Hugo Chia Yong Zhi, A<Redacted>L
Ericia Chay Yen Yee, A<Redacted>A

Nuclear Power and its Feasibility in Singapore's context

1. Research Question

This report seeks to explore "How feasible is adopting nuclear energy to meet Singapore's energy needs and advance Singapore's goal of net-zero by 2050?"

2. Research methodology and framework

This report uses the PESTLE (Political, Economic, Social, Technological, Legal and Environmental) framework to aid with the analysis of the feasibility of nuclear power. Although the PESTLE framework is mainly used by businesses to gain a macro picture of an industry environment, it has been adapted for use in this context, given its clear and structured way of analysing macro trends.

3. Introduction

The global energy crisis (2021 - Present) was in part due to 1. Supply side shocks from the reopening of economies worldwide post-pandemic 2. Climate change induced impact on renewable energy, such as dams producing lesser energy (Murtaugh and Ding, 2022) 3. The ongoing Russian-Ukraine War in Europe 4. The lack of investment in oil exploration and pipelines in recent years. (International Energy Agency, n.d.)

Additionally, Singapore is currently exploring tapping Nuclear energy by 2050 and is 1 of 3 pathways Singapore could take to achieve net-zero by 2050. (MTI, 2022)

4. Advantages of nuclear energy

4.1 Nuclear as a strategic importance to "Energy Independence"

Energy is weaponized amidst the Russian-Ukraine War. Gas supplies from Russia to several European countries are cut. (REUTERS, 2022) European countries are facing massive socio-economic costs from their dependence on Russia's natural gas.

This shows that there is a need to study whether Singapore can gain "Energy Independence" or be self-sufficient in energy. Singapore has done so with water by having NEWater and desalination plants. We are ensuring food security with the "30 by 30" plan.

Presently, 95% of Singapore's electricity is generated using natural gas. (NCCS, n.d.) Although natural gas is the cleanest form of fossil fuel, they are non-renewable energy and produce carbon emissions. Traditionally, Singapore imports natural gas from Malaysia and Indonesia (Sumatra and Natuna Gas fields) through pipelines. (EMA, n.d.) Since 2013, Singapore has been diversifying its sources and has started to import liquified natural gas (LNG) from countries such as Australia, the United States and Qatar. (EIA, 2021) This current arrangement still poses risk to Singapore. In the event of a conflict, there is a possibility gas supplies to Singapore are cut. The risk of an incident (civil accident or military conflict) occurring in the Straits of Malacca or South China Sea which could hinder supplies of LNG reaching Singapore remains high.

Singapore needs to have an independent, self-sustaining source of energy to meet its energy needs. Nuclear energy provides an alternative to Singapore. It helps Singapore to diversify its energy mix, while reducing its reliance on other countries. This can be achieved by having small-scale nuclear reactors that are deployed in Singapore for electricity generation.

4.2 Socio-economic Impact

Energy is essential to support the stability and sustainable development of our economies and society. In Europe, soaring energy prices have led to 1. Business going bankrupt (Liz Alderman, 2022) 2. Fertiliser prices spike, threatening a food crisis (Gebre & Elkin, 2022) 3. Inflation in Europe hitting decade highs. (Randow, 2022; European Central Bank, 2022) Studies have also shown that rising oil prices usually preceded most recessions. (L. Kliesen, 2001) Energy impacts all aspects of society, and thus Singapore should wean itself away from fossil fuels.

Singapore cannot insulate itself from the volatilities in the global energy market and will face pressures from rising energy costs. By adding nuclear energy to its energy mix, Singapore can build more buffers and shield itself from price shocks as it is not subjected to the demand-and-supply of global energy. Singapore is currently not an energy producer, but it can aspire to be one. The government (MTI, 2022) has acknowledged that the protracted energy crunch has highlighted the need to make Singapore's energy systems more resilient and less susceptible to fuel supply shocks.

