Assessing factors hindering feasibility and build programmes of nuclear power in South Africa

Thendo Yeolaine Masutha

1612627

1612627@students.wits.ac.za

A research report submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Management in Energy Leadership

Johannesburg, 2025

ABSTRACT

The nuclear energy industry in South Africa has faced various challenges that have hindered its development. This study examines the factors contributing to the slow expansion of the nuclear energy capacity within South Africa's energy mix, focusing on key barriers such as policy inconsistencies, financial constraints, and technical limitations. It also aims to form recommendations for an improved South African nuclear energy sector. The study is framed within the conceptual context of energy policy, sustainable development, and the just energy transition.

The study employs the qualitative approach of case studies and semi-structured interviews as forms of data collection. It explores successful case studies from France and India, where consistent energy policies, strong state support, and strategic funding have enabled substantial growth in their respective nuclear energy sectors. This comparative analysis provides practical recommendations for South Africa, focusing on the importance of improving regulatory frameworks, enhancing financial support mechanisms, and fostering innovation, technical capacity, and improved stakeholder management. Additionally, data were collected from a purposively selected sample of experts in the South African nuclear energy industry. Thereby utilising semi-structured interviews to gain a comprehensive understanding of the challenges faced. The findings highlight several critical barriers, including inadequate policy frameworks, limited financial incentives, a lack of technical expertise, and poor stakeholder engagement.

South Africa has the potential to significantly expand its nuclear energy capacity, but this requires targeted interventions to address the existing barriers. The conclusion emphasizes the need for a coordinated approach between government, industry, and stakeholders to create a conducive environment for the development of the country's nuclear energy sector.

Key Words: Nuclear energy, South Africa, energy policy, sustainability, Koeberg power station, energy transition, NNR, France, India.

DECLARATION

I, Thendo Yeolaine Masutha, declare that this research report is my work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Management in Energy Leadership at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Name: Thendo Yeolaine Masutha Signature: T.Masutha

Signed at the University of the Witwatersrand, Johannesburg

On the 24th of February 2025

DEDICATION

This paper is fondly dedicated to my parents, Betty and Mmbudzeni Masutha, whose unwavering support and encouragement have carried me through this journey, to my siblings (Mpho and Alinah), who have remained my primary source of inspiration to complete this research paper, and to my uncle, Vukosi Maluleke, who motivated me to apply to the energy leadership programme and supported me throughout my journey at Wits. To my grandmother, Kokwani Mamaila, whose tenacity has propelled me to this point.

This research paper is dedicated to all the black girls who have dared to dream, those who are working towards their dreams, those who have achieved their dreams, and those who were not able to reach the other side of their dreams.

To Ntsako Mashaba, a thirteen-year-old from Nkuzana Village who aspired to become a doctor but sadly passed before her dream came to fruition.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my research supervisor, Dr Steven Mathetsa, for his invaluable expertise, feedback, and guidance throughout this research project.

I also extend my appreciation to Dr Goitsione Emily Olifant for her indispensable insight and constructive input that helped improve this research paper.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS and ABBREVIATIONS

DAE	Department of Atomic Energy
DMRE	Department of Mineral Resources and Energy
GHGs	Greenhouse Gases
HLW	High-level Waste
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
LLW	Low-level Waste
Mt	Megaton(s)
MW	Megawatt(s)
NASA	National Aeronautics and Space Administration
NDC	Nationally Determined Contribution
NECSA	South African Nuclear Energy Corporation
NERSA	National Energy Regulator of South Africa
NNR	National Nuclear Regulator
PBMR	Pebble Bed Modular Reactor
PWR	Pressurized Water Reactor
REIPPPP	Renewable Independent Power Producer Programme
tU	tonnes of elemental uranium
UNFCCC	United Nations Framework Convention on Climate Change
VRE	Variable Renewable Energy
WMO	World Meteorological Organization

CHAPTER 1. INTRODUCTION

1.1 Purpose of the Study

This qualitative study seeks to identify factors that have hindered the adoption of nuclear power build programmes as the alternative dispatchable energy in South Africa and explore the feasibility of nuclear power in supporting the country's baseload electricity supply.

1.2 Context of the Study

Energy is the driving force of the global economy. Multiple countries have relied on fossil fuel-driven energy technologies that have come under severe scrutiny in recent times. The scrutiny is prompted by the perceived effects of global warming, a phenomenon prominently observed by researchers and scientists in the nineteenth century (National Aeronautics and Space Administration [NASA], 2023). Several researchers argue that global warming is exacerbated by anthropogenic activities such as the burning of fossil fuels, particularly coal (Clark and Jacks, 2007; Hanlon, 2016). This has resulted in the global drive to mitigate climate change, which is actively pursued by various global organisations such as the United Nations' Intergovernmental Panel on Climate Change (IPCC). The IPCC was established by the World Meteorological Organisation (WMO) in 1988 with the mandate to assess and review the science of climate change (IPCC, 2024).

Following the establishment of the IPCC, the United Nations drafted the United Nations Framework Convention on Climate Change (UNFCCC), which was signed by 154 nations in Rio de Janeiro in 1992 (Kuyper et al., 2018). The main objective of this international treaty was to counter the threatening effects of human interference on the global climate system (United Nations, 1992). Furthermore, the UNFCCC adopted the Kyoto Protocol (1997), which outlined the mechanisms paramount in reducing the global emissions of greenhouse gases (Rosenqvist et al., 2003). In keeping with its principal mandate of stabilising greenhouse gas (GHG) emissions, the UNFCCC adopted the Paris Agreement (drafted in 2015) to fortify the collective response to climate change of the 196 countries that signed it (Kuyper et al., 2018). This collective global response is expected to help meet the main target of keeping the century's average temperature rise below 2 °C (Kuyper et al., 2018). Central to the Paris Agreement is the reduction of global reliance on fossil-fuel energy systems. This has resulted in plans to introduce low-carbon technologies across the globe.

As a member of the UNFCCC and a signatory to the Paris Accord, South Africa is on a quest to address its energy trilemma by pursuing a balanced approach between energy security, sustainability, and affordability. These endeavours are motivated by the country's position of being the largest GHG emitter on the African continent, with emissions approximating over 400 Mt CO_2 in the last decade (Crippa et al., 2022). This position is attributed to the country's carbon-intensive coal-fired power stations, which account for approximately 70% of the energy generation, thereby accounting for a major portion of the 400 Mt CO_2 emitted within the country's borders (Tiseo, 2023; International Energy Agency [IEA], 2024a). As outlined in its Nationally Determined Contributions (NDCs), the country has embarked on multiple initiatives to reduce its GHG emissions, particularly targeting a CO_2 emission reduction by 15% to 350 Mt CO_2 by 2030 (UNFCCC, 2016; International Monetary Fund, 2023; Republic of South Africa, 2021). Furthermore, the country has laid out plans to reduce emissions post-2030 by planning to decommission some of its coal fleet in favour of renewable energy and other forms of clean technology (DMRE, 2019). These plans are briefly touched upon in the 2023 draft of the Integrated Resource Plan (IRP), where a nuclear build programme in the form of small modular reactors is suggested post-2030 in a two-horizon analysis (DMRE, 2023).

While these developments have brought into question the future of coal in the energy sector and the undertaking to find practical alternative energy sources that will meet the country's rising energy demands, debates about which technology will succeed in achieving sustainability, affordability, and overall energy security for South Africa remain ongoing. Energy sources explored to varying degrees include the Variable Renewable Energy (VRE), such as wind and solar energy, which both present the challenge of intermittency (Crippa et al., 2022; DMRE, 2023). This raises the urgent need for less carbon-intensive dispatchable energy sources to support the country's baseload whilst easing it through the energy transition. Coal, natural gas, and nuclear power have been used as dispatchable energy sources supporting the baseload of several nations across the world (MIT, 2021). It is through this study that the feasibility of nuclear technology is being assessed to validate the role that it can play in promoting South Africa's energy security in an environmentally sustainable manner to help the country meet its GHG emission reduction goals.

