condenser system pools remove decay heat during power operations (GEH Nuclear Energy Americas, 2022). The BWRX-300 has been "specifically designed to enhance safety through simplification and reducing its dependence on human intervention," (GEH Nuclear Energy Americas, 2022). A small additional reason that nuclear has been chosen by SaskPower is the safety of the technology in a place like Saskatchewan where there are very few extreme weather events that could cause a nuclear accident. [SaskPower employee] stated, "Saskatchewan is a great place for nuclear reactors. It's a pretty stable environment, there's low risks from a seismic and weather concern, you know we got lots of tornadoes but those can be designed for pretty easily." Weather like the tsunami that caused the Fukushima accident is pretty avoidable in landlocked Saskatchewan and therefore indirectly makes the technology safer.

Technology readiness is a factor in choosing a reactor model and for SaskPower to consider when making a decision in 2029 on whether to implement nuclear power. [SaskPower employee] stated, "We wanted to see SMRS in the vendor design review process with the Canadian regulator, the CNSC. We wanted to see other jurisdictions in North America or in Canada particularly start to really look at SMRS and deploying them, and so that all speaks to technology readiness and having a jurisdiction who is comfortable with nuclear and knows how to manage nuclear safely and securely, demonstrate SMRS before we do." Canada has a licensing process for and is experienced with CANDU reactors, but since there are no CANDU SMRs, a new technology had to be chosen. In the technology selection process, SaskPower not only looked at GEH's BWRX-300, but also X-Energy's XE-100, and Terrestrial Energy's Integral Molten Salt Reactor (IMSR) (SaskPower, n.d.d). Light-water reactors are not a new technology, and OPG was looking into the BWRX-300 so choosing it meant that there was already some expertise and would be more if and when it came time for Saskatchewan to implement it. Out of the three reactors, the BWRX-300 would likely be the smoothest based on technology readiness and reduce associated regulatory and operating costs as well as keep the schedule within its timeline (SaskPower, n.d.d).

Spent nuclear fuel and low- and intermediate-levels of waste are a necessary consideration when considering expanding nuclear energy. It is a problem that so far has a passive solution. When considering SMRs, SaskPower has to consider the associated waste both during operation and during decommissioning, and it seems they have. The CNSC has strict regulations about waste handling and planning, and it is these regulations, and the relatively small amount of waste, that makes SaskPower confident that spent nuclear fuel won't be unmanageable. As [SaskPower employee] puts it, "Before we go to build a reactor, the regulator in Canada will make sure we have a full decommissioning plan that accounts for all the waste products that we're going to produce. Not only will they review it and make sure it's technically sound, before they let us build they will make sure we have the money in the bank to deal with it….the other aspect is the quantities that we find really attractive when we look at SMRs and nuclear power in general. You get a huge amount of energy out of an extremely small footprint and so the volumes of say, high level nuclear waste which is used fuel, that would come out of a [300 MWe] reactor are very manageable. They don't take up much space, they do need a lot of infrastructure to manage the radiation aspect… So all of that could easily be stored on site though on a very in a very small footprint… Canada does have a national strategy to centralize these materials and that's what the NWMO is looking after." Considering that the reactors in Ontario have been operational for decades and have been storing their waste on-site, it seems that although spent nuclear waste is something to thoroughly plan for, it perhaps makes selecting nuclear energy easier. As [Nick] succinctly put it, "The issue of waste is manageable."

The BWRX-300 technology is a "tried and true kind of technology," according to [Civilian] even if the scale of the light-water technology is new. Nuclear provides stability to the grid that most renewables cannot supply with certainty, and Saskatchewan provides the source of uranium for the fuel, however, it needs to be enriched internationally. Out of the three examined technologies, SaskPower was confident enough in the technological readiness of the BWRX-300 after OPG's selection of the same technology that it became even more enticing. The issue of spent nuclear fuel has been handled successfully by other nuclear reactor facilities, so track record would dictate that SaskPower would be able to successfully handle their own spent nuclear fuel and other levels of nuclear waste. All of these technological aspects are reasons as to why nuclear power has been selected as a low-carbon energy source by SaskPower.

4.2.5 Environmental

Although debated in literature, as shown in Section 2.1.5, nuclear power, including SMRs, can reduce greenhouse gas emissions, especially if coupled with fossil-fuel phase-out policies. When asked what the main reason for looking at SMRs as a potential low-carbon energy source was, [SaskPower interviewee] said that managing a target of net-zero greenhouse gas emissions was the main motivator. As Saskatchewan is currently very reliant on fossil fuels as their energy source, and there is limited access to hydro power, nuclear became a clear contender for decreasing greenhouse gas emissions and providing reliable and stable electricity. Coupling nuclear power implementation with a fossil-fuel phase out should more than likely reduce carbon emissions in the electricity sector. The ability to continue to provide a stable source of electricity and work to meet a 50% reduction in greenhouse gas emissions by 2030 compared to 2005 are the most compelling reasons for why Saskatchewan has chosen to entertain the idea of SMRs as a potential low carbon energy source.

Nuclear power has a very small carbon footprint in general and is one of the lowest, if not the lowest, compared to other sources of low-carbon energy sources. The physical footprint of an SMR facility is also smaller than that of a conventional reactor facility, so the amount of land needed for the energy is smaller. As [Nick] puts it, "I think we are in a desperate situation in dealing with climate change and nuclear, as you know, has its own challenges in terms of particularly waste management but it's carbon free. The lowest carbon free you can get, the only technology that closely competes is offshore wind." The lifecycle greenhouse gas emissions from an average conventional nuclear reactor is the lowest for all types of energy sources, including wind and solar (United Nations Economic Commission for Europe [UNECE], 2022). Assumedly this would hold true for SMRs, however there is not enough working SMRs to create an accurate comparison at this time. Fossil gas, nuclear, and wind have the smallest land occupation and nuclear has material resource demands on the lower end of the spectrum (UNECE, 2022). The water use for nuclear, however is ranked rather high (UNECE, 2022). Not only is nuclear seen as an effective low-carbon source to reach climate goals by SaskPower, but it has a substantially low impact on the environment from the facility and life cycle alone when compared to renewable options. The UNECE report also included the fuel element supply chain which encompasses extraction to fuel fabrication, however, the non-GHG emissions negative effects on the environment from the fuel life cycle were not included (UNECE, 2022).

It seems SaskPower's sole environmental reason for selecting nuclear as a technology is for the sake of reducing emissions. There are other environmental reasons that could make nuclear a viable choice, such as the fact that Canada's track record with handling nuclear incidents in terms of environmental effects is rather good. But there are environmental reasons as to why SaskPower perhaps shouldn't have chosen nuclear energy. Although used in Section 4.2.1, [Willow]'s response to the province's climate goals is worth restating, "I mean, it's been pretty clear from recent statements by Premier Moe that they're not at all interested in cutting down their carbon emissions at the level that the federal government is asking them to, and so the nice thing about SMR is it's a wonderful delaying tactic for any province that wants to keep with their oil, keep basically burning fossil fuels, because they're not going to be ready in the next 10 years even though they say they are." If nuclear energy is being used as a stalling tactic instead of investing more heavily in renewables and transitioning away from fossil fuels then that should definitely be made public, however, coal plants are no longer running at full power capacity and according to SaskPower, there are plans to increase their renewables by 700-3000MWe. [SaskPower employee] stated, "We're looking at upwards of 3000 megawatts of more wind and solar on the grid. So it's not a matter of why are you doing nuclear, why aren't you doing wind and solar, it's about advancing all of these options and finding the right balance that hits our business objectives which is a reliable grid and affordable grid and sustainable from an emissions perspective." Unless nuclear stalls the committed solar and wind projects and coal phase-out, then it seems like it would not be the most well thought through stalling tactic.

The issue of uranium mining and nuclear waste was brought up as a factor that should deter anyone from choosing nuclear. [Civilian] noted how there were more radionuclides in the mining waste than in the uranium itself and was concerned for both peoples' health and the environment. [Willow] commented on the issue of decommissioned reactors and the intermediate level waste that would be the reactor as well as the amount of land or water that could be impacted in the wake of a nuclear accident. In an agricultural province like Saskatchewan, contamination of farmland could be detrimental to the local economy. Abandoning nuclear energy will not stop the mining of uranium as Canada still uses it for medical purposes, but it would greatly decrease the amount needed. In terms of the decommissioned reactors, the CNSC mandates that the producers of the waste have to handle it, usually on site (Government of Canada, 2021a). SaskPower assumedly has created a decommissioning plan that accommodates for the reactor once it is considered waste, in accordance with the CNSC, and must make sure that it is protected accordingly so that it does not contaminate the environment. One of the last issues that was raised in regards to a nuclear projects potential impacts was the stability and availability of the water source that is used for its cooling. Both siting considerations are on reservoirs, one that supplies drinking water. [Civilian] stressed, "They are on reservoirs that are basically created by damming rivers. In fact one of them, the one in the southeast of the province, is on damming a creek. I mean how long is that creek going to run?" The concern is that the water flow stops and the water levels start to decrease which will affect the availability of water as well as the aquatic ecosystems that it houses. SMRs could escalate the effects that may already come from dams themselves. It seems that there are more guaranteed benefits of nuclear energy in terms of fighting climate change than there are possible detractors that could affect the surrounding environment of nuclear supply chain and operations. That is not to say that physical environmental harms are less important than decreasing emissions, only that the benefits seem more concrete than the detractors. This may have lead SaskPower in selecting nuclear, and if it did, then the possibilities of environmental harm should not be ignored in their planning, implementation, and decommissioning.