Countries in Europe, such as Germany, are postponing plans to shut down its nuclear plants, given the energy crunch. (Eckert & Marsh, 2022) Shutting down operational plants during an energy crisis is akin to self-sabotage. The need remains in the short term for countries to keep their nuclear plants online, for price stability of energy. The reason for shutting down such plants has a history which can be traced to the 1980s Chernobyl accident which changed public perception. (World Nuclear Association, 2022) Psychological resistance to nuclear energy will be further discussed in section 5.1.

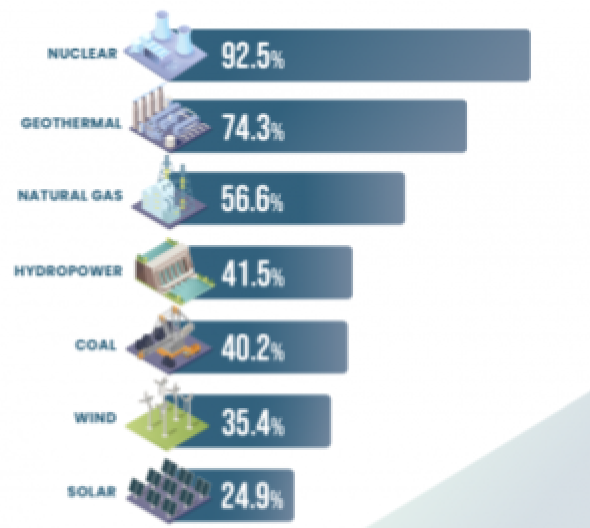
Socially, stable energy prices are a net positive for society. Large scale protests have been taking place across Europe as anger mounts over soaring energy prices and costs of living. This could potentially snowball into civil unrest if the situation is not handled properly. A stable society ensures Singapore's competitiveness as a hub for trade.

4.3 Energy generation potential of nuclear energy compared to other sources

While conventional sources of clean energy like solar energy, wind energy and hydroelectric power generation have potential to provide energy with lower carbon emissions than fossil fuels (Owusu & Asumadu-Sarkodie, 2016), it may not be sufficient in our transition towards a more sustainable energy grid. This is because of the inefficiency and unreliability of such sources of energy in the future, given climate change induced unpredictability in both short and long-term climates (Salinger, 2005). We will focus on the use of solar energy in particular, since it is likely the most viable source of energy generation in Singapore given our plan to expand solar energy generation by 2030. Energy generated using solar photovoltaic (PV) facilities rely on consistent and abundant solar thermal radiation. However, the utility of such systems declines steeply during extended periods of intense precipitation, which may be expected in tropical regions like Singapore as the climate changes (Robinson et al., 2021). On the other hand, Nuclear Energy Generation (NEG) has a much more consistent output, as it does not rely on external and uncontrollable sources to generate energy, unlike that of solar energy (Nuclear Energy Institute, 2015a). In fact, nuclear energy has the highest capacity factor (92.5%) of any other energy source, which means that nuclear power plants are capable of producing at maximum capacity for more than 92% of the time during the year, which is estimated to be three times or more effective than wind and solar plants, as seen in Figure 1 (Office of Nuclear Energy, 2021; Energy Information Administration, 2016).

Figure 1

Capacity Factor by Energy Source in 2020



Note. Comparison of capacity factor different energy sources in order of highest to lowest. It can be seen that Nuclear energy has the highest capacity factor of close to 100%, allowing it to be more productive to other sources of energy, most significantly solar energy.

Furthermore, nuclear energy may instead be a more space-saving source of energy generation, compared to solar energy. A nuclear energy facility has a relatively small area footprint, requiring about 1.3 square miles (about 3.4 km²) per 1,000 megawatts of installed capacity. Solar PV facilities on the other hand, have a significantly higher land footprint, requiring about 75 times the land area required by nuclear facilities (Nuclear Energy Institute, 2015b).

Overall, NEG not only has a smaller land footprint, but is also far more efficient and reliable than solar energy, making it a viable and crucial energy source for Singapore in our strive to be more energy independent.

5. Potential challenges of adopting nuclear energy in Singapore

While we have discussed the possible advantages of using Nuclear as a source of energy in the above sections, what we are missing is a crucial consideration of its challenges, contextualised to local characteristics. In the below sections, we will further elaborate the challenges that Singapore may face in adopting NEG, and propose solutions to consider in overcoming these issues.