1.3 Research Problem

In South Africa, the Department of Mineral Resources and Energy (DMRE), now called the Department of Energy and Electricity, upholds the mandate to promote energy security in a sustainable manner (South African Government, 2024). The department oversees the planning and diversification of the country's energy mix and has highlighted the provision for nuclear power in its energy planning (DMRE, 2019, 2023). However, there has been no addition of new nuclear power capacity onto the grid since the dawn of the nation's democracy. Instead, the 2019 Integrated Resource Plan (IRP) made mention of the decision to extend the lifespan of Koeberg Nuclear Power Station by a further twenty years, a process that has since been implemented (DMRE 2019, Erasmus, 2023). More so, public comments were reiterating the observed minimal consideration of nuclear power programmes in the 2019 IRP (DMRE, 2019).

It was also observed in the latest draft version of the IRP (made available for public comments until March 2024) that the country explored energy planning using two horizons; the first horizon catered to the period ranging from present-day up to 2030 whilst the second horizon focused on the duration from 2030 until 2050 (DMRE, 2023). Nuclear power was only considered in the second horizon on the third pathway that outlined an energy mix dominated by clean, renewable energy technology. As highlighted in the 2023 Integrated Resource Plan (IRP) draft, the proposed nuclear pathway includes both large-scale reactors and small modular reactors (SMRs). The classification into either category is based primarily on the size of the reactor core or its thermal energy output. Large reactor technologies that have garnered interest in South Africa include the Advanced Pressurised Reactor (AP-1000) from the United States, the European Pressurised Reactor (EPR) from France, and the Water-cooled, Water-moderated Energy Reactor (VVER) from Russia (World Nuclear Association, 2025). SMRs, by contrast, are a size-based category that encompasses a range of reactor technologies, including pressurised water reactors (PWRs) (Fernández-Arias et al., 2023) and high-temperature gas-cooled reactors (HTGRs) such as the Xe-100 and the PBMR (Nuclear Engineering International, 2024).

South Africa is the most coal-dependent country in the world, trailblazing ahead of known coal giants such as China (Venditti, 2023). This over-dependence on a carbon-intensive energy source positions the country amongst the top GHG emitters and thus threatens the climate change commitments of the country. Nuclear power, which is widely considered a clean energy technology, presents itself as a possible solution for the reduction of GHG emissions in the country, as it does not emit CO_2 directly into the atmosphere. Furthermore, nuclear power has proven to be a reliable energy source with the ability to support the baseload of multiple countries, including France and Japan (Brook et al., 2014). As such, it is imperative for South Africa to consider nuclear power as a formidable energy source to support baseload, as endorsed by energy experts.

Given South Africa’s extensive nuclear power history, the successful operation of the Koeberg Power Station, and the country’s commitment to reducing reliance on carbon-intensive coal-fired power plants, it is relevant to investigate why there has been no new nuclear addition to the country’s energy mix. Based on these observations, this study seeks to examine the extent to which the country's plans, including policies and legislation, have delayed the development of nuclear power in the country.

1.4 Research Aims and Objectives

This study aims to identify the factors that have contributed to South Africa's lethargic uptake of nuclear power programmes and to form recommendations that will create an enabling environment for the growth of the sector.

To achieve its aim, the objectives of this study are summarised below:

1. Analyse international case studies pertaining to countries with successful nuclear power programmes to draw a comparison between their nuclear power strategies and South Africa's.
2. Identify and expand on the factors that have hindered the growth of South Africa's nuclear power programmes through the consideration of socio-political, environmental, economic, and leadership aspects.

1.5 Significance of the Study

South Africa is confronted with a myriad of challenges in trying to decarbonise its energy sector while ensuring energy security, affordability, and accessibility. Empirical evidence shows that the failure to urgently address these challenges has had a significant impact on key economic sectors and, consequently, the country's gross domestic product (GDP) (Statistics South Africa, 2023). Should these problems persist, they would prove to be detrimental to the economy and consequently would affect the social fabric of the country.

South Africa is well-endowed with renewable energy resources, which the government aims to utilise to increase energy generation capacity through initiatives such as the Renewable Energy Independent Power Producer Procurement Program (REIPPPP) (DMRE, 2019; DMRE, 2023). However, the intermittent nature of renewables poses a threat to the country's energy security; thus, the need to ensure a stable power supply through dispatchable energy sources such as nuclear power (Meng et al., 2021).

This study is significant within the context of South Africa's energy mix as it provides lessons for nuclear build programmes by observing several factors that are critical in establishing a nuclear energy baseload. The study seeks to contribute towards the assessment of the feasibility of nuclear build and expansion programmes. This will help in forming recommendations that will aid South Africa's energy transition by employing nuclear energy programmes in its policy framework.

1.6 Delimitations of the Study

This section briefly outlines the boundaries of this study as follows:

Geographic Delimitation: This study seeks to identify factors that have hindered nuclear build programmes in South Africa. This extends to external influences that have had a profound impact on South Africa's nuclear build programmes. The participants (interviewees) of this study were selected from a pool of experts who are working or have worked in South Africa's nuclear power industry or have published peer-reviewed work on the industry.

Time Delimitation: This study considers important nuclear power developments before 1994 to present a brief history of South Africa's current nuclear industry. However, the focus of the study is on identifying factors that have hindered the country's nuclear build programmes post the adoption of the White Paper on Energy Policy in 1998 by parliament. The study does not attempt to predict the future pathway of the nuclear industry.

Population Delimitation: The sample of individuals interviewed is limited to nuclear industry experts with cumulative experience at institutions such as the National Nuclear Research (NNR), the South African Nuclear Energy Corporation (NECSA), and others alike. The participants include individuals who have experience working with companies that finance the country's energy projects, such as the National Treasury and policy developers in the nuclear space.

Methodological Delimitation: This study is limited to the use of the following qualitative methodological research types: interviews, literature appraisal, and case studies.

1.7 Structure of the Report

This research paper has five chapters outlined as follows:

Chapter 1: This section serves as an introduction to the focus of the study. It provides the background and context for the research problem. It includes the aim and objectives. It also illustrates the importance of the study and its delimitations.

Chapter 2: This section is the literature review where the background and context of the study are fully established with the use of existing locally and internationally published literature and policy documents. The chapter also highlights the propositions stated in the research objectives in the first chapter.

Chapter 3: This chapter provides a clear outline of the research approach and design, which includes the methods/procedures employed in the study. It also justifies the reasons why qualitative methods such as case studies and interviews were chosen. This section further provides clarity on how the data was collected and analysed/interpreted. Additionally, ethical considerations are discussed in this chapter.

Chapter 4: This chapter presents the findings, discussion, and recommendations from the case studies and the interviews conducted with the participants, along with the recommendations they made.

Chapter 5: This chapter summarises the findings from the study and addresses the research objectives based on the analysis of the data.

1.8 Definition of Words

Nuclear Energy	:	A form of energy that is released from the nucleus (central core) of an atom. It is produced when the nuclei split up into multiple pieces (fission) or when the nuclei of atoms fuse together (fusion) (Galindo, 2022; Martin, 2024).

Nuclear Build Programme	:	A structured initiative that is pursued by an institution or government to build new nuclear power plants and associated infrastructure in accordance with predetermined objectives/goals (International Atomic Energy Agency [IAEA], 2001).
Dispatchable Energy	:	A type of energy that can be adjusted according to demand or fluctuations in electricity demand. Nuclear, gas & coal are classified as dispatchable energy sources (University of Calgary, 2024).
Baseload (of a grid)	:	The lowest level of electricity required to sustain an electrical grid at any given moment (Gyamfi et al., 2018).

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This section briefly reviews literature that pertains to both the global and South Africa's nuclear energy landscape, whilst probing into a multitude of factors that influence the establishment of nuclear build programmes. This was achieved through probing into the history of nuclear power in South Africa and tracking its advancement by exploring key subject matters such as policy development, uranium mining, etc. The section concludes with the proposition statements concerning the research objectives.