4.3 What is the realistic timeline for implementing nuclear energy and is it in line with SaskPower's foreseen timeline? (RQ2)

4.3.1 SaskPower's timeline - Inside view

SaskPower has published an official SMR Project Schedule which incorporates Ontario's budgeted time for constructing their BWRX-300. As shown in Figure 2, feasibility studies and the selection of the technology have already been completed with a forecasted site selection to be completed by the end of 2024. Saskatchewan is also in the planning stages and will be preparing for construction and operation licenses and impact assessments. After the decision in 2029, SaskPower expects to be operational by the end of 2034 which is a 5 year site prep and construction window. Unfortunately, the overall timeline is quite slow from a clean energy transition perspective, yet fast from a new technology and licensing perspective. The SMR built in Ontario will be a FOAK, which means there will be uncertainty and likely setbacks. By learning from Ontario's experiences, Saskatchewan can perhaps pre-emptively avoid certain issues and follow their projected timeline closely with minimal delays.

4.3.1.1 Site Selection

The next step in the Project Timeline is site selection, which will likely be completed on time. SaskPower is looking at the Elbow and Estevan regions as possible sites for SMR construction and operation. Specific criteria they are looking at are existing infrastructure, emergency services, access to a workforce, proximity to water, proximity to highway infrastructure, and proximity to a larger community (SaskPower, n.d.c). SaskPower has also completed a suitability analysis, water intake study, and regional evaluation process which culminated in a suitability map for both Estevan and Elbow. On May 6, 2024, Premier of Saskatchewan Scott Moe mentioned that although it had not been announced yet, the site selected for SMRs will likely be in the Estevan area, however, the Minister for Crown Investments Corporations Dustin Duncan, which encompasses SaskPower, said the next day that no decision has been made yet and there are still steps to complete before a decision is announced (Cairns, 2024a; Cairns, 2024b). As of May 31, 2024, SaskPower officially announced, however, that the potential site has been narrowed down to either Boundary Dam or Rafferty Reservoir, both near the City of Estevan (SaskToday.ca Staff, 2024). It does not seem likely that this final decision will be delayed, but if it is, then that will affect the site preparation licensing and any impact assessments that are lined up.

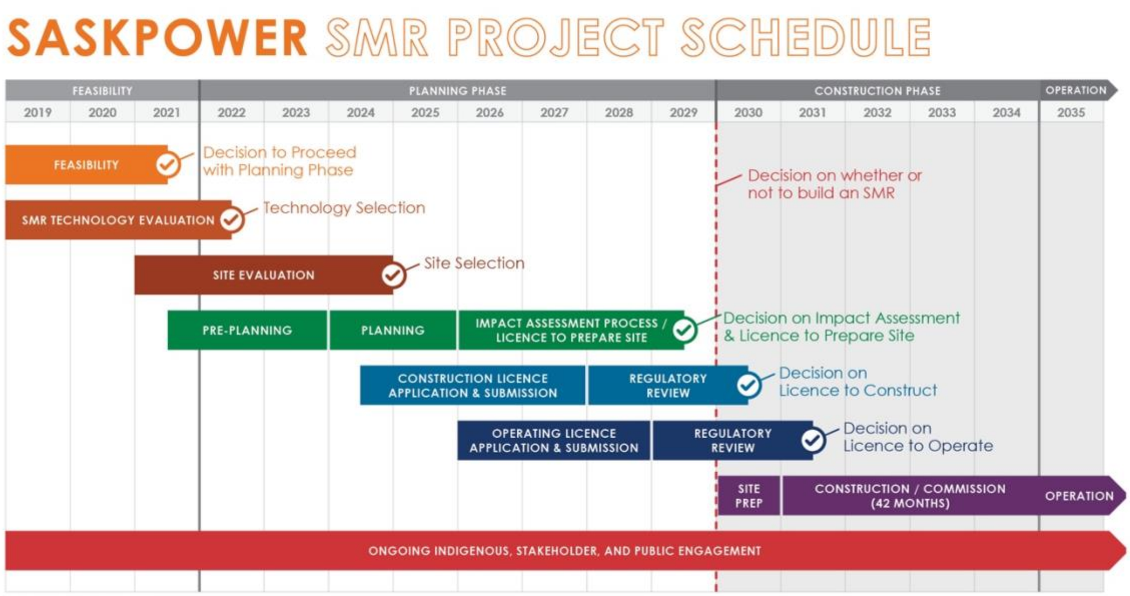

Figure 2. SaskPower SMR Project Schedule Timeline (SaskPower, 2024a)

4.3.1.2 Impact Assessments

One of the next steps after site selection will be environmental, economic, social, and Indigenous impact assessments and various licensing. According to [SaskPower employee] the timeline is driven by federal requirements and the SMR project will be subjected to both a federal and provincial impact assessment. There were some attempts to streamline both levels of impact assessment into one process, but both assessments will have to happen separately. Impact assessments and licensing for a new-to-Canada technology may take much longer than expected. SaskPower is allotting about 4 years for the impact assessment process and from 2024 to 2029 for the site preparation, construction, and operation licensing processes (SaskPower, 2024a). [Civilian] mentioned in relation to the proposed timeline, "I don't know if they can do it in four years. Certainly if they don't have a federal environmental assessment agent period to go through that will shave off some of the time." However, there will be a federal environmental assessment period. A delay in the licensing or impact assessment phase in OPG's process may cause SaskPower's 2029 decision to be delayed, but hopefully SaskPower will have stayed on schedule and completed their impact assessments and licensing by 2029. The ability for OPG to build an SMR first and then learn from their experience may keep SaskPower on track, but there does seem to be concern that both licensing and impact assessments could take longer than expected, especially in a province that is not used to preparing for a nuclear project.

4.3.1.3 Technology and licensing

The aspect of a new technology also raises some concern in terms of the ease of licensing and construction. Canada is familiar with their CANDU reactors and how to license them, but it has been years since a new reactor was built, let alone one of a new technology. The BWRX-300 is foreign and creating licensing requirements and then being able to get licensed may be a lengthy process. The technology of light-water reactors is not new, they just have not been built in a small size before, so hopefully Canada can learn from some American expertise in light-water reactors. [Nick] stated, "The biggest challenge will be the licensing and very likely the licensing of the first unit will cost as much as building it because they have to convince the regulator, that it is safe to Canadian standards. Not American standards, they are similar but the Americans license those reactors and know them inside out – we don't. So it will be a delayed process." The physical construction of the reactor may cause setbacks as well. [Willow] commented in regards to SaskPower's construction timeline, "Why that particular timeline is very ambitious and probably not realistic is because there has never been a BWRX-300 built before and it's basing its design on, as far as I understand, a [small] reactor that was never built or they started to build it and it became unfeasible." This claim is likely based on the fact that the BWRX-300 is an evolution of the Economic Simplified Boiling Water Reactor (ESBWR) which started as a Simplified Boiling Water Reactor (SBWR) at 670 MWe (IAEA, 2019; Hylko, 2010). This SBWR design was acceptable for review by the United States Nuclear Regulatory Commission (USNRC) but General Electric withdrew their application as they deemed the technology too expensive compared to its power output (Hylko, 2010). In that sense the original design did not work out, but seemingly more for economic reasons as opposed to long-standing delays. The effects of economics on the success of nuclear projects will be discussed in Section 4.4.

OPG has set their construction completion date to 2028, but there is a likely chance that OPG's construction process will face delays since it is a FOAK. This would likely push back SaskPower's 2029 decision and subsequent construction. [Nick] expressed, "When CANDU reactors started, for example, we had a demonstration plan, we had a pilot plan, started small, tried it out, then we went big. Now there is no time to do that so the industry is relying on knowledge from the 50's and 60's when most of this technology was created. So the hope is that they will be strong background to build on, however, knowledge is not doing. You can have the knowledge and do things, but reality is different than theory and the hope and theory is that you iron out everything in the FOAK." When asked about the likelihood of timeline delays, [SaskPower employee] responded, "That timeline is still aggressive but it's still achievable with where we're at today...we feel that with SMRs, they're small enough. The modular aspect of how they're designed is meant to help mitigate some of that construction risk that has plagued big nuclear projects in the past...we've allowed ourselves 4 full years for construction and commissioning which we're very comfortable with today." So far, the process from both OPG and SaskPower's side of things are on target, but that can quickly change and has not always been the case with other similar projects.

4.3.2 SaskPower's timeline - Outside view

SMRs are a relatively new technology with little literature and almost no historical cases to compare to present predictions. Therefore, reference cases here will have to be applied a bit differently. While infamously prone to delays both economically and timewise, the study by Rubio-Varas (2022) shows that nuclear projects aren't necessarily delayed because of the inherent characteristics of nuclear, rather the time and location and economic arena that they are being built in. In that line of logic, almost any large project would face setbacks, not just nuclear. Construction of nuclear projects are beginning again in a type of nuclear renaissance that is a completely different environment than the nuclear projects of the past. Energy projects either of a certain size or type are looked at to see if there have been setbacks in the timeline or budget.

4.3.2.1 Nuclear Reactors

There are hundreds of conventional nuclear reactors that have been built before that can be used to assess the likelihood of expecting delays in the licensing and construction process of an SMR. There is, however, a micro modular reactor at the Chalk River Laboratories site in Ontario that began an environmental impact assessment process in 2019. This reactor is designed to produce 15 MWe of thermal energy and have a lifespan and singular fuelling cycle of 20 years (Ontario Power Generation [OPG], 2021). It is still in progress and was proposed to take 5 years, and the first power is proposed for mid-2028, (OPG, 2021). The environmental impact statement was expected to be submitted in the summer of 2023 but has been delayed and the new submission date was assigned for early 2024, which has arguably passed at this time (Schneider et al., 2023). An environmental review officer from the CNSC personally confirmed to me that they are still waiting for the environmental impact statement. Neither a license nor construction can commence until the environmental impact statement has been submitted, so the process is already delayed.