5.1 Psychological Resistance

One of the biggest challenges is the resistance stems from the stigmatisation of NEG by the general public. This is perhaps caused by the perception of elevated risks of disastrous health consequences, which paints a negative image of nuclear facilities (Weart & Winkler, 1989), while simultaneously drawing false negative associations between NEG and the safety of the population. Furthermore, the media plays a significant role in influencing how the general public perceives NEG. As found by Nakayama et al., (2019), different sources of media consumption have significantly different outcomes in the levels of civilian anxiety following the nuclear disaster in Fukushima, as there are significantly higher levels of anxiety for groups relying on information received through the “use of internet” sites, rather than credible sources of news reporting such as local news agencies. Furthermore, the extent and proportion of media news coverage of large-scale catastrophes including that of nuclear disasters like the Fukushima disaster, could have contributed to elevated levels of anxiety surrounding NEG (Vasterman et al., 2005), which has persisted into present day fears. Lastly, we recognise that an individual’s willingness to accept the risk of living near nuclear energy facilities impedes on not only their individual perceived benefits and costs, but also strong societal pressures (Nam-Speers et al., 2020). Overall, we can extend this stigmatisation to influence the placement of nuclear energy facilities in Singapore, as it is likely an issue of significant concern to Singaporeans who perceive NEG as a threat to their safety and well-being. We will discuss this in the section below.

In reality, NEG may in fact be less harmful than energy production from fossil fuels (Kharecha & Hansen, 2013). In fact, even nuclear waste produced from NEG has been found to be much less radioactive than traditional coal-fired power plants (McBride et al., 1978). One way to allow Singaporeans to gradually accept implementation of nuclear energy is via education campaigns, in bid to facilitate a smaller divergence between the perceived and actual risks and benefits of nuclear energy, and more importantly to destigmatize NEG through community reassurance.

5.2 Nuclear and Land-use in Singapore

Another concern lies in the sheer size of most traditional reactors, in contrast to the small land space of Singapore, of a mere 719 km^2. Singapore’s land use plan for 2030 by category can be found in table 1 (Ministry of National Development, 2013) . The main land use needs seem to be divided across Defence Requirements (19%) Housing (17%), Industry and Commerce (17%), Land Transport Infrastructure (13%), and Parks and Nature Reserves (9%). This leaves a low 3% for utilities that include the power generation. Even with the small land footprint of nuclear facilities, it is unlikely that we have sufficient land space dedicated to the allocation of nuclear facilities such as the power plant, and more pertinently, the storage and disposal facilities for nuclear waste generated.

Table 1

Singapore's Land Use Plan for 2010 and 2030

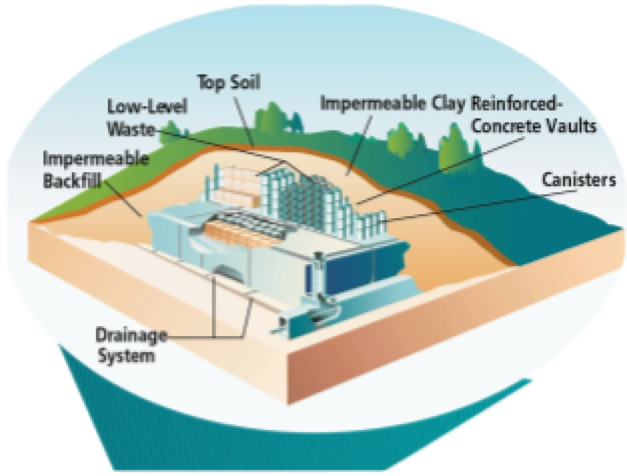
Land Use	Planned Land Supply (ha)	
	2010	2030
Housing	10,000 (14%)	13,000 (17%)
Industry and Commerce	9,700 (13%)	12,800 (17%)
Parks and Nature Reserves	5,700 (8%)	7,250 (9%)
Community, Institution and Recreation Facilities	5,400 (8%)	5,500 (7%)
Utilities (e.g. power, water treatment plants)	1,850 (3%)	2,600 (3%)
Reservoirs[2]	3,700 (5%)	3,700 (5%)
Land Transport Infrastructure	8,300 (12%)	9,700 (13%)
Ports and Airports	2,200 (3%)	4,400 (6%)
Defence Requirements	13,300 (19%)	14,800 (19%)
Others	10,000 (14%)	2,800 (4%)
Total	**71,000 (100%)**	**76,600 (100%)**

Note. Land use plan with planned land supply split into categories by hectares and by percentages of overall land in Singapore. Comparison of land use between 2010 and 2030 is included.