2.2 Background Discussion

2.2.1 Brief History and Global Developments of Nuclear Power

The twentieth century saw the advent of nuclear energy in sporadic pockets, mostly documented across Europe and North America (World Nuclear Association, 2020). This technology has since been employed across several varying facets, ranging from the formation of the nuclear bomb to the establishment of nuclear-powered stations for electricity generation. Several countries across the globe have successfully developed their nuclear power programmes, thus increasing the share of nuclear-driven electricity generation within their energy mixes. These countries include France, with approximately 36% of its total energy supply being accounted for by nuclear power, and Japan, which produces 29% of its domestic energy using nuclear technology (International Energy Agency (IEA), 2024b, 2024c). Nuclear power plants enable countries such as France to generate sufficient electricity, such that they can export it to other countries across Europe (Harmsworth, 2023). This emphasises the important role played by nuclear energy in promoting energy security in those countries.

Nuclear power has come a long way since the discovery of radiation by Henri Becquerel and the paramount supporting work carried out by scientists such as

Pierre and Marie Curie on radioactivity (Chater, 2005; USA EPA, 2023). It was upon the culmination of previous studies that German scientists Otto Hahn and Fritz Strassman were able to discover the first steps to building atomic bombs through splitting the nuclei of uranium atoms (Chater, 2005). This development resulted in some of the most calamitous events of the 20th century, the bombings of Hiroshima and Nagasaki orchestrated by the United States of America (Britannica, 2024b). The effect of the bombings proved to be pivotal to the direction of nuclear research approaching mid-century, with historians believing that it also exacerbated the Cold War and sparked the proliferation of nuclear power weapons across the world (Britannica, 2024b).

It was in 1953 that then-USA President Dwight D. Eisenhower addressed the United Nations General Assembly at their 470th plenary meeting about his plea for nations to repurpose nuclear weapons for activities other than war and to dedicate nuclear research to uses that could benefit mankind (Eisenhower Presidential Library, 2024; Leszczynska, 2023). In 1954, the Soviet Union opened the Obninsk Nuclear Power Plant, the first nuclear power station to generate power for a grid and the first fully-fledged nuclear plant solely devoted to electricity generation (Petros'yants, 1984; Chater, 2005). Since then, other nations, including England and the USA, followed suit with the construction and operation of their nuclear power stations (Chater, 2005). Distinct types of nuclear reactors have since spawned from global nuclear power research that include but are not limited to the common light water reactors (pressurised-water reactors and boiling-water reactors) and the infrequent high-temperature gas-cooled reactors (Britannica, 2024a; World Nuclear Association, 2024d).

2.2.2 Nuclear Power in the Context of South African Electricity Generation

The country's interest in nuclear power began long before the opening of its first and only commercial nuclear power plant. It dates to the discovery of uraninite in heavy mineral concentrate at City Deep Gold Mine in 1923 by R.A. Cooper (Brynard et al., 1988). In 1944, South Africa's assistance in procuring uranium to be utilised by the Manhattan Project was requested by Britain (Brynard et al., 1988; Van Wyk, 2021). This involvement inspired great interest in atomic energy such that in 1948, South Africa promulgated the Atomic Energy Act and consequently established the Atomic Energy Board (AEB). South Africa's first uranium mine was opened shortly after these events (Brynard et al., 1988).

Furthermore, the National Nuclear Research Centre at Pelindaba was constructed in 1961, resulting in the development of SAFARI-1, which is a light water-cooled reactor that went critical in 1965 (Brynard et al., 1988). The aforementioned are milestones within the timeline that led to the construction of Koeberg, a nuclear power station located in the Western Cape. Its construction commenced in 1976, and its first reactor unit was completed by 1984 (Eskom, 2022). Koeberg 1 and 2 were both synchronised to the grid by 1985. Radioactive waste from the plant is handled at Vaalputs Radioactive Waste Disposal Facility (National Radioactive Waste Disposal Institute, 2021). It is important to note that the then government opted into the disarmament of its nuclear weapons programmes with the assistance of the International Atomic Energy Agency (IAEA) in 1989 (Albright, 2001).

It is now evident that South Africa inherited its legacy nuclear power head start from the then government, which included the Koeberg Nuclear Power Station in the Western Cape (DMRE, 2019; Fig, 2010; Van Wyk, 2021). The 1860 MW installed capacity of Koeberg Nuclear Power Station accounts for approximately 5% of the country's energy mix (DMRE, 2019; Eskom, 2024), and it is the only source of the country's commercial nuclear power since it began operation in 1984 (Van Wyk, 2021). The power station has since reached the end of its initial forty-year-long lifecycle, but a twenty-year-long extension was granted through the National Nuclear Regulation (Erasmus, 2023). The 2019 IRP elaborates on the aforementioned life extension and the expansion of nuclear power programmes henceforward with a special focus on manageable and cost-favouring small nuclear units (DMRE, 2019).

Although the IRP 2023 holds space for nuclear power in the future, it does not address the extensive research and development that was once poured into the Pebble Bed Modular Reactor (PBMR) project. The PBMR was of great significance to South Africa's nuclear power history as it symbolised a period where nuclear power received a considerable amount of support from the democratic government, with approximately R8.67bn set aside for the PBMR company (Fig, 2010). The PBMR presented the country with the opportunity not only to reduce the GHGs from the energy sector but also to potentially produce clean hydrogen, fuels, and chemical products from the process heat (PBMR, 2017). However, before a test reactor could be built at Koeberg Power Station, the government announced its decision to stop further funding of PBMR (Pty) Ltd in 2010, thus resulting in its halting (Department of Public Enterprises [DPE], 2010; World Nuclear News, 2010). The government also accounted for the factors that were considered in making the decision. The demise of the PBMR is paramount to consider as it will assist the study in identifying the obstacles that have hindered the growth of the country's nuclear programme and the factors that have influenced its state.

2.3 South Africa's Current Outlook on Nuclear Power

With the 2030 net-zero target looming on the horizon, the dusk of the nation's coal-fired power plant fleet is imminent. It is therefore suggested that nuclear power lends itself as a viable alternative to coal, with the potential to provide consistent and reliable power to the national grid. Several authors argue that South Africa is well-positioned to run a successful nuclear programme expansion due to its high amount of proven uranium reserves (Brook et al., 2014; Kenan & Chirenje, 2014). However, the success of a nuclear programme is influenced by multiple factors such as governance of the state, environmental concerns, and capital costs for establishing the infrastructure, amongst others. Furthermore, global views have highlighted multiple challenges associated with nuclear power, which include nuclear-related incidents such as the Chernobyl and Fukushima accidents (Cardis & Hatch, 2011).

South Africa has the potential to be a net exporter of electricity given the abundance of varying renewable energy power sources, critical minerals, and proven gas reserves (DMRE, 2022; The Presidency, 2022). To become a net exporter, South Africa must have a reliable dispatchable energy source, which, it can be argued, is possible through the implementation of a successful nuclear programme. The working principle of nuclear energy generation and fission ensures that nuclear reactors do not release direct CO_2 into the atmosphere, thus making it an ideal alternative for South Africa to reduce its GHG emissions (Brook et al., 2014).

There have been several attempts made towards procuring new nuclear capacity by the South African government in the past. This includes an agreement with Russia (signed by NERSA) that would have allowed South Africa to develop a strategic partnership aimed at improving power plant and waste management practices (Nuclear Engineering International, 2014). The governments of both Russia and South Africa went on to sign an agreement with the prospect of building 9 600 MW of nuclear capacity using Russian 'water-water energetic' reactors, much to the dismay of multiple stakeholders (Vásquez-Maignan et al., 2024). In 2015, the cabinet approved the action of issuing a Request for Proposal (RFP) by the then Department of Energy for the 9 600 MW new nuclear build programme in hopes that this would assist in developing a funding model (Department of Energy, 2015). National Treasury ended up withdrawing this authorisation and changing it to a non-binding Request for Information (RFI). However, in 2018, the government announced that it would not be going forward with the 9 600 MW nuclear build programme, citing several reasons such as high capital costs, safety concerns, etc. (Vásquez-Maignan et al., 2024).