In terms of conventional-sized reactors in North America, the story is somewhat similar. [Civilian] noted, "We've had how many nuclear power plants built in North America, somewhere like 200 or 300, and not one has been on time or within budget." In relation to that claim, there have been 202 construction starts in North America of which 42 American reactors were later abandoned (WNISR, 2024). Pickering 1 and 4 (both 508 MWe) and Bruce 1 (732 MWe), 2 (732 MWe), and 3 (750 MWe) reactors all took 4.8-5.8 years to construct which isn't far off from SaskPower's 3.5-4-year construction predictions (WNA, 2024c). The last reactor in Canada connected to the grid was in 1993, Darlington-4, and Vogtle-4 in the US was just connected to the grid on March 2, 2024 (WNISR, 2024). There were several American operable reactors that took less than 5 years to build, however they were all completed by 1974 (WNISR, 2024). Some were suspended before the Three Mile Island incident in 1979, and some were suspended after. The power capacity of the American reactors that had an under 5-year construction period ranged from 22 MWe to 1,040 MWe which is a huge range (WNISR, 2024). Only 4 of 25 total nuclear reactor projects in Canada took less than 5 years to construct and their power capacity ranged from 17 MWe to 508 MWe (WNISR, 2024). The last reactor that took less than 5 years to build in Canada, Pickering-3, was connected to the grid in 1972 (WNISR, 2024). The Three Mile Island incident seems to not have had a large effect on Canada's reactor plans as the Bruce-7 and -8 reactors started their construction later that year (WNISR, 2024). It is worth noting as well that none of Canada's nuclear projects were abandoned and none of the construction periods lasted more than 10 years, which cannot be said about the US. Data for the expected versus real duration of construction from construction start to grid connection is difficult to find as almost all North American reactors were built before 1993. However, the real construction times for the reactors are readily available and show that the track record of Canadian-built CANDU reactors, even in the face of a nuclear disaster, is to finish the construction in under 10 years. The historical context of the 1970s where interest rates in the US were proportionately high, leading to many American reactor projects being abandoned, did seem to affect Canadian reactors by increasing the construction lead time trend from under 5 years to 5-10 years. Longer lead times in Canada are also associated with higher power output, where the larger plants took longer to construct. This does not imply that OPG or SaskPower will be able to construct their respective SMRs on schedule, but it does imply that if there are construction delays, they likely won't be ridiculously stretched out.

Common reasons for nuclear lead times to be delayed have been investigated both in an internal and external context. Conventional reactors are often affected by the experience of the entity pursuing them, in this case SaskPower, the regulatory environment, project management, supply chain maturity, labour productivity, and design maturity (Stewart et al., 2022). Another study investigated 51 nuclear-related projects including engineering, modification and maintenance, and facility projects, in order to identify causal factors of delay and reasons for each category of delay (Alsharif & Karatas, 2016). The thirteen major causal factors of delay were missing schedule updates, design errors/engineering change requests, scope changes, contractor issues, materials/vendor issues, funding problems, schedule unproductivity, resource unproductivity, plant support engineering issues, reworking designs or implementation, owner decisions, weather, and other delays such as poor coordination or equipment failure (Alsharif & Karatas, 2016). Rubio-Varas (2022) also emphasizes the historical and geographical context of nuclear projects, however, it is hard to apply historical context to a present case especially when the historical context was so influential for how and why reactors were delayed. The likely applicable factors that could affect the timeline of SMRs in Saskatchewan are economic factors, changing regulations, and any institutional crises or extreme changes (Rubio-Varas, 2022). High interest rates can cause financing for a nuclear project to become strained, and in the light of recent global inflation, the impact of the economic arena in which SMRs are being built should be monitored. Regulations set out by the CNSC could affect how smoothly SMRs are implemented, especially as certain regulations for a nuclear project of a new technology and size are somewhat uncertain right now. If initial regulations are set but then changed if something comes to light, then construction of projects will likely be delayed. There does not seem to be concern by interviewees for any crises to arise from political changes or upheavals which would impact SMR timelines. It seems likely from both internal and certain external contexts that there will be construction delays if not impact assessment and licensing delays, which will shift the SaskPower Project Schedule timeline by a certain, but not extreme amount.

4.3.2.2 Non-Nuclear Energy Projects

Comparing available data on the time it has taken to build other energy projects of a comparable size in Saskatchewan can be valuable as an approximation for the efficiency of SMR construction. The available information for different power facilities is somewhat limited, however, as many of the facilities were constructed and opened before 1999. The coal and hydroelectric facilities essentially predate widespread use of the internet and thus information on their construction durations and budget predictions here are from local newspapers. The solar facilities in Saskatchewan have a capacity of only 10 MWe each so are not as fit for comparison.

The smallest coal facility, Shand Power Station (Shand), has a power capacity of 276 MWe. Construction of Shand started in May of 1988 and was scheduled to be completed, and was completed, in 1992 (Petrie, 1988). The predicted cost of the project was CAD 579 million at that time, which converts to CAD 1.3 billion in 2024 (Petrie, 1988). There was an unfortunate accident with a crane that killed 2 employees and seriously injured 6 others which stalled the project a bit, but not by much (Gent, 2020). Shand was the third coal plant that SaskPower opened and therefore they had experience constructing that kind of technology, and Shand has a lower power capacity than the other two coal plants in Saskatchewan, which can lead to a shorter construction time in general.

The E.B. Campbell Hydroelectric station is the 2nd oldest hydroelectric dam in Saskatchewan and has a power capacity of 292 MWe. Construction started in the spring of 1960 and finished in 1963 and the predicted cost of the project was approximately CAD 46 million which is CAD 476.6 million in 2024 ("Squaw Rapids work started," 1960). The dam was previously known as the Squaw Rapids Dam until the 1980s when it was renamed the E.B. Campbell Dam (MBC News, 2017). This project was predicted to finish in 1963, which it did.

The North Battleford Generating Station is a natural gas facility with a power capacity of 289 MWe and was constructed in 3 years, from 2010 to 2013 (SaskPower, n.d.b; John Cairns Staff Reporter, 2013). The predicted cost of the project was CAD 700 million, which is CAD 969 million in 2024, and it was predicted to be completed by the fall of 2013 (Leader-Post Staff, 2010). It was the 9th out of 10 natural gas facilities built in Saskatchewan. The Chinook Power Station, which is also a natural gas facility has a power capacity of 353 MWe and took just shy of 3 years to construct, from January 2017 to December 2019 (SaskPower, n.d.a). The project cost CAD 605 million (SaskPower, n.d.a).

The final project to look at is the Golden South Wind Energy project. It covers approximately 34,000 acres of land and has a power capacity of 200 MWe and consists of 50 turbines, an underground electrical collection system, access roads, and other operation and maintenance buildings (Francis, 2022). The project started in 2009 but the construction itself lasted about 3 years from 2019 to 2022 and cost CAD 340 million (Francis, 2022).

The longest amount of construction time from these alternative power projects was 4 years and it seems that all of them were on schedule in terms of years of completion. In all these cases, Saskatchewan had prior experience with constructing at least another facility of the type which can lead to quicker and more efficient construction times. It is also worth noting that all these projects were significantly less expensive than what the province is budgeting for their first hypothetical SMR. The SaskPower's Project Schedule timeline does not seem unrealistic, however, based on similarly sized energy projects. A 42-month, or 3.5-year, construction prediction is in line with the projects showcased above. Based on purely a power capacity aspect, SaskPower will likely finish their construction within their predicted timeline but there are many other variables to be considered that may stall a project such as SMRs. Industry experience, accidents on site, technology, financial issues, and more, are all possibilities for setbacks. It will be imperative for SaskPower, assuming they have a positive decision in 2029, to analyze and minimize causal factors of delay to stay within their budgeted timeline.

4.4 Under what conditions might nuclear power succeed or fail in Saskatchewan? (RQ3)

The literature, research, and interviews procured for this thesis project give many factors that can positively or negatively impact SMR implementation in Saskatchewan which goes to show how nuanced the topic is and project must be. There are three stages in which SMRs might fail in Saskatchewan: during the decision period in 2029, during construction, and after the SMR has been connected and is fully operational.

4.4.1 Decision period stage

It seems relatively transparent that the decision that SaskPower will make in 2029 on whether to start building an SMR heavily depends on the learning experience and success of OPG's SMR endeavors. If the OPG project experiences too many setbacks and becomes way off schedule, then that could impact SaskPower's decision. If there are too many budget overruns, then SaskPower can only reasonably expect that they will have to adjust their budget accordingly and it may become financially unfeasible to pursue their own SMR when there are cheaper energy sources in progress or already available. Separate from OPG's project, if the social consensus on nuclear power in Saskatchewan changes and becomes heavily anti-nuclear before 2029, then SaskPower may find themselves deciding against SMRs. [Nick] put it this way, "It's important, the first time, to have a buy-in, to have consensus, to have people supporting the project. Even at the expense of some delay, Saskatchewan has some time to go out, talk to people, talk to the public and hear people out and hear their concerns." Social consensus could change if there was a nuclear disaster, likely closer in geographical proximity to Canada. Social consensus or political influence could determine that nuclear power is not necessary for combatting climate change, either because the technology is not adequate or because climate change becomes less of a priority. If OPG's project is relatively successful and SaskPower believes they can implement their own SMR more smoothly, and if social support is relatively unwavering, then it is highly likely that SaskPower will go forward with a decision to start the construction process in 2029.