Nuclear waste, although produced in small amounts , must be dealt with in a highly calculated, safe manner since it is highly toxic to life on earth (Lappi & Lintunen, 2020). This is because there are many different classes of nuclear waste, all of which contain different concentrations of radioactivity and time needed for decay (World Nuclear Association, 2022). Thus, there is a need for different methods of disposal, using procedures and facilities unique to each class. Figure 2 (United States Nuclear Regulatory Commission, 2019) shows an example of how Low-Level waste can be disposed of safely. It is visually clear that such facilities require substantial planning in order to prevent incidents of radioactive leakage and contamination. This would require meticulous planning of both land use and construction, on top of being extremely cost-intensive, considering facilities for different classes of waste. Most significantly, the dedication of land for nuclear facilities like the reactors and waste disposal would place significant stress on our already limited land for competing needs.

Figure 2

Low-Level Nuclear Waste Disposal



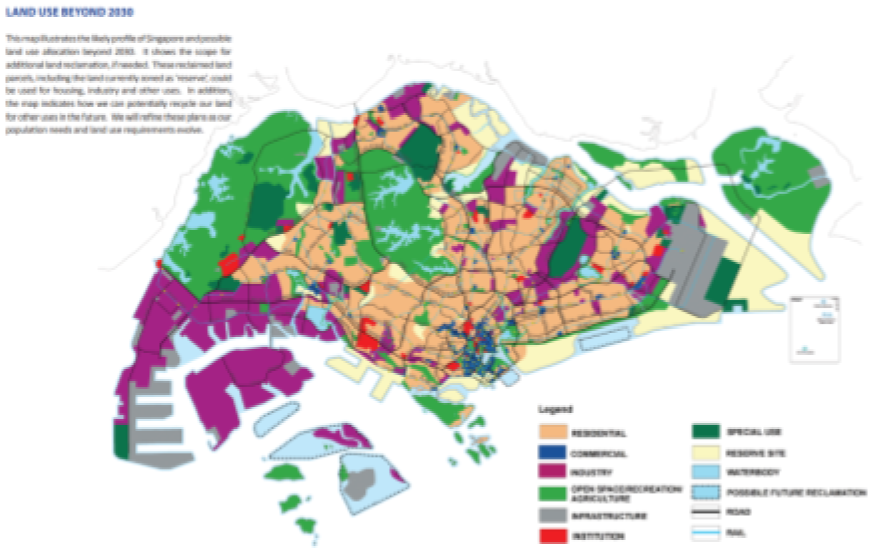
Note. Underground facility for the storage of low-level nuclear waste

5.3 Locating nuclear energy facilities in Singapore

To address the multiple challenges of adopting nuclear energy, we propose that the placement of nuclear facilities needs to be strategic; harmonising the consideration of minimising psychological resistance barriers posed by the general public, and land scarcity. It is ideal that nuclear facilities be offshored from the mainland, on nearby islands. Jurong island contains a spatial concentration of energy generation facilities, which could bring about economic benefits for nuclear start-up firms (Gorter & Nijkamp, 2001). However, being a mere 2.3 km away from mainland Singapore, it is likely that the public will still be opposed to NEG facilities being situated there due to the above mentioned psychological resistance. Thus, another viable island is Semakau Landfill, as it has a lower spatial proximity of 8km, and is possibly going to undergo land reclamation as seen in figure 3 (Ministry of National Development, 2013). This may allow for greater spatial flexibility for the placement of nuclear facilities both above and below ground. Furthermore, we do acknowledge that any other offshore islands that meet the operational needs of a functioning nuclear reactor necessitates safety and security safeguards in place. This will be explored in the below section about the defence and safety of nuclear reactors.