Through the IRP-2019, the DMRE has stated that they are holding space for 2 500 MW to be sourced from nuclear energy (DMRE, 2019). It was in this same IRP that the DMRE communicated plans to extend the design life of Koeberg Power Plant whilst introducing the idea of employing small modular reactors (SMRs) as a viable possibility due to their advantage of lower cost compared to full-sized power plants (DMRE, 2019).

In 2024, the DMRE published a new draft of the IRP for public comment. This draft outlined two distinct timelines (referred to as horizons in the IRP 2023 document) upon which the pursuit of a diversified and balanced energy mix will be carried out. The first horizon was from 2023 to 2030, whilst the second horizon encompasses a period beyond 2030. The second horizon had four different pathways that the country could embark on, with pathway number three highlighting possible new nuclear capacity. A total of 14 500 MW of new nuclear capacity by 2050 has been envisioned and projected to be built at an affordable pace (DMRE, 2023). However, these pathways are hypothetical, and there have been no strategies shown within the draft IRP-2019 detailing how this would be achieved. These observations present uncertainties to the future of nuclear build programmes as a dispatchable energy source in the country. At the time of compiling this report, the DMRE was finalising the IRP following public comments.

2.4 Factors that Influence the Nuclear Power Industry in South Africa

2.4.1 Uranium Mining in South Africa

Uranium owes its prominence to the advent of the atomic bomb; it was then that extensive research was dedicated to finding ways to use uranium for power generation (Chater, 2005). South Africa's earliest documentation of uranium dates back to 1915 when radioactivity was noted by the then Director of Geological Survey, Dr A.W. Rogers, within the Witwatersrand gold ores (Ford, 1993). Upon further investigation, R.A. Cooper was able to identify a dense mineral called uraninite found in constituents of concentrates from corduroys (Ford, 1993). However, the economic importance of these discoveries had still not been proven at this point. In 1949, the first plant aimed at developing a process for uranium extraction, the Blyvooruitzicht pilot plant, was opened (Brynard et al., 1988).

After a satisfactory uranium extraction process was developed, the first commercial uranium plant was opened in 1952 at the West Rand Consolidated Mine (Brynard et al., 1988; Ford, 1993). In 1959, the production of uranium rapidly peaked, leading to a total production of 4 953 kilotons (kt). The country would not witness such a peak in production for over a decade due to the decline of nuclear armament programmes across the world (Mogni, 1983). In the 1970s, the world oil crisis fuelled the increased demand for uranium, and South Africa was well-positioned due to its long history of gold mining activities, which had provided tailing deposits that contained expansive amounts of uranium. The country's uranium production has since decreased by 35% to 257 tU in 2016, translating to a 45% decrease in uranium export sales generated to R170 million in the year 2017 (Van Wyk, 2021).

The last publicly accessible documented uranium mining-focused survey (to date) to be carried out by the government was in 2007. It outlined the importance of uranium mining for uranium beneficiation. The survey report reinforced the idea that the government had a strategy for uranium use in the future to boost the economy (Department of Mineral Resources, 2007). This was followed by the publishing of a mineral beneficiation strategy that highlighted the importance of completing preparatory work that would have facilitated the growth of the nuclear power sector. The strategy outlined the interventions that the government was planning to take, which included quantifying the uranium/thorium reserves in the country, ascertaining the viability of re-establishing uranium enrichment, expansion, and planning for waste treatment facilities, along with rehabilitating mines and finalising a uranium policy (Department of Mineral Resources, 2011).

To date, uranium mining in South Africa has declined since its peak in the 1980s, with current production limited to the Witwatersrand Basin as a by-product of gold mining (Kenan & Chirenje, 2014). However, exploration efforts in the Karoo Uranium Province, Namaqualand, and Springbok Flats Basin are ongoing, with drilling and geophysical surveys aimed at expanding resource potential (Kenan & Chirenje, 2014).

2.4.2 Nuclear Policy Development in South Africa

The DMRE is the national department with the task of administering all matters relating to nuclear energy (nuclear technology, safety, and non-proliferation) in keeping with legislation and international agreements (DMRE, 2024). The main acts and international agreements are listed in Table 1 below:

Table 1: Nuclear Acts & International Agreements (DMRE, 2024).

Nuclear Acts	International Obligations
Gazette 44076: Notice in terms of section 28	Non-Proliferation Treaty 1970
Nuclear Regulator Act, 1999 (Act No 47 of 1999), on fees for	Safeguards Agreement 1991
Act 46 of 1999 Nuclear Energy	Additional Protocol 2002
Act 47 of 1999 National Nuclear Regulator	Convention on PPNM 1980
Act 53 of 2008 National Radioactive Waste	Pelindaba Treaty 2009
Act 87 of 1993 Non-Proliferation of WMD	Zangger Committee
Act 15 of 1973 Hazardous Substances	Nuclear Supplier Group 2011
National Radioactive Waste Disposal Institute Act 53 of 2008	

*Not included in the table above are the nuclear notices, policies, and bills that are crucial to the nuclear sector of the country.

As shown in Table 1, South Africa's nuclear sector is governed by a robust legislative framework that includes the Nuclear Energy Act (1999) and the National Nuclear Regulator Act (1999), alongside international commitments such as the Non-Proliferation Treaty (1970) and the Pelindaba Treaty (2009). These regulations ensure compliance with global safety, security, and non-proliferation standards, reinforcing the responsible management of nuclear materials, products, and activities (DMRE, 2024).

The subsequent chapters of this study will gather data and information that will probe into the effectiveness of the country's policy development to ascertain whether it has been not only conducive but also encouraging for new nuclear build programmes.

2.4.3 Radioactive Waste Management

South Africa's nuclear regulatory framework has developed progressively over several decades, transitioning from an early phase of informal, industry-led self-regulation to a formalised system of state oversight. A significant turning point in this evolution was the establishment of the Council for Nuclear Safety (CNS) in 1988. This body emerged from the licensing division of the Atomic Energy Corporation and adopted regulatory practices informed by the British nuclear oversight model (Leotlela, 2017). The regulatory landscape was further consolidated with the promulgation of the National Nuclear Regulator Act 47 of 1999, which established the National Nuclear Regulator (NNR) (Leotlela, 2021). The NNR is a regulatory body that was established to exercise control over various facets of the nuclear power industry, ranging from mining radioactive material to ensuring the safety of nuclear installations (DMRE, 2024). The NNR also undertakes the role of ensuring that policy guidelines are adhered to when it comes to the management of radioactive waste within the industry to safeguard the environment and the health of the people (NNR, 2022). The policy development and regulations pertaining to radioactive waste management are summarised in the flow diagram shown in Figure 1 below:

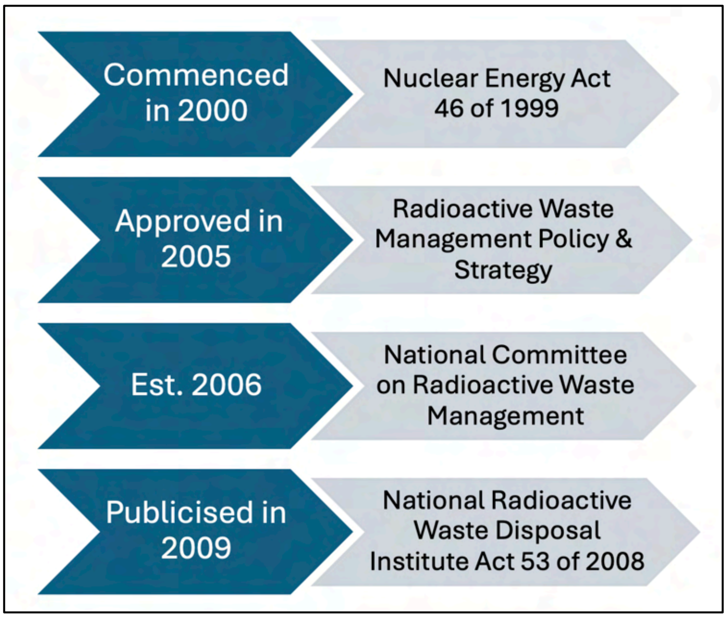

Figure 1: Legal framework to manage radioactive waste (DMRE, 2024).