4.4.2 Construction phase

The construction phase holds many more factors and nuances than the decision period stage and draws more on interviews and historical reference cases for reasons for which construction would stall and be abandoned or be completed and therefore be successful. Some of the preconditions for success during construction are political, governmental, and regulation stability, economic capability, population stability or growth and social support, supply chain stability, and absence of environmentally damaging and lasting incidents.

4.4.2.1 Political

Political stability in Saskatchewan and Canada's case means that a change in the political party in power won't negatively affect the construction of a nuclear project. The opposition party in Saskatchewan is the New Democratic Party (NDP) and the opposition party federally is the Conservative party. Currently, it does not seem like a change in political parties would affect the viability of an SMR project either in the present or in the future based on interviewee responses, legislative history, and party platforms. As [Alex] put it, "NDP is not going to renege on agreements about nuclear power from an anti-nuclear perspective, if it comes to power, doesn't matter who's in government they [will] support nuclear power." The Government Effectiveness Indicator (GEI) of Canada in 2022 is 1.57 compared to an upper limit of 2.5 and a global average of –0.05 (World Bank, 2022). This means that the average Canadian province is well above the global average in terms of maintenance of public services and commitment to policies and projects separate from political pressures (Jewell, 2011). In terms of regulatory stability, because SMRs are a new technology to Canada, the CNSC does not have extensive experience and regulations as they do with CANDU reactors. If regulations were to change mid-construction that drastically affect how SMRs are to be built or regulated, this may cause extreme delays or even lead to abandonment. However, if the licensing phase is complete and the CNSC does not change regulations while SaskPower is mid-construction, then construction will not be affected.

4.4.2.2 Economic

The economic capability of the province of Saskatchewan to procure enough funds for the duration of construction as well as the planning and operation stages must remain strong for construction to be completed. SaskPower seems to be planning on financing their construction phase through provincial loans and perhaps additional grants from the federal government, but this is one of the most, if not the most, expensive energy projects the province will be taking on so there is room for economic uncertainty. If SaskPower is taking loans from the government, then they in turn must have enough money to provide a loan. If the construction phase is delayed and becomes more expensive, then there may not be enough funds to continue with the construction phase, resulting in abandonment. However, there will have to be tangible funds invested towards nuclear waste management that are verified by the CNSC, so if there is enough money dedicated and secured for construction, then that phase can successfully be completed. Saskatchewan's energy market is not liberalized, that is, there is no real competition. This makes it much easier for SaskPower to implement a socially contested technology like SMRs. It also makes it easier for them to succeed as there is no competition from other private energy suppliers that could provide electricity for a cheaper price and drive SaskPower's SMR out of business. This may not affect the decision phase as much as it does the construction and operation phases, as that is the manifestation of implementation. So not only does the economic capacity and strategy matter, but so does the economic environment into which the technology is being introduced.

4.4.2.3 Social

The social aspect in a successful construction phase is population stability or growth and maintained social support for the project. A steady or growing population ensures that the demand for energy is still present and creates a reason for the SMR to be completed. The generation capacity of Saskatchewan is usually substantially larger than the actual demand of the population and therefore SaskPower can adjust generation accordingly and sell excess energy. Adding an expensive energy project to the mix works as there is also a planned coal phase out, so the SMR will not be creating excessive amount of energy but will be replacing lost power possibility. A population that suddenly starts rapidly decreasing reduces the energy demand and an extra 300 MWe from an SMR may not be financially or realistically needed. If this were to happen during the construction phase, then SaskPower may find it economically unsustainable to continue to construct an energy project that is not needed and therefore may abandon it. However, the population of Saskatchewan has been steadily increasing for the last 80 years and likely won't drastically and unexpectedly decrease without warning while SaskPower is in the midst of SMR construction, so this means that from a population perspective, construction will be completed (Government of Saskatchewan, 2024b). From a social acceptance perspective, it will likely remain positive unless transparent public engagement is neglected, or a nuclear disaster occurs that quickly changes the public's opinion on the necessity of SMRs in Saskatchewan. When asked whether she thought that Indigenous communities could impact or impede the progress of an SMR, [Annie] responded that Indigenous communities are playing a bigger role in projects and have gained more industry knowledge over time. Although it was mentioned before that political will has and can out-muscle community voices, SaskPower is involved with and engaging with Indigenous communities which means that those communities have more power to impact progress if relations are mismanaged. Mismanaging Indigenous relations can turn the general public against the project as well. They may continue to support the technology but may not support the companies engagement or lack thereof. Social acceptance is a fickle criteria, but as long as it remains positive, then it seems reasonable that SMR construction would be successfully completed.

4.4.2.4 Technological

During construction, the availability of manpower and materials can determine whether construction will be successful, delayed, or abandoned. SaskPower looked at technology readiness when selecting the model of the SMR that they would hypothetically implement, but there may be components of the supply chain that aren't as readily available. Construction materials could become scarce or expensive, or there could be transportation delays from the BWRX-300 manufacturing hub to the site in Saskatchewan. Relevant expertise in building an SMR will also need to be accommodated for and in a province that does not have prior experience of constructing and operating nuclear power plants, Saskatchewan will need to import some relevant experience at first. Unless there is a complete absence of a certain necessary component for the physical construction of the SMR however, it is unlikely that delays or expected challenges would lead to the construction phase failing.

4.4.2.5 Environmental

One of the final considerations for a successful construction phase is the absence of any environmental disasters or grievances. As has been mentioned already, a nuclear disaster, especially somewhere geographically close to Canada, could lead to a decline in public approval of the project which could tangibly impact the construction of a nuclear power, perhaps to the point where construction must be abandoned. As [Nick] stated, "This is an industry that is unique in that sense, an incident in the industry affects it around the world." However, evidence from reactor construction start times in Canada compared to nuclear disasters in the world show that even in the face of a nuclear disaster, Canada has still gone forward with starting and completing construction, so it is a logical progression to assume that if another nuclear disaster were to occur, it won't necessarily affect SMR construction in Saskatchewan. It remains a slight possibility but not a certainty. Lastly, if construction of the SMR were to negatively impact the environment in some way that the surrounding communities or the Saskatchewan population protested the continuation of the construction, then the construction could be foreseeably abandoned. Examples of a negative impact could be water source contamination or destruction of a protected or valued species or habitat. That said, the environmental impact assessment that SaskPower will conduct should summarize these possibilities and include guidelines to avoid such an occurrence.

Within the construction phase it seems likely that there may be events that could realistically delay the process, but without an extreme event with serious repercussions, it seems unlikely that construction will be abandoned.

4.4.3 Operation phase

Many of the reasons that SMR implementation may succeed or fail post-completion are the same as those for during construction, just applied in different contexts. Political support for SMRs, economically competitive electricity prices, social approval and support, safe technology and consistent supply chains, and lack of environmental damage are all factors that will support SaskPower's SMR in its operation phase.

4.4.3.1 Political

Due to SaskPower being a Crown Corporation, they are subject to public opinion and political influence in a way that a private company would not be. Currently, both the Conservative Party at the provincial level and Liberal Party at the federal level will likely not oppose nuclear power or cancel any projects that are proving to provide a reliable source of power. It also seems that the opposition parties, NDP at the provincial level and Conservatives at the federal level, will not oppose nuclear projects if they are safe and reliable. According to [Willow], the only two parties that would oppose nuclear power and would perhaps shut it down would be the Green Party and the Bloc Quebecois, but there is a very slim chance that they will obtain enough power to properly push their anti-nuclear agenda. Because SMRs are a low-carbon energy source that can help minimize GHG emissions and because they are a reliable base load source of energy, it is very unlikely a completed and operational SMR will be shut down before its life cycle has ended by a political party in power without an external reason.

4.4.3.2 Economic

The economic aspect of SMR operation may be the most influential in whether it succeeds or fails. SMR construction is extremely expensive compared to other energy projects, as can be seen in various previous sections. This price tag typically carries over to electricity prices which consumers must pay. If the electricity prices become too high, then consumers will demand that they generate the electricity from cheaper sources so that it is more affordable, thus resulting in failure of the SMR. However, [Nick] commented, "Electricity cost is going to go up with or without nuclear, I think that is inevitable. As you get economic growth and population growth, and you want to retain the same standard of living, even climate change is now imposing on us severe cold days and severe hot days, so the electricity very likely will go up. The developers of nuclear reactors talk about it being competitive. Competitive with renewables, nuclear has a unique situation compared to other power sources, it's high capital costs, low operating costs. The fuel is reasonably cheap and lasts for a long time. So once you build a reactor, you essentially build in the costs of operation." Historical reference cases for electricity prices post-SMR operation can start to materialize once OPG has started operating their SMR. The other economic consideration is the upfront costs of construction, so the approximate CAD 5 billion it will take to build SaskPower's SMR. If during the operation phase, there are additional costs required from unforeseen sources that make operating the SMR unaffordable, then that is another point that may cause SMR failure. However, there does seem to be a level of confidence in the funding at this point, especially from [SaskPower employee]. SaskPower does have the benefit of being linked to the government and in a sense represents the success of the government. With a private company, the funding strategy is less flexible and a failure of the private company reflects only on them. With a Crown Corporation, there is provincial support and certain levels of federal support, and the Government of Saskatchewan is invested in its success as they are indirectly the power providers of the province. This creates flexibility and a longer repayment period, as [SaskPower employee] mentioned which is overall an indicator for success. It is hard to predict whether SMRs will succeed or fail from an economic perspective as they don't truly exist yet, but if the finances become too strained and electricity prices are unaffordable then the SMR will fail and if the financial capacity of SaskPower is adequate, then SMRs will succeed.