Figure 3

Map of projected land use in Singapore beyond 2030



Note. Planned land use in Singapore, divided into categories represented by different colours. This includes land could undergo possible reclamation in the future (marked out in light blue shading with dotted border)

5.4 Considering Small Modular Reactor technology

In understanding the challenges discussed above, it is thus wise to consider NEG from smaller generators. Small Modular Reactors (SMRs) are nuclear reactors which operate similarly to a traditional power plant, at a fraction of its size, generating a capacity of up to 300 megawatts of electricity (International Atomic Energy Agency, 2018). Its modular nature implies that individual components can be assembled from factory and transported to a suitable site for installation, rather than having traditional large-scale nuclear power plants custom designed and constructed at a particular location. On top of driving costs down, this also allows SMRs to be gradually adopted as needed, when energy demands increase (International Atomic Energy Agency, 2021). Overall, we believe that SMRs can take the place of traditional Nuclear power plants in a unique Singapore context that keeps in mind land scarcity.

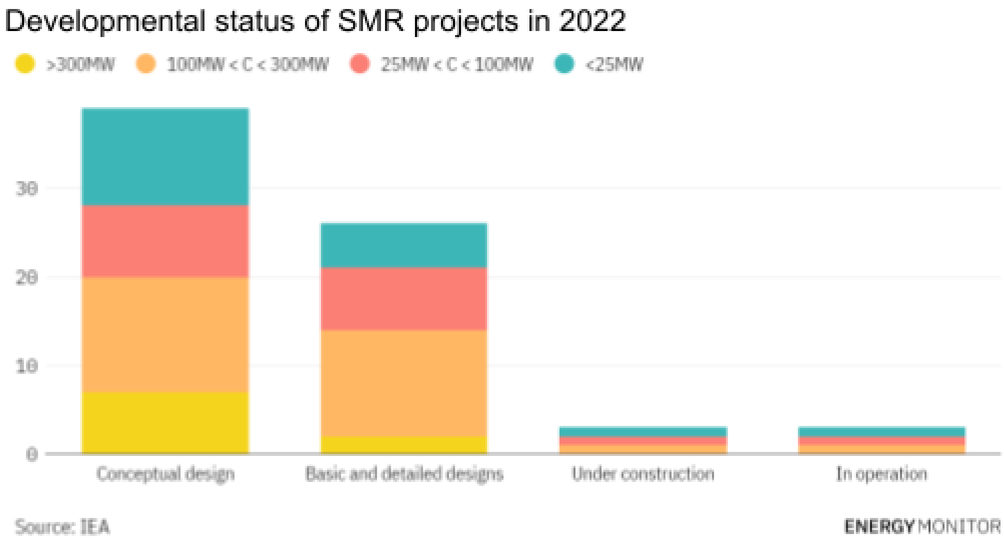
6. Feasibility of Nuclear in SG Context

In this final section, we will attempt to evaluate the overall practicality and likelihood of NEG being adopted into Singapore's energy grid, given its benefits and challenges. We attempt to acknowledge any additional factors that may influence our understanding of what SMRs can offer.

6.1 Infancy of nuclear technology

SMRs are still a relatively new technology, making it premature in comparison to more conventional sources of energy. In other words, the greatest area where SMRs are lacking is simply the lack of research and how early SMR technology is in its developmental stages. As seen in figure, almost all SMRs are presently in the "Conceptual design" stage, leaving those "Under construction" and "In operation" to be the large minority (International Energy Agency, 2022).

Figure 4



Note. The global number of SMR projects, categorised by developmental status and energy generation capacity (coloured)

Needless to say, we simply do not have enough information to fully place all our trust in SMR technology to be a silver bullet in providing a clean and reliable source of energy.