Radioactive waste is produced by several industries such as academia, medicine, and power generation. This waste is classified into two categories, namely, low-level waste (LLW) and high-level waste (HLW). All nuclear waste in South Africa is managed by the South African Nuclear Energy Corporation (NECSA), which operates and manages the only nuclear waste facility in the country, the Vaalputs Radioactive Waste Disposal Facility (National Radioactive Waste Disposal Institute, 2021).

The management of spent nuclear fuel in South Africa is governed by the National Radioactive Waste Disposal Institute (NRWDI), established under the National Radioactive Waste Disposal Institute Act 53 of 2008. The NRWDI is responsible for the safe and secure storage, handling, and disposal of radioactive waste, including spent fuel from nuclear (National Radioactive Waste Disposal Institute, 2021). This institution ensures that radioactive waste management practices conform to national and international safety standards, thereby protecting public health and the environment.

Spent nuclear fuel is stored in specialised facilities designed to contain radioactivity and prevent environmental contamination. The long-term strategy involves the eventual disposal of this waste in deep geological repositories, a method recognised globally as the safest approach to radioactive waste management (OECD Nuclear Energy Agency, 2007). In South Africa, current storage practices adhere strictly to these internationally accepted guidelines, with oversight provided by the NRWDI in collaboration with the National Nuclear Regulator. The integration of these regulatory frameworks fosters transparency and accountability in the nuclear industry, helping to address public concerns and support sustainable nuclear energy development.

2.4.4 Health and Safety Risks/Concerns

Every industry comes with its own set of risks, including the global nuclear sector. The high energy density nature of nuclear power plants increases the likelihood of potential hazards, which is accounted for when designing nuclear reactors to ensure an adequate level of safety (World Nuclear Association, 2022). Nuclear safety is contained in the following parameters: limiting the unintended release of radioactive material within nuclear power facilities in the interest of public health, prohibiting the intentional misuse of nuclear energy by any entity, and restricting activities by various institutions. These are activities that could lead to unlawful acquisition and/or development of nuclear weapons (World Nuclear Association, 2022).

Nuclear power researchers and scientists have devoted time to minimising the chances of nuclear accidents occurring, and as a result, there have only been three major accidents in the history of nuclear power generation (Högberg, 2013; Ohba et al., 2021). These three accidents occurred at the following places: Three Mile Island in the USA (1979) due to a damaged reactor, Chernobyl in Ukraine (1986) resulting from the destruction of a reactor from a steam explosion and Fukushima in Japan where four old reactors were written off due to the effects of a major tsunami that occurred in 2011 (World Nuclear Association, 2022). To date, the number of fatalities due to nuclear power accidents has remained relatively low. Furthermore, it must be noted that commercial power plants cannot explode due to the enrichment of the fuel being kept to below 5%, with the requirement for explosion being well above that percentage (Degueldre et al., 2011).

Although the frequency of nuclear power plant accidents has remained low over the years, a 2012 paper brought forth the notion that the International Atomic Energy Agency (IAEA) can further improve its regulatory inefficiencies in attempts to safeguard nuclear facilities against natural phenomena (Wang & Chen, 2012). The IAEA is an intergovernmental organisation created by the UN in 1957 to act as an auditor by promoting relevant safety practices and strengthening the security framework of global nuclear power safety (World Nuclear Association, 2022). Wang and Chen (2012) further suggest that the IAEA has not done justice to its role in nuclear non-proliferation by not being strict when it comes to countries or regions adopting nuclear safety measures, it is shown that countries can adopt these measures voluntarily as opposed to mandatorily doing so.

Nuclear safety in South Africa is part of the NNR's mandate. They are responsible for ensuring that every player within the nuclear industry adheres to the policies and regulatory dispensations that exist (DMRE, 2024). The NNR carries out compliance inspections, assessments, and periodic safety reviews in efforts to ensure nuclear safety and the health and safety of the people and the environment (National Nuclear Regulator, 2023). Through its commitment to transparency, the NNR also publishes its findings to the public. The NNR regulatory programme conducts its checks at Koeberg power station, Pelindaba, Vaalputs, and facilities that handle Naturally Occurring Radioactive Material (National Nuclear Regulator, 2023).

2.4.5 The Opposition to Nuclear in South Africa

The opposition to nuclear power has been influenced by environmental and health concerns held by the public because of witnessing the aftermath of nuclear accidents (Adamantiades & Kessides, 2009). This anti-nuclear power stance has resulted in a global social movement that supports initiatives opposing the growth of nuclear build programmes. The current anti-nuclear power movement is derived from the nuclear disarmament agenda that arose in the late 1960s due to the threat that nuclear arms could pose to humanity when detonated (Herring, 2007; Cohn, 1997). Local and international groups have since emerged in support of varying anti-nuclear causes; these include groups such as Greenpeace International (Burkett, 2009).

In South Africa, plans to expand nuclear programmes can be traced back to the White Paper document written and published by the then Department of Minerals and Energy (DME, 1998). These plans have been further expanded in the IRP 2019 and the IRP 2023 (DMRE, 2019, 2023). However, the prospect of adding new nuclear capacity has been polarising, giving rise to two camps of coalitions that are either in support of the expansion of the nuclear build programmes or in opposition (Leifeld, 2014). The opposing coalition in the country does not have a central entity influencing the network of the coalition; instead, it consists of a range of majority civil organisations that are against the nuclear programme for varied reasons. Amongst these reasons of opposition is the cost of a nuclear build programme and the impact it might potentially have on the growth of the economy. These organisations and institutions raise concerns that they believe ought to be thoroughly examined before embarking on nuclear build programmes (Arent et al., 2017). They suggest that the cost of nuclear build programmes would be burdensome to the National Treasury, further reiterating the notion that the investment should rather be funnelled into growing the country's renewable energy capacity. This can be achieved by redirecting the investments to independent power producers (Arent et al., 2017). Other reasons are in the realm of health and safety in cases of nuclear accidents and the effect it might have on the economy. Figure 2 summarises the main concerns expressed by nuclear opposing entities:

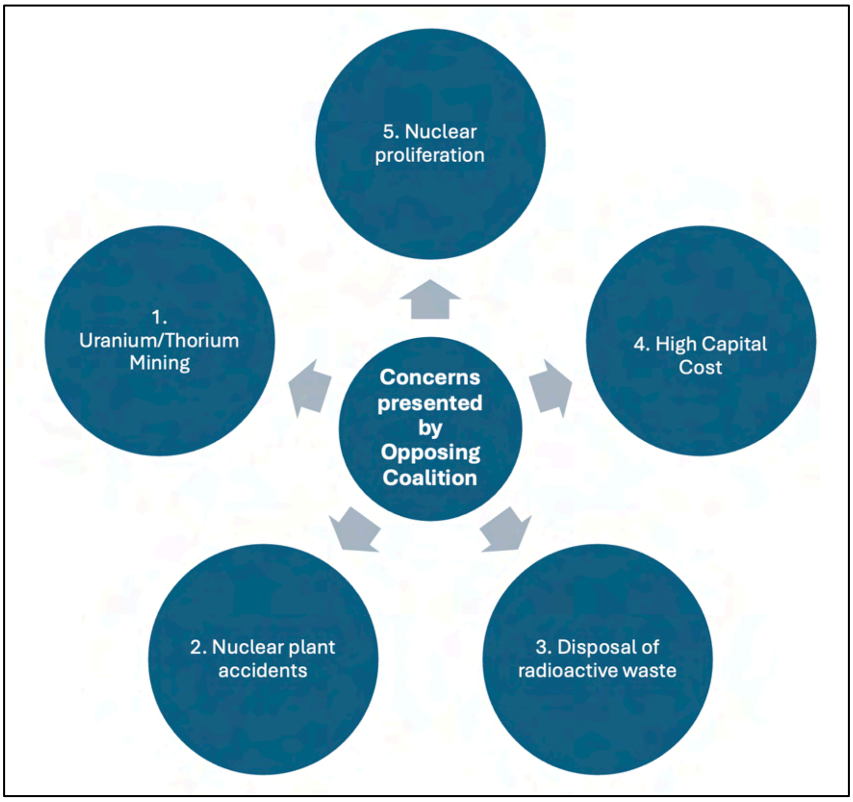

Figure 2: Concerns presented by the opposing coalition. Data sourced from: (Arent et al., 2017).