4.4.3.3 Social

Social approval and support will continue to depend on public engagement and international nuclear events. In terms of previously mentioned population growth, it seems unlikely that the population of Saskatchewan will shrink enough for SMRs to become unnecessary based on the growth trends of the last 80 years. Social approval, however, may sway with electricity prices, how SaskPower is engaging with the public, Indigenous relations, and the affect SMRs have on surrounding communities. [Alex] commented specifically on Indigenous relations, "Wherever you go in Saskatchewan, and wherever you go in Canada, you are going to be dealing with issues of indigenous rights and title…The CNSC will call them on that so even if the non-Indigenous population is still pro-nuclear, if they mismanage relations with local Indigenous people they face decades of legal challenges potentially the disruption of the whole program." Social approval has been improving over time and as long as SaskPower is transparent and does their due diligence in engaging with the public and respecting the feedback then there likely will continue to be support from a majority of the public. Nuclear disasters or even environmental effects from operation may decrease support however which in turn can cause the SMR to fail. It is hard to predict whether that will happen of course, and there are countless ways in which nuclear and environmental disasters are being avoided in the design and licensing processes. Based on the trends it seems that social support will continue to be on the same side as SMRs which will lead to SMR success.

4.4.3.4 Technological

Likely one of the largest concerns with nuclear technology is the safety aspect and from various professionals' points of view, the supply chain of SMRs is a consideration that could greatly affect the viability of operation as well. Nuclear disasters are some of the most prominent and remembered events in the field of power production, likely because of their direct effect on humans. Canada has had five nuclear incidents resulting from both human error and the technology in 1952, 1958, 1983, 1994, and 2009 (Government of Canada, 2021b). In three of the five cases, the fuel rods were at fault as they overheated or ruptured (Government of Canada, 2021b). In 1994 a pipe break in Pickering led to a loss of coolant heavy water, however systems activated emergency cooling of the reactor core (Government of Canada, 2021b). In 2009, human error led to a large amount of water with trace amounts of the radioactive isotope of hydrogen, tritium, to be released to Lake Ontario, but it was not to be a risk for residents (Government of Canada, 2021b). Clearly there is a chance for a nuclear accident with SMRs, but the technology is also designed with this in mind. Unless something disastrous happens that harms humans or the surrounding environment, it is not likely that the SMR will be shut down. As was mentioned in Section 4.2.4, the BWRX-300 technology is a model of reactor that Canada has not dealt with before. The fuel needed for the BWRX-300 cannot be directly supplied by Canada without being enriched by a different country. Saskatchewan uranium will have to be sent to the US or Europe to be enriched and then imported back to Canada and transported to Saskatchewan. This amount of transportation and international cooperation can create supply chain issues which will in turn affect operability of the SMR. The positive side to SMRs is that they only need to be refuelled every 1 or 2 years which decreases the chances of not being able to access the fuel they need. The unfortunate part is that there is a Covid-19-like event that disrupts and slows down supply chains internationally, a lack of proper fuel will lead to the SMR being shut down and effectively "failing," even if temporarily. But as long as the supply chain is stable and there are no impactful nuclear accidents, then the SMR will continue to operate.

4.4.3.5 Environmental

The environmental aspect to SMR success has already been touched on a bit in terms of environmental damage from nuclear accidents. Any degree of nuclear accident that harms the environment could warrant a certain amount of public backlash that would affect the success of the operation phase. It somewhat depends on the public's priorities and how much they care for certain environmental features such as water sources, critical species or habitats, soil, etc. There is likely a chain of impact that determines how much an accident will garner public attention. An example of this is the difference between destruction of a rare and endangered plant species versus contamination of a water source. Contamination of a water source directly impacts people much more than the disappearance of a critical plant species, and therefore their reaction will be different. A concern about water sources specifically has been vocalized by community members in both the Elbow and Estevan area. Lake Diefenbaker, Rafferty Reservoir, and Boundary Dam Reservoir are the lakes that are proposed to be used as the necessary water source for SaskPower's SMR. Lake Diefenbaker residents are concerned with the water quality as Lake Diefenbaker is a drinking water source for many Saskatchewan residents (SaskPower, 2022). Residents of the Estevan engagement session have expressed concern for water quality and temperature in the Boundary Dam reservoir because of bass fishing and ice fishing (SaskPower, 2022). If an SMR in either location was to seriously disrupt the quality of water so much that it impacts surrounding residents and communities, the public backlash might be enough to shut down the SMR. The storage of nuclear waste plays into this as well, not just the physical SMR itself. Nuclear waste needs to be handled in such a way that there is not radiation leakage or contamination of the environment.

There are clearly many aspects and considerations when assessing the conditions that may lead to success or failure of SMRs. The decision in 2029 will likely result in SaskPower choosing to move forward with SMR construction, unless OPG is facing great difficulties with their initial reactor. During the construction phase, the most influential conditions for failure would be overruns of the budget or a nuclear accident occurring that turns the social support tide away from nuclear power. Canada has a pattern of finishing their reactors, however, so based purely on reference cases, SMR construction will be a success. And once a hypothetical SMR is in the operation phase, electricity prices and the presence or absence of adverse nuclear incidents on people and the environment will determine the success of failure of SMRs.

5 Discussion

5.1 Socio-Political

The findings in the results regarding the political and social aspects of the PESTE framework reveal how political maneuverings are often closely linked to social dynamics. Society shapes the politics that represents them and therefore, political decisions must be informed by the people they represent. As was discussed in Section 4.2.1, the three main political parties at the federal and Saskatchewan provincial levels are not against nuclear power and are in favour of maintaining or increasing the number of nuclear projects. In a sense, there is political consensus about the stance on nuclear power. There is not, however, consensus on phasing out coal and subsequent fossil fuels. The Saskatchewan Party has taken a sort of middle ground by acknowledging they will phase out coal, but it likely will not be by 2030, and they are considering building an SMR as a replacement for the coal. The Liberal Party of Canada asserts the role of nuclear in a clean energy future and is the party instigating the coal phase out. The NDP will likely maintain whatever course of action in terms of coal phase-outs and nuclear, if they ever become the majority party. The Conservative Party of Canada, however, is not supportive of the coal phase out (Conservative Party of Canada, 2023). SMRs are being seen as an addition to coal instead of a replacement. Adding SMRs but maintaining coal will likely not lead to emission reductions under a CPC government. This is somewhat representative of Saskatchewan as there is a growing support for nuclear as a replacement for coal power, but coal communities such as Estevan are more likely to disagree with that sentiment. But at the same time, there is some acknowledgement from coal-communities like Estevan that nuclear can provide an alternative to coal that will sustain their job force and hopefully lead to a healthier environment. As the Saskatchewan Party is a conservative political party and is closely aligned in values with the CPC, it will be interesting to observe whether their commitment to a coal phase-out and nuclear "replacement" will remain if the CPC becomes the next federal governing party, assuming the Saskatchewan Party also remains the provincial majority.

There is a greater ease in building nuclear power which, in the case of SMRs, can be argued both as an old technology or a new technology, as opposed to phasing out coal. This could be because building something portrays opportunity and growth whereas shutting something down leaves people without jobs and could eventually end a sector of economic opportunity. There are various reasons as to why the CPC strongly supports coal and nuclear power. They are both centralized power sources which keeps energy distributors, many of whom are government-run, in charge and profiting. They both capitalize from the mining sector in Canada, and specifically in Saskatchewan. Some of the strongest supporters of the CPC are in the provinces that produce Canada's fossil fuels, so the CPC would not want to jeopardize their support. The CPC is also arguably the least committed to GHG emission reductions and acknowledging the harmful environmental impacts of the fossil fuel industry. This can lead to a general passiveness about the concerns regarding nuclear power, particularly regarding radiation risks to humans and the environment. If the upcoming elections result in a CPC government, then SMR projects will not be affected, but GHG emission rates will probably not decrease.

There are strong arguments stemming from the anti-nuclear side of the conversation that raise the issue of radiation risks, waste, climate goals, and finances. Nuclear power is accurately associated with the radiation and waste it produces, but it is interesting to see how different sides of the narrative approach it. On the anti-nuclear side, toxic waste is something that has not been well managed in the past and probably won't be well managed in the future because politicians do not want to deal with it. Communities are at risk of becoming toxic waste dumps and the amount and severity of the waste that has been and will be generated is not worth building more nuclear power. On the pro-nuclear side, nuclear waste is dangerous and therefore the regulations for it are very strict and management takes all of this into account. Spent nuclear fuel has been maintained within the facilities where it is generated and will be able to for decades to come. There is no acknowledgement about leaking or dumping toxic waste from the pro-nuclear side, for likely obvious reasons. An example of the different conceptions of nuclear waste in terms of SMRs comes from my interviews. Multiple interviewees were skeptical about how the waste was going to be handled and raised concern about its mismanagement. The two pro-nuclear interviewees were quite confident in the plans for nuclear waste management, which would imitate Ontario's plans of storing it on-site until a DGR was created, and expressed that the raw amount of spent nuclear fuel was minimal and had usefulness even after being defueled compared to something like chemical waste. They both emphasized the strict regulations from the CNSC and NWMO regarding funding for waste management and how waste is handled. There is either a lack of transparency from SaskPower about their waste management plans, their information is not reaching certain audiences, or people on the anti-nuclear side have recognized their plans and still find it inadequate. Radiation risks are similarly approached where professionals in the nuclear industry assert that there are very little radiation risks from operation and waste management but acknowledge that in the face of a nuclear accident where radiation escapes, the nuclear industry will be threatened. The anti-nuclear voices that were represented in my research say that the risk of radiation from leaks or waste are too threatening to count nuclear power as a solution.