6.2 Hopeful potential of new nuclear technologies

Nevertheless, there is hope in the potential that SMR technology can bring. Apart from recent breakthroughs in cooling technology by SMR startup Nuscale (Ingersoll et al., 2014), what lies behind SMR technology seems to be a fundamentally safer system (International Atomic Energy Agency, 2017) , with enhanced safety features like 'passive cooling', which have been adopted based on lessons learnt from past nuclear accidents and meltdowns. This may potentially act as a source of reassurance to many, with SMRs being a self-regulating system that can be trusted to generate energy safely and reliably without the risk of a catastrophic event. Thus, it appears that research and development in NEG and hazard risk management has made it, and will continue to make it ever more feasible for nuclear to be a safe and reliable source of energy.

Furthermore, countries such as the United States of America, United Kingdom and Canada are presently investing heavily in SMR technology (Economic Research Institute for ASEAN and East Asia, 2021), providing the funding required to propel more in-depth research and development, to further elevate the potential that SMRs can have. In fact, Singapore has already begun investing in start-up SMR companies like General Fusion for their research and development in fusion reactor technologies (General Fusion, 2020). This gives us an understanding of the potential that SMRs can offer Singapore in future energy generation, and is a hopeful indicator that Singapore is indeed making efforts to shift towards cleaner and more sustainable sources like nuclear energy.

6.3 Defence & Security of nuclear reactors

The security of nuclear reactors cannot be understated. First, the threat of terrorist attacks on such facilities is real. (World Nuclear Association, 2022) Nuclear reactors are a form of utility infrastructure and are critical infrastructure vital to maintaining the operations of a country. Second, in the event of a conflict, nuclear facilities above ground pose a serious threat to those who live around them.

This is evident from the ongoing Russia-Ukraine war, where shelling on Europe's largest nuclear power plant, the Ukraine's Zaporizhzhya Nuclear Power Plant (ZNPP) has resulted in increased risk of a nuclear accident. The Director General of IAEA noted "that any military firepower directed at or from the facility would amount to playing with fire, with potentially catastrophic consequences". Moreover, any military activity (i.e. shelling or other forms of attacks) have the potential to cause unacceptable radiological consequences. (IAEA, 2022) The Nord Stream pipeline, is a network of offshore natural gas pipelines, runs from Russia to Germany. On 26th September, there was reportedly an act of sabotage, with explosions recorded. (CNBC, 2022) An attack on critical energy facilities is not unthinkable.

The defence of the proposed nuclear reactor will be undertaken by the Singapore Armed Forces (SAF). Since 2001, the SAF has been conducting homeland security operations at key installations such as Jurong Island to deter terror attacks. (Eng Beng, 2020)
Additionally, a new agency needs to be created to oversee nuclear regulation, management, security and safety. Similar organisations seen in other countries are the Japan Atomic Energy Agency and the United States Nuclear Regulatory Commision. (JAEA n.d.; NRC, n.d.)

6.4 Financing such infrastructure (SINGA)

The capital costs of constructing nuclear reactors would be much greater in comparison to gas-fired plants. (World Nuclear Association, 2022) To fund such infrastructure, we propose borrowing under SINGA (SIGNIFICANT INFRASTRUCTURE GOVERNMENT LOAN ACT 2021). In May 2021, Parliament passed a law to "authorise loans to be raised by the Government for the purposes of the Development Fund in relation to nationally significant infrastructure." "Nationally significant infrastructure", sub-section b.v - "means any structure … is intended primarily for any of the following purposes…: the generation, transmission or distribution of electricity, gas or other energy or power." SMRs would meet this requirement. (SSO AGC, 2021)

7. Conclusion

This paper discussed the advantages of nuclear: 1. Strategic needs, 2. Socio-economic benefits, 3. Environmental (The potential to replace natural gas) However, challenges are present with 1. Psychological concerns and 2. Competing land use needs being the biggest challenges.

Given that there is only one operational SMR in the world, the feasibility of adding nuclear energy to Singapore's energy mix hinges on the success of SMR technology. The EMA termed this as “Critical Uncertainties”. (EMA, 2022) If breakthroughs are made in SMR and the benefits outweigh the risks of adopting nuclear energy, Singapore should consider adopting SMRs to support its goal of achieving net-zero by 2050 and together with that its economic, environmental and social sustainability.

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