Some of these actors include the mine workers' unions, business associations, and a few governmental departments, along with various academic institutions (Chauke, 2018). There have been a few political parties that have come on board to oppose the further development of the nuclear sector due to the concerns stated above (Arent et al., 2017). Through an examination of the extensive network of anti-nuclear actors in South Africa, it can be observed that they also exist within the government. In contrast, the same government also argues for the expansion of the nuclear sector, thus presenting a conundrum to external observers.

2.4.6 Financial Costs of Nuclear Power

The emergence of nuclear power plants in the 1960s promised a 'cheap' form of power generation to such an extent that electricity produced from it was termed "too cheap to meter" (Cohn, 1997). However, this period of low-cost electricity from nuclear power was short-lived. The capital costs of building nuclear power plants have since skyrocketed, resulting in hindering the growth of the nuclear industry across the world. In 2009, a Massachusetts Institute of Technology (MIT) study used data from Japan and South Korea’s nuclear power plants to calculate the cost of nuclear power plants that were built between 2003 and 2007. The overnight cost of the plants was calculated to be an average cost of £ 4885 /kW with an annual increase rate of 15% between 2002 and 2007 (Du & Parsons, 2009). Harris et al. (2012) calculated the cost of a nuclear build programme in the UK to have overnight cost of approximately £ 4885 /kW (equivalent to $ 7 728 /kW in 2012) with an approximated levelized cost of electricity (LCOE) of £ 160 /MWh (Harris et al., 2012).

The capital cost of a nuclear plant is influenced by interest rates and the construction period for the plant. Furthermore, capital costs have a bearing on the LCOE accounting for over 60%. As technology improves, construction periods of plants have decreased, and this has allowed countries with continuous development programmes to maintain the capital costs of nuclear build programmes (World Nuclear Association, 2022). Once the hurdle of high capital costs has been overcome, nuclear power plants would come to offer a sense of relief in the form of low production cost of electricity and stability for the grid. To further illustrate this, Figure 3 shows the cost structure of nuclear power plants.

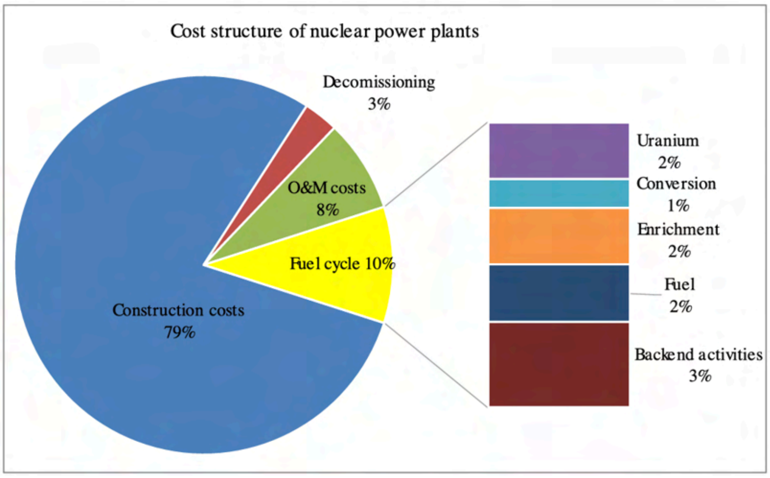

Figure 3: Cost Structure of Nuclear Plants (Haas et al., 2019).

2.5 Archetype of Nations favouring Nuclear Power

In 2012, Sovacool and Valentine published a book wherein they enquired about the factors that they believe must be intrinsic to a nation to serve as catalysts for the proliferation of prosperous nuclear programmes (Sovacool & Valentine, 2012). In this book, they have identified six aspects that catalyse nuclear power development, which are shown in Figure 4.

Figure 4: Theory of nuclear socio-political (Sovacool & Valentine, 2012).

The two authors studied eight nations at distinct levels of industrialisation, which were Japan, France, India, USA, Canada, Russia, South Korea, and China. The authors focused on the decades in which these countries' nuclear industries emerged and were able to identify these six commonalities among them that helped support their theory (Sovacool & Valentine, 2012).

In the book, Sovacool and Valentine identify six key factors shown in Figure 4 that sustain nuclear energy programmes: centralised and technocratic governance, strong state financial support, an established industrial base, strategic or military interests, a culture of secrecy, and international collaboration (Sovacool & Valentine, 2012). These elements are said to collectively drive investment in nuclear build programmes, shape policy framework, and reinforce institutional commitment, often outweighing economic or environmental considerations in nuclear decision-making (Sovacool & Valentine, 2012).

2.6 Conclusion of Literature Review

The literature review shows that South Africa has an extensive history of nuclear power, which dates back a half-century. In that time, there have been various developments ranging from policymaking to changes within the political structures, which have had significant bearing on the state of the country's nuclear power industry. Through continued research and development within the nuclear space, the country has been able to make some remarkable strides with the PBMR as evidence of this. This brings to light the heights that can be achieved when the government invests in purposeful skills development. However, the abandonment of the PBMR project at its height highlights the need to introspect the country's nuclear strategy and funding methods. The country's dependence on foreign investments and customers proved to be detrimental in that regard.

Drawing from Sovacool and Valentine's theory, it can be argued that South Africa shows deviations from the six commonalities they claim to create a successful nuclear nation. Testament to this is the departure the nation makes from the *'marginalisation of opposition in deference to political authority'* factor, especially with the freedom that is afforded to members of the nuclear opposition coalition.

The country's nuclear industry must adhere to diverse levels of regulation, including those set by domestic regulators NNR and NERSA and international regulator IAEA. This ensures that discussions and all major decisions about nuclear are not closed to the ruling party but are open to other participants such as direct-action groups and trade unions.

Although the government has made plans for the expansion of the nuclear power industry, looking back on some of the plans that were made over a decade back shows that there is a lack of follow through. Additionally, some of the proposed plans are not implemented or were not implemented. An example discussed in the literature review is the beneficiation strategy for uranium. There exists a lack of accountability in these government departments. There are various facets of the nuclear power industry highlighted in the literature review that the government can look to for improvement.

Table 2: Consistency table: Research Propositions

RO #	**Research Objectives**	**Proposition**
1	Analyse international case studies pertaining to countries with successful nuclear power programmes to draw comparison between their nuclear power strategies and South Africa's.	Countries such as France that have had successful nuclear build programmes lend themselves as perfect case studies to draw learnings from that will later form the recommendations.
2	Identify and expand on the factors that have hindered the growth of South Africa's nuclear power programmes through the consideration of socio-political, environmental, economic and leadership aspects.	South Africa has had opportunities that could have led to new nuclear build programmes; however, they all fell through due to lack of investment and limited customer interest (in the case of the PBMR). Other factors that came up within the global perspective include active nuclear opposition coalitions exacerbated by

RO #	Research Objectives	Proposition
		negative public attitudes towards nuclear health and safety.

CHAPTER 3. RESEARCH METHODOLOGY

This section provides insight into the methodology that the study followed in addressing the propositions that arose from the literature review. This chapter explains the research techniques that have been chosen for this research report. Furthermore, the section achieved its objectives by clearly outlining the research approach, research design, data collection methods, and the work schedule that was followed to ensure the completion of this project.

3.1 Research Approach

This research was carried out using qualitative research approach. A qualitative approach is an inclusive term for research methodologies that investigate events by analysing the behaviours and relations withholding the use of mathematical analysis and data processing (Basias & Pollalis, 2018). This type of methodology employs a variety of techniques that researchers use to explain, describe, or decode phenomena as opposed to measuring the frequency of certain events (Tenny et al., 2022).

This type of research methodology is well suited for this investigation as it provides recommendations based on learnings from nations that have successful nuclear build programmes. Qualitative research methodology allowed the study to examine South Africa’s nuclear industry by delving into literature, interacting with research participants through semi-structured interviews, and interpreting the data without dependence on mathematical analysis.