Another disagreement between the pro- and anti- nuclear sides is the role that nuclear plays in achieving GHG emissions reduction targets and whether SMRs will be financially viable. The Green Party is a big proponent for alternative solutions for a clean energy transition, including national grids, energy storage technology, and more renewable sources. Specifically in Saskatchewan, renewables are not necessarily being pushed to the side as there are plans to build 700-3000 MWe of energy from wind and solar, but the financial commitments seem larger for SMRs. National grids are achievable but will likely take just as long as a NPP to retrofit and build, and they don't directly tackle the hole that will be left from a fossil fuel-phase out. Connecting a national grid will also likely require just as much, if not significantly more, financial investment to create. Energy storage technology is progressing and could be a viable solution, but will only decrease GHG emissions when paired with low-carbon energy sources that produce a surplus of energy. Objectively speaking, the nuclear solution and alternatives solutions are both viable, but both require lots of time and money to implement. That's why the reasoning behind why the Government of Saskatchewan and SaskPower have chosen SMRs as a solution, possibly over alternative solutions, is so relevant.

5.2 Economics and Ownership

The results regarding the economic aspect of the PESTE framework show how critical the financial strategy and stability of SaskPower is to the success of SMR implementation. And yet, three of my interviewees expressed that they did not know where the money was coming from for SaskPower's SMR project. In a highly capitalistic society such as Canada, it is no wonder that money plays such a major role in the viability of projects, no matter how vital they may be. The projected construction costs for Saskatchewan's first SMR are extremely high, especially when compared to other energy projects of similar or higher power capacity. It was surprising that most people I interviewed or sources I researched did not know where the projected CAD 5 billion was going to come from. The SaskPower employee I interviewed was quite transparent with how it would be funded, but this transparency does not seem to have carried over to the public, or even researchers and professionals in the field. People are aware of the millions of dollars that have been granted to Saskatchewan already for the research of SMRs, but not how the SMR construction will actually be paid for.

The finances need to be secured for both construction and waste management for SaskPower to be able to initiate construction of the SMR. Money plays a huge role in the success or failure of SMRs, from both a construction point of view, but also an electricity price point of view. If electricity prices post-SMR jump up much higher than they were, then there is serious risk of SMRs failing before there is a chance of economy of multiples to take over. There were also concerns from interviewees about budget overruns from delays, which will end up in a loss of lots of money and no energy source. What makes SaskPower confident in their financial strategy is the secure lending system backed by the provincial government. State-owned utilities, or in this case province-owned, can usually implement a new or risky technology easier than private utilities and handle financial hurdles with more leniency. And this is such the case with SaskPower, where the price tag on an SMR is big and possibly a deal-breaker, but because they have the financial and political support of the provincial government at the moment, there is less of a chance that the finances will cause the SMR project to be a failure. In this sense, if there is a will there is a way, but at what cost to the electricity rate payers?

5.3 Technological and Environmental

The results from the technological and environmental aspects of the PESTE framework are closely linked, mostly through adverse causes and effects, but also through the role SMR technology will play in combatting climate change. Notably, the proposed expansion of nuclear power in Saskatchewan does not contradict the expansion of wind or solar power. SaskPower plans on increasing solar and wind capacity by at least 700 MWe in addition to the 300 MWe of initial proposed nuclear power, which can be interpreted as them taking a fossil fuel-phase out seriously. Nuclear will form the baseload along with lingering natural gas while solar and wind create the excess, or cover SMR refuelling periods. The role of nuclear in decreasing carbon emissions is debated, but also generally supported by government and international organisations like the IAEA, the United Nations (UN), and many national governments. Nuclear also has one of the smallest, if not the smallest, carbon footprints out of non-fossil fuel technologies. The adverse aspects to nuclear technology are the spent nuclear fuel and possible accidents. Both have the potential for harmful effects on humans and the environment. Uranium mining at the beginning of the nuclear cycle is a concerning industry. Radon emissions and water contamination are huge risks for humans and the environment. During nuclear reactor operation, water is used for cooling and although there is a very small chance that water would become contaminated, warm water is deposited back into the original source which can disrupt the aquatic ecosystem. Spent nuclear fuel is recognized for its danger and is managed and housed accordingly. There have not been any accidents in Canada regarding spent nuclear fuel and leakage, but the transport of nuclear waste to a DGR could cause issues for safety in the future. There is also the fact that the spent nuclear fuel will remain radioactive for hundreds to thousands, if not more, years. Decommissioning nuclear facilities requires care for the environment it inhabits so that radioactivity does not spread past the exclusion zone. It's an environmentally challenging process, so it is critical that reactor designs continue to meet and exceed CNSC safety standards to negate any potential harms to humans or the environment.

5.4 Optimism and realistic expectations

A unique occurrence during this research has been the optimism from SaskPower concerning their financial strategy and timeline. SMRs are a new technology in the sense that OPG is building a FOAK reactor and some companies are pursuing this size of reactor for the first time. Simply looking at the price tag of a new SMR compared to a conventional reactor would likely deter a company from making such an investment. When one looks at one of the most recent wind projects in Saskatchewan, the Golden South Wind Energy project, that has a 200 MWe capacity for only CAD 340 million, it begs the question as to how necessary nuclear is as a base load. For the projected price of CAD 5 billion, one could build another 2,600 MWe of wind energy. There needs to be energy diversity for stability and affordability, but it seems that affordability is slightly threatened when discussing SMRs. For SaskPower to be preparing for such an expensive project means that they have confidence and financial backing from a reliable source that can help them spread the repayment over so many years that the electricity prices hopefully don't increase much.

There is also a sense of confidence in the aggressive timeline for Saskatchewan's SMR. OPG has just started to prepare the site and yet projects to have the reactor up and running in 4 years. For an industry that usually has setbacks, it seems like a tight schedule, especially for a new technology. However, at the moment, there have not been any delays that would affect SaskPower, so in that sense the confidence makes sense. Realistically speaking, there will likely be setbacks in the timeline, and depending on how conservative the budget estimation is, there will be cost overruns. The confidence in the financial strategy does not sway everybody as there are still skeptics that think that an SMR will never get off the ground for the simple sake of it being too expensive. The voice of the majority presently is supportive of nuclear power but there will always be an opposition advocating for the health and safety and financial stability of the environment and people. If SaskPower maintains good relations with the public, if the majority of people continue to support nuclear, if the technology has the proper safeguards, if funding is adequate and stable, and if there are no nuclear accidents, then SMRs in Saskatchewan stand a chance of succeeding.

6 Conclusions

Canada, responsible for about 1.4% of global emissions, has proportionally high per capita emissions, primarily from its energy sector. Despite a national electricity mix dominated by low-carbon sources, significant regional disparities exist where some provinces like Saskatchewan are still reliant on fossil fuels. The consideration of SMRs by SaskPower as a possible low-carbon electricity source has sparked both criticism and hope. SMRs face great uncertainty as a new-to-Canada technology. The reasoning for SaskPower's selection of SMRs is questioned, the proposed timeline for SMRs is slow in the face of climate change, yet fast for an untested new technology, and the success of SMRs depends heavily on its economic standing and public support. A successful implementation of SMRs in Saskatchewan may be just what the province needs, or it might be more trouble than it's worth.

The aim of this research was to supply a deeper understanding of the process and factors by which an emerging nuclear technology, specifically SMRs, are selected as an energy source and assess the subjective factors regional to Saskatchewan in whether SMRs will succeed through different stages of implementation. The three research questions that guided my research were:

1. Why has nuclear power been selected as a potential low carbon energy source solution for Saskatchewan?
2. What is the realistic timeline for implementing nuclear energy and is it in line with SaskPower's foreseen timeline?
3. Under what conditions might nuclear power succeed or fail in Saskatchewan?

6.1 RQ1

In exploring why SMRs have been selected by SaskPower as a potential low carbon energy source, I found that financial sustainability, emission reduction goals, and energy stability, are the three main criteria. SaskPower is a monopoly and its revenue comes from its clients. It is financially motivated to maintain a centralized grid where residents are reliant on SaskPower for their energy needs. Alternative energy solutions like micro-grids and smart grids challenge the perceived right of SaskPower to create energy within the province for its residents, which is one of the reasons SaskPower is investing so heavily in an option that maintains their monopoly. Direct answers from [SaskPower employee] substantiate that SaskPower is committed to reducing their carbon emissions, and while implementing nuclear may not do that directly, the real strategy to do so is to phase out their coal power, and eventually natural gas, and SMRs can be the low-carbon power source that replaces them. SaskPower is not opposed to renewable sources of energy, in fact they are planning on increasing the power capacity through renewables significantly more than that of nuclear, but energy stability is extremely important. Renewables are known for their intermittency, and providing an entire energy grid out of a limited kind of variable sources can result in an energy crisis. Nuclear power can be the baseload that Saskatchewan requires while generating investments in renewables.