3.2 Research Design

A case study approach was chosen as a way to achieve one the research objectives. The case study approach is well suited for this research paper as it involves in-depth analysis of a particular phenomenon, and it also allows the exploration and understanding of complex phenomena (Zainal, 2007). For this application, the use of case studies is particularly useful in drawing learnings from other nuclear nations using various data sources so that rich, detailed, and informed recommendations may be formed. Some researchers have criticised case studies by stating that they lack rigour and can introduce bias into the findings (Yin, 1994). However, this is far outweighed by the advantages of the use of case studies and the ability of the researcher to improve the reliability and validity of the case study through meticulous planning (Quintão et al., 2020). Coupled with the case study is the use of interviews to collect information from the research participants.

3.3 Data Collection Methods

Data collection and analysis are imperative for conducting research. They are required to properly address the research objectives through methodological analysis and interpretation (Mazhar et al., 2021). Many data collection methods are suited for varied applications and are categorised accordingly. Primary data collection refers to data that is collected by the researchers themselves using questionnaires, interviews, etc, whilst secondary data is data that has been collected by other institutions such as the government, research institutions, or health facilities (Benedictine University Library, 2024). This study made use of both forms of data collection and the following data collection methods:

3.3.1 Interviews

Primary data was collected using interviews with selected participants. An open-ended interview, often referred to as an 'unstructured' interview, offers a considerable amount of flexibility to both the interviewer and interviewee when preparing the questions and other contents of the interview (Gubrium & Holstein, 2002). This study employed the semi-structured interview approach, which offers the benefits of the unstructured interview whilst maintaining a sense of organisation (George, 2022). In this case, the interviewer had the opportunity to ask follow-up questions to gain more information while the interviewee elaborated on particular points. An interview schedule was used to guide the interviews that were conducted for this study. The use of interviews was key to extracting crucial information from interviewees regarding their views and lived experiences within the nuclear power industry in South Africa.

All the interviews were conducted via Zoom. Each participant was interviewed individually, with the duration of the interviews varying between twenty minutes to an hour, depending on the length of the participants' answers.

3.3.2 Case Studies

According to Yin (2011), the use of case studies is appropriate when seeking to address a descriptive and/or explanatory research question. Case studies can provide rich descriptions of particular phenomena whilst also yielding insightful explanations of real-life events (Yin, 2011). Two countries (France and India) with successful nuclear build programmes were chosen for this study as they provided the chance to draw learnings from them that assisted in forming recommendations.

3.3.3 Literature

Literature reviews play a vital role in establishing the context of the research and equipping the researcher with enough information to form an opinion of the subject of study (Snyder & Hannah, 2019). Considering literature from different decades and places has helped provide an outlook on the current nuclear power industry and new developments. The literature was sourced from peer-reviewed journal articles, online newsletters/magazines, relevant nuclear power institutions, and government records and policies. These sources were accessed using search engines such as Scopus and Google Scholar. Publicly available literature sources such as operational manuals, government nuclear strategies, and published articles were sourced from search engines that include Scopus, Google Scholar, and government websites. This research made use of search key phrases that include 'nuclear energy', 'nuclear power plants', 'nuclear power build programmes', 'nuclear policy', etc.

3.4 Population and Sample

The study relied on purposive sampling for participant selection. In purposive sampling, participants of a study are chosen based on predetermined criteria

(McCombes, 2019). Participants of this study (also referred to as interviewees) were experts or role players from different facets that make up the nuclear industry of South Africa. Participants who have worked or currently work at institutions such as NECSA, NERSA, NNR, DMRE, private industry involved in nuclear operations, higher institutions of learning, National Treasury (and DFI’s), etc, participated in the study. They were either approached directly or through HR managers/personal assistants at their respective organisations. Those who were approached directly were telephoned and sent an email to which they confirmed their acceptance or refusal to be part of the study. The participants had the option of choosing between online interviews and face-to-face interviews to accommodate their schedules. The study aimed to interview 15 participants. However, only eleven (11) agreed to participate in the study.

3.5 The Research Instruments

3.5.1 Interview Schedule

The preparation for conducting interviews involved crafting an interview schedule that was able to extract useful information from the research participants. An interview schedule is a structured plan that outlines the topics to be discussed in an interview, along with the order and timing of the questions to be asked. It ensured that the interviewer was able to gather information systematically. An efficient schedule contains questions that prompt rich, nuanced responses from the interviewees (Bearman, 2019).

The interview schedule used in this study may be found in the appendix.

3.6 Data Analysis and Interpretation

Thematic analysis was used for this study. Cavendish (2011) described thematic analysis as a qualitative data interpretation method that entails systematically reading and rereading transcripts, all the while using comparative methods. This method of analysis allows researchers to organise and analyse complex data sets by searching for themes that accurately capture the narratives residing in those data sets (Cavendish, 2011; King, 2004).

Thematic analysis lends itself well to be applied to sets of data obtained through interviews and transcribed audio as it makes it possible to identify recurring themes (Caulfield, 2019). Although widely used in qualitative research, thematic analysis was not richly demarcated such that Braun and Clarke (2006) provided a guideline. The guideline outlines six steps researchers can use when analysing their data sets (Braun & Clarke, 2006). The six steps are shown in Figure 5 below:

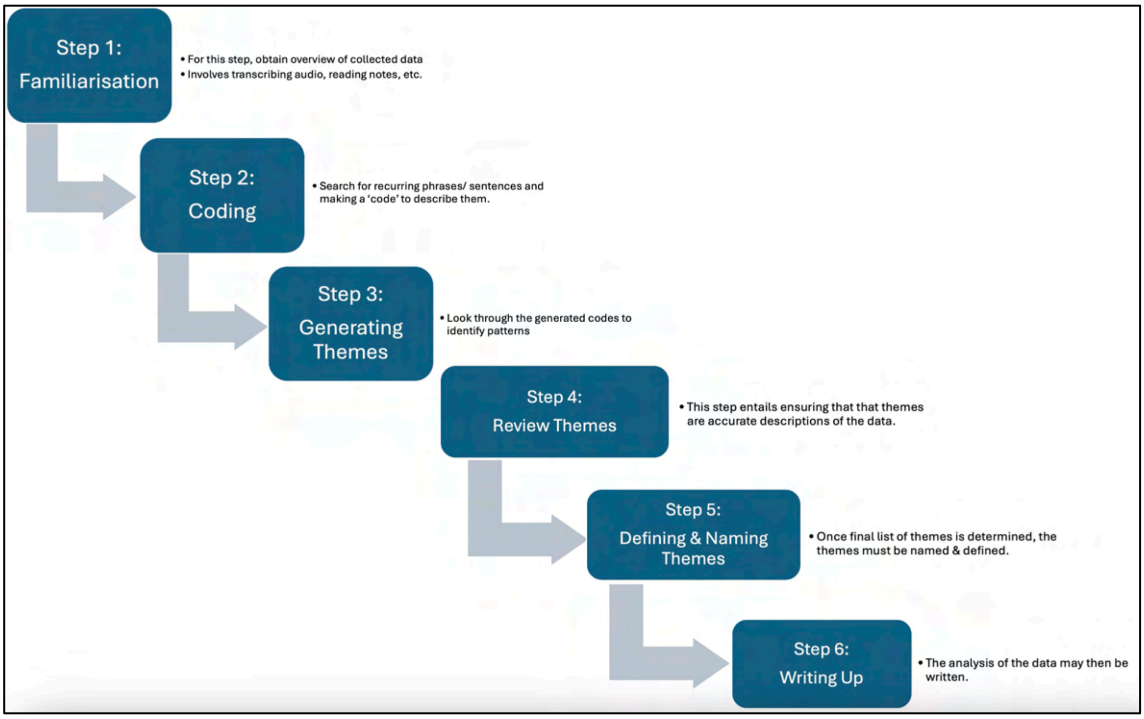

Figure 5: Steps for Using Thematic Analysis (Braun & Clarke, 2006; Caulfield, 2019)

Researchers suggest that following this six-step process can help to avoid confirmation bias, which is defined as the tendency to search and prioritise data or information that supports the researcher's pre-existing beliefs (Nikolopoulou, 2022a).