6.2 RQ2

The main takeaways from SaskPower's projected SMR Project Schedule Timeline are the decision point in 2029, licensing periods, and the construction period leading up to operation in 2035. Some criticisms of SMRs highlighted that even without delays or setbacks, this project won't be operational for another decade which is unhelpful for the required clean energy transition. Objectively looking at the timeline, though, shows that it may be ambitious and both in the licensing stages and construction stages. There are very little reference cases to compare SMRs with so OPG's reactor will have to set the Canadian standard. An environmental impact statement is already delayed for Ontario's micro modular reactor, and likely SaskPower's licensing process will be at least slightly delayed as well. It may not affect the decision point in 2029, but the site prep and construction period are also vulnerable to delays. Realistically, there will likely be setbacks along the way and unless SaskPower can expedite the construction process, 2035 is a bold estimate for when we can see SMRs in Saskatchewan.

6.3 RQ3

The success or failure of SMR implementation is assessed through three checkpoints: the decision phase, the construction phase, and the operation phase. Success in the decision phase is characterized by SaskPower deciding to initiate site prep and construction of an SMR. The largest factor that would affect this stage is the success or failure and general experience of OPG's SMR. Timeline setbacks or large budget overruns in OPG's project are the two most likely reasons why SaskPower's proposed SMR would fail before it even truly gets started. In the construction phase, the most influential factors would be economics, public support, and nuclear incidents. If budget overruns become too overwhelming, or if for some reason there is not initially enough money, then the SMR could foreseeably be abandoned mid-construction. Public support for nuclear is growing but can waiver and fail, and if that happens then the electrical utility of the people cannot implement a project that the people are against. Nuclear accidents are memorable events, big or small. If something, even internationally, happens that turns the tide of the public, then construction may be abandoned. Additionally, if during construction an ecosystem were to be contaminated or people's health was put at risk, then that could also lead to the SMR failing in the construction phase. And lastly, in the operation phase, the subsequent electricity prices and nuclear effects on people and the environment are the guiding factors to SMR success or failure. If electricity prices become too high then residents will demand a more affordable source of energy. And similarly to other phases, if the SaskPower SMR has an incident that effects a critical ecosystem or human health, then there will likely be strong repercussions for the SMR operation.

6.4 Reflections

There is a large degree of interconnectedness that economics and the risk of nuclear accidents have with public approval. When determining the conditions for success or failure for an SMR project, especially with a public utility, the support of the customers one serves is vital. This support is gradually increasing, which is good news for SaskPower, however there are international examples of nuclear incidents causing anti-nuclear sentiments to flare and projects to be abandoned. Canada has a consistent track record of finishing their nuclear projects, however, there is a first time for everything. As the cost-of-living crisis is on every Canadian's mind, the risk of nuclear creating a more expensive and unaffordable kind of electricity becomes a prevalent issue. Fossil fuels are comparatively cheaper, renewables are cheaper and are steadily decreasing in price, so the economic case for SMRs becomes harder to defend. But even if SaskPower has the money, the people it serves do not.

Canada has consistently set an example for the rest of the world when it comes to nuclear technology. Successfully implementing SMRs and reducing GHG emissions could be an addition to that reputation. And on the flipside, a failure could set the tone for the rest of the world as to the infeasibility of SMRs. Some say that the benefits of nuclear power do not outweigh the risks and negative effects, and this narrative too, could set a global example depending on the outcomes of both OPG's and SaskPower's SMR projects. There is a huge potential for energy in Saskatchewan to have global impacts, whether that be good or bad.

From the results of the conducted interviews, it was striking and informative, to hear and resonate with both sides of the nuclear argument. The neutrality of this research is important so as not to diminish one voice for the sake of the other. There are strong and justifiable concerns regarding the past and potential effects on humans, the economy, and the environment from nuclear technology. At the same time, there are stakeholders involved directly in the business, which understandably can introduce bias, who tout the extreme precautions taken and the safety of the technology yet do not undermine the devastating effects a nuclear accident can exact. The aim of this research was not to conclude whether an SMR would be beneficial or harmful for Saskatchewan and its residents, however, it is something that someone will perhaps think about while reading this. I believe this research has answered its designated research questions and will hopefully encourage its audience to think about the topic further.

6.5 Policy recommendations

The most recurrent recommendation from my interviewees is for ongoing public engagement to ensure good customer and Indigenous relations. This stems from both a duty-to-consult and building trust and transparency between the public and SaskPower. It is also beneficial to SaskPower because they can easily and quickly gauge public concerns and approval trends which they can then address in a positive way.

There seemed to be a lack of information about the financial strategy of SaskPower's proposed SMR project. The information was revealed to me through an interview, but none of the other professionals I interviewed that were not directly involved in the process knew how an SMR was going to be funded. This is a common occurrence in public utilities compared to private utilities. Going forward, a level of transparency as to how energy projects are going to be funded should be ensured either through regulations, or voluntarily by SaskPower and enforced in their corporate policies. This builds trust and communication between the company and customers, or even researchers, and allows for more feedback from customers who will likely be directly affected.

A new uranium supply chain will be required for the BWRX-300 reactors as they require enriched uranium and Canada does not have the facilities to do that. Although it may be ambitious to invest in enrichment facilities initially, depending on the trajectory of SMRs in Canada it may be required down the line. As the enriched uranium will be coming from the US or Europe, it is recommended that political collaboration is discussed in order to get the most affordable enriched uranium until such a time that Canada can enrich it ourselves. In other words, international policies should be negotiated and put in place to economically benefit stakeholders in the enrichment supply chain.

Lastly, there is a large amount of employees in the coal industry and natural gas industry that will eventually be out of a job should the fossil-fuel phase out be successful. Some of these people will not have training or a profession to fall back on, and should therefore be offered the chance to be retrained, for free, for entry into a green job, that is a job that contributes to a more healthy and sustainable world. A clean energy transition should be beneficial, even for the employees in the fossil-fuel industry. The Government of Saskatchewan and SaskPower should create green job transition policies and programs for displaced employees in order to maintain loyalty and trust and a more sustainable workforce.

6.6 Future Research Recommendations

There were many proposed benefits to SMRs in addition to low-carbon electricity generation that should be explored in the future. Saskatchewan is a province that reaches extremely cold temperatures in the winter months. Research on the viability, both technology- and economic-wise, of SMRs for heating purposes could help reduce reliance on fossil fuels in the province. Comparing life cycle emissions of SMRs compared to conventional reactors would help create a better picture of which low-carbon technology has the lowest carbon footprint, which can then be used to inform decision-making processes when choosing a clean energy source. Business partnerships with Indigenous groups have also been suggested, so dedicated research into the social benefits of SMRs for Indigenous economics would help create a stronger incentive for collaboration. The impact of inflation or shipping disruptions have on construction materials which would subsequently impact the price of SMR construction should be investigated as economics play such a large role in the success of SMRs. Small modular reactors are a new technology to Canada and their attributes and effects, both positive and negative, create a large research space to fill in the future.

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Appendices

Appendix 1: Interview Protocol

RQ 1: Why has nuclear power been selected as a potential low carbon energy source solution for Saskatchewan?

RQ 2: What is the realistic timeline for implementing nuclear energy and is it in line with SaskPower's foreseen timeline?

RQ 3: Under what conditions might nuclear power succeed or fail in Saskatchewan?

<u>Description of the research project:</u>

As a resident of Saskatchewan, I am highly invested in our sustainable future, which includes the energy future of the province. Saskatchewan and Canada have various climate goals they are trying to meet and SaskPower has proposed small modular nuclear reactors as an alternative to at least a portion of the province's fossil-fuel-powered electricity. I am interested in discovering why they have chosen such a controversial and expensive technology, whether their proposed timeline is accurate or whether they will face classic setbacks, and whether SMRs will be successfully implemented in Saskatchewan.

<u>Purpose of the interview:</u>

I am hoping to gain more insight into my research questions by asking you, someone who has dedicated a significant amount of time to the topic, in order to understand the research scope more deeply. Often professionals can offer up information and expertise that is not readily available in open access web sources.

General Interview Questions (not all questions were always asked, and some different ones were asked in the spur of the moment because it is a semi-structured interview process):

- Reasons for selecting nuclear power / SMRs
    - What was the main reason/goal of deciding to build nuclear/SMR in SK?
    - What other alternatives were considered to achieve these goals?
    - Who advocated for and against nuclear/SMR?
    - Why was nuclear/SMR chosen?
        - What criteria were used (e.g. cost, time, availability, performance, environment, reliability)?
        - What was the decision-making process/timeline/participants?
- Implementation strategy and timeline
    - How was the timeline indicated in XXX established?
    - Do you think the timeline indicated in XXX is realistic?
    - What do you see as the main barriers and risks for implementing nuclear power on this timeline
- Potential risks and barriers
    - Political

        - What are some legislation and policies that would have to be implemented in anticipation of nuclear power?
            - Is there adequate capacity within existing institutions to support the transition from coal to nuclear?
        - Are there any potential broader regulatory changes that present risks/opportunities for nuclear power?
        - Can changes in political parties (in power) affect nuclear success or priorities and if so how?
    - Economic
        - What can be economic risks to timely implementation of the nuclear plans in SK?
            - Is there a risk of lack of financing? How is the construction and operation of nuclear power facilities financed?
            - Is there a risk of nuclear being unprofitable and leading to economic problems of SaskPower?
            - Is there a risk of raising electricity prices in SK and can this affect the implementation of nuclear?
            - What can be other economic risks and opportunities of introducing nuclear power (e.g. GDP growth, SaskPower profits; employment)
    - Technological
        - Can nuclear waste disposal or other technological issues present risks in implementing the project.
    - Environmental
        - What do you think may be environmental risks that can affect the implementation of nuclear power plans?