3.7 Limitations of the Study

3.7.1 Limitations Arising from Obtaining Participants

South Africa's nuclear industry is relatively small compared to the coal electricity generation industry, which may present a challenge in obtaining a higher number of participants for the study. This may lead to the reduced generalizability of findings and difficulties in obtaining a representative sample.

3.7.2 Limitations Arising from Data Collection

The availability of participants to take part in the study is not completely guaranteed in this instance. Their availability may be subject to their schedules, prior commitments, responsibilities, etc.

3.7.3 Limitations Arising from the Literature

There exists a challenge in finding peer-reviewed articles and related publications on South Africa's nuclear industry for a myriad of reasons. This might present a challenge when it comes to applying the historical analysis method.

3.7.4 Limitations Arising from the Research Instrument

The disadvantages associated with this research instrument are mainly rooted in the level of reliability and validity they offer with some authors going as far as believing that participants may exhibit Hawthorne's theory, which suggests that participants behave differently when they believe that they are being observed (George, 2022; Nikolopoulou, 2022b). However, there exist ways to increase reliability in interviews, which include the use of alternate-form questions. Ways to increase validity include purposeful sampling, triangulation strategies, peer debriefing, and using a guiding theory (Franklin et al., 2009). These validity and reliability techniques were considered in this study.

3.8 Validity and Reliability OR Trustworthiness

Trustworthiness of a study is described as the degree of confidence in the data, analysis/interpretation, and methodologies used to guarantee the quality of the study (Polit & Beck, 2021). Validity, as defined for qualitative research, refers to the suitability of the tools, processes, and type of data used for the study (Leung, 2015). It can be assessed by examining the alignment of the results with theories that have already been established, along with other metrics of the same idea (Middleton, 2019).

Increasing Validity in this Study

- Purposeful sampling: The process of sampling was informed by the research questions and objectives. Being able to reproduce findings across participants from different aspects of the South African nuclear industry increases credibility.
- Data triangulation: In qualitative research, data triangulation is a technique that involves employing varying methods or data sources to obtain a thorough grasp of the phenomenon (Carter et al., 2014). For this study, this meant a comparison between findings from interviews with existing literature about the subject at hand.
- Recording interviews to ensure that data is captured and transcribed as accurately as possible.
- The use of a guiding theory to confirm findings: The theory reported by Sovacool and Valentine (2012) of successful nuclear nations described in Chapter 2, was used briefly as a guiding theory.

Reliability refers to the extent to which the findings of the study can be reproduced (Middleton, 2019). For this study, reliability and dependability were increased by the following actions:

- The use of alternate-form questions in the interviews helped reduce response bias by allowing the interviewer to ask the same question in varied wording/format.
- Cross-checking the interview transcriptions.

3.9 Ethical Considerations

This study involved human participants who were interviewed to collect the key primary data. The risk category associated with this level of human participation, according to the University of Witwatersrand, was ‘minimal risk’. Minimal risk was considered, at worst, an inconvenience to the participants. Adopting ethics when conducting research is vital to the protection of the research participants’ rights, well-being, and dignity (Resnik, 2020). Additionally, ethically conducting research safeguards the integrity of the study. In a quest for an ethical research process, ethical clearance from the University and relevant authorities was pursued. Ethical clearance provided by the University is attached to the appendix.

Further actions that were taken to ensure an ethical research process included the following:

- Ensuring that the research participants understood the purpose of the study, the extent of their participation, the risks, and how their inputs were going to be utilised in the study.
- Obtain informed consent from the research participants.
- Safeguard the rights and privacy of the research participants by maintaining their anonymity.
- Acknowledge research participants’ autonomy and inform them of their right to withdraw from participating in the research at any point without facing consequences.
- Ensuring that interviews took place in a safe manner and area that was free from harm.
- Review and address other ethical concerns that would arise at any point during the research process.

3.10 Consistency Table

Table 3: Consistency table: research questions, propositions, data collection, and data analysis

RO #	State Research Objective	Data collection detail	Data analysis method
1	Analyse international case studies pertaining to countries with successful nuclear power programmes to draw comparison between their nuclear power strategies and South Africa's.	Case Study Interview schedule	Thematic analysis
2	Identify and expand on the factors that have hindered the growth of South Africa's nuclear power programmes through the consideration of socio-political, environmental, economic and leadership aspects.	Interview schedule Literature Review	Thematic analysis

CHAPTER 4. FINDINGS & DISCUSSION

4.1 Introduction

This study intends to provide a brief overview of the current state of the nuclear energy industry in South Africa, whilst critically examining the policy development, regulatory frameworks, strategies, successes and challenges of nuclear power programmes in the selected countries. The study further identified and expanded on factors that have influenced South Africa's nuclear energy industry.

The first two sections of this chapter assess nuclear build programmes in France and India. Each case study examines the policy developments and regulatory frameworks that have facilitated successful nuclear energy programs in those two countries. These case studies also explored a range of other factors such as social, economic, and political aspects. The case studies follow a standardised format to enable meaningful comparison across the different contexts.

The third section of this chapter presents the discussion of the case studies and findings from the interviews with the energy industry experts, thus giving a picture of South Africa's nuclear energy opportunities and barriers. A detailed interpretation and analysis of the themes that link them to a broader context and the research objectives was also presented in this chapter. The fourth section presents the themes and findings from the semi-structured interviews.

4.2 Case Study 1: France

4.2.1 Overview of the Nuclear Energy Sector in France

France, as shown in Figure 6, is a developed country situated in Europe with a population of approximately 68 million people (Central Intelligence Agency, 2024a). The country serves as an excellent case for this study as it hosts what is considered one of the world's most established nuclear power programmes with a high nuclear share within its electricity mix. Its long-standing nuclear programme brings with it insight into the French government's commitment to supporting nuclear as a strategic energy source and the centralised planning that upheld this commitment.

Figure 6: Map of France. Source: (Central Intelligence Agency, 2024a)

Furthermore, France offers this study an opportunity to take lessons from its regulatory structures, standards, crisis management, and technological expertise encompassing reactor advancements and nuclear fuel cycle management, along with economic and environmental considerations taken by the country. Based on the aforementioned statement, it is of the view that these are some of the aspects to consider when formulating recommendations that will provide a multi-faceted approach to create a framework that enables the growth of a successful nuclear programme.

4.2.2 Brief history of Nuclear Programmes in France

The foundation of France's nuclear power history is based on research work that was done by French scientists, which led to the discovery of radioactivity within radium (Center for Nuclear Studies, 2012). This resulted in the French government instituting the Commissariat à l'Enérgie Atomic (CEA), which served to encourage further advancements of nuclear research and application in the fields of energy, medicine, and defence (Center for Nuclear Studies, 2012). All those advancements resulted in a joint project between the CEA and state utility Électricité de France (EDF), which developed the country's first completely French nuclear reactor, Marcoule, in 1955. This reactor was used primarily for military and research purposes. France's first commercial nuclear reactor, the Chinon A-1, was connected to the grid in 1963 (Center for Nuclear Studies, 2012; International Institute of Nuclear Energy, 2021).

In the 1970s, France's electricity supply industry experienced a significant shift. This shift was rooted in the oil crisis that occurred as the Organisation of Petroleum Exporting Countries (OPEC) increased the price of a barrel from $1.80 to $11.65 from 1970 to 1973 (Yergin, 2023). This prompted France to strive towards energy independence and thus launch an ambitious nuclear energy programme referred to as *Plan Messmer,* which was coordinated by the then government (Le Gros, 2020).

Plan Messmer, launched in 1974, drove the construction of 13 nuclear power plants, with each plant producing 1000 MW of power (Le Gros, 2020). The programme was managed by the state-owned utility company Ėlectricitė de France (EDF). The country streamlined the construction of the reactors, thereby enabling rapid adoption, expansion, and operational efficiency across its nuclear fleet. This decision resulted in France becoming the world's most nuclear-dependent