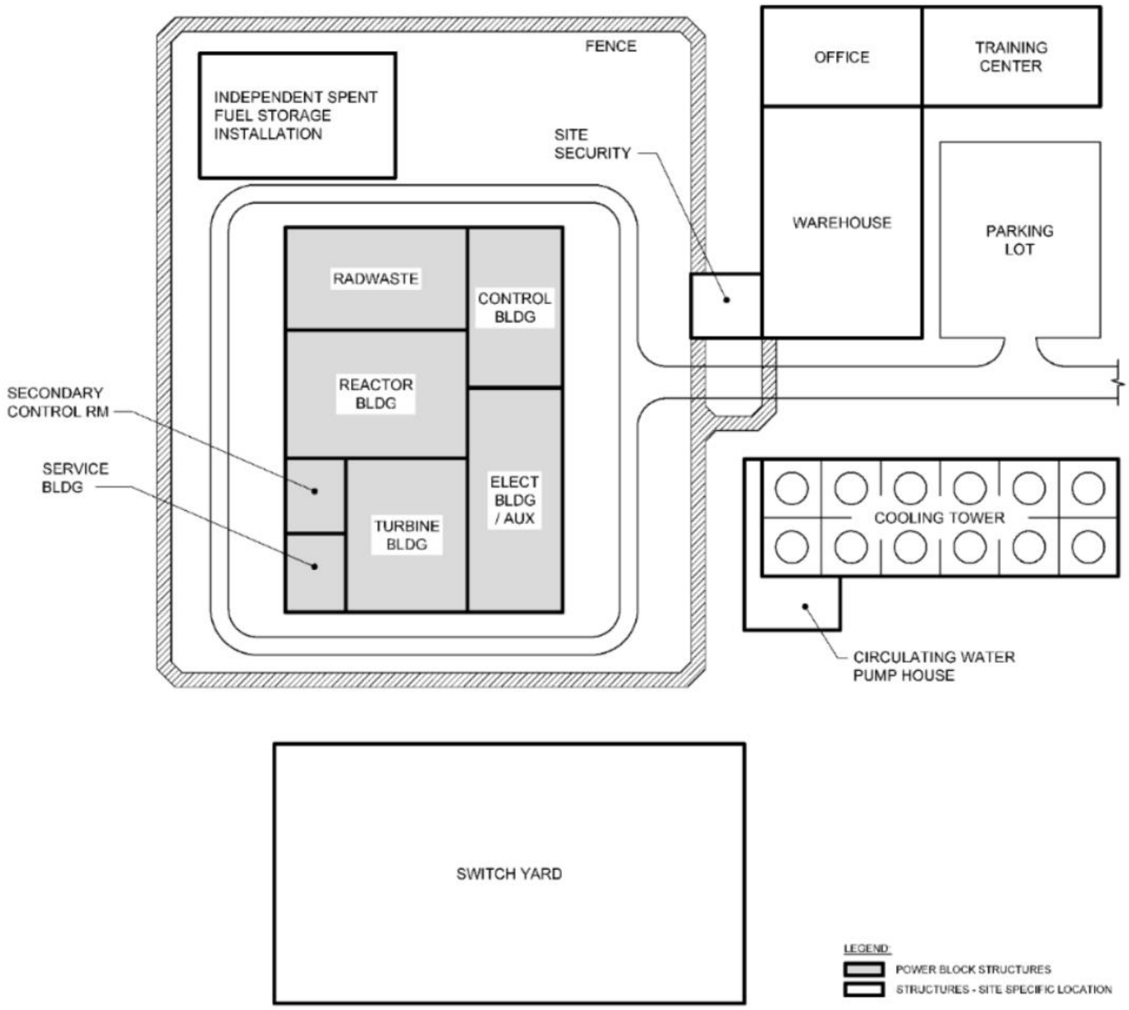
Appendix 2: Interviewee Table

Interviewee Code Name	Relevant expertise	Gender	Stance
Civilian	Layperson	Female	Against
Willow	Academia	Female	Against
Annie	Academia	Female	Neutral
Alex	Academia	Male	Neutral
Nick	Academia	Male	Supportive
SaskPower employee	SaskPower Employee	Male	Supportive

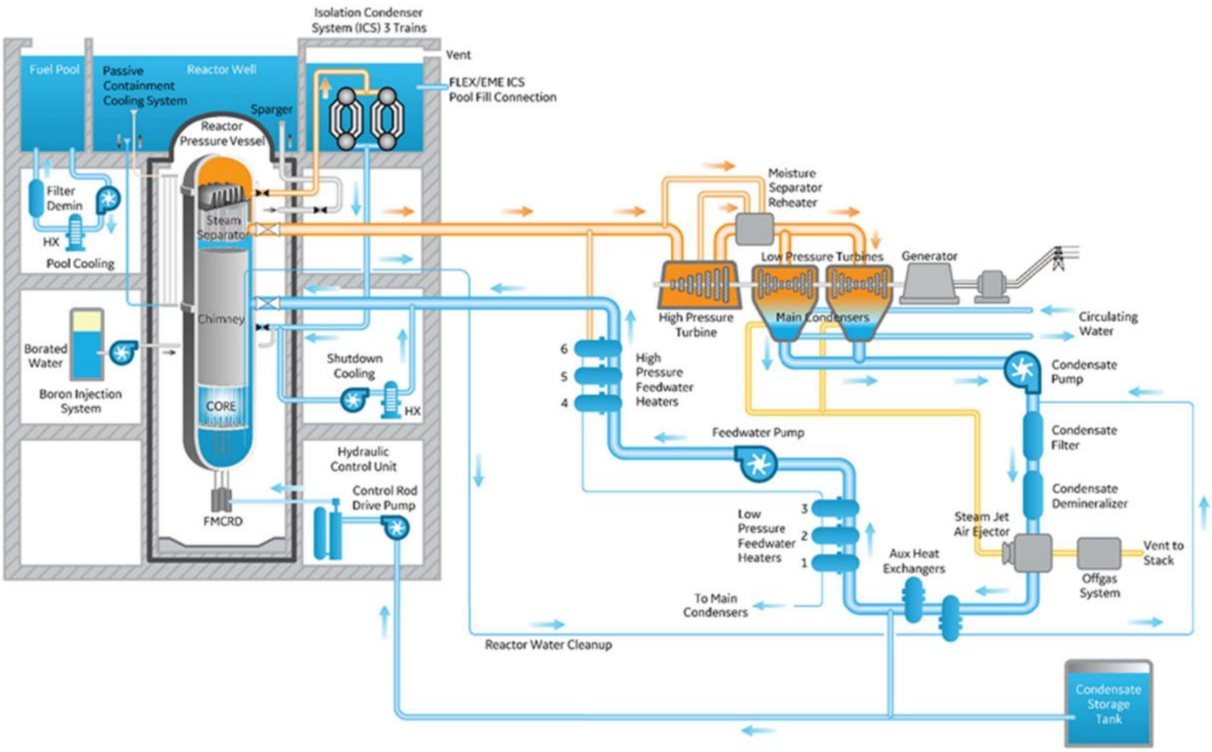
Appendix 3: Canadian Political Parties and their Platforms

Party	Commitment to phasing out fossil fuels	Stance on nuclear power
Conservative Party of Canada (CPC)	"We continue to support hydrocarbon exploration, pipeline construction, transportation efficiencies and plant improvements to increase energy conversion efficiencies and reduce pollutant and greenhouse gas discharges" (Conservative Party of Canada, 2023). So not committing to phasing out fossil fuels.	Pro-nuclear energy (Conservative Party of Canada, 2023)
Liberal Party of Canada (LPC)	Eliminating thermal coal exports, phasing out fossil fuel-heating, eliminating fossil fuel subsidies, recognizes that a coal phase-out is necessary and decreasing emission from the fossil fuel sector is necessary (Liberal Party of Canada, 2021). However, the liberal government has purchased a pipeline to transport fossil fuels and has increased fossil fuel subsidies within the past 6 years (Green Party of Canada, 2021).	Pro-SMRs, although it is absent from their platform documents (O'Donnell & Edwards, 2021)
New Democratic Party (NDP)	"We will fulfill Canada's G-20 commitment to eliminate these fossil fuel subsidies and redirect these funds to low carbon initiatives, and make sure that future governments can't reverse this by putting in place legislation to ban any future oil, gas and pipeline subsidies" (New Democratic Party of Canada, 2021).	Believes in halting nuclear expansion, however platform is not always clear on nuclear funding, and different NDP representatives have different stances on nuclear energy's role in Canada's energy future (O'Donnell & Edwards, 2021; Zinchuk, 2022).
Bloc Québécois (BQ)	Supports a green energy transition, demands an end to fossil fuel subsidies, against oil transportation projects, supports phasing out fossil fuels (Bloc Québécois, 2021).	Anti-nuclear energy (Bloc Québécois, 2021)
Green Party of Canada (GPC)	"End all production of fossil fuels" (Green Party of Canada, 2021). Supports phasing out fossil fuels, including transitioning fossil fuel-jobs to green jobs.	Anti-nuclear energy (Green Party of Canada, 2021)
Saskatchewan Party (provincial party)	Is not mentioned in official platform, based on research they will phase out fossil fuels on their own timeline, as motivated by the current federal government. They may not want to but they kind of have to.	Pro-nuclear energy (Saskatchewan Party, 2020)

Appendix 4: Technology Diagrams



BWRX-300 Plant layout example (IAEA, 2019)



BWRX-300 Reactor Diagram (GEH Nuclear Energy Americas, 2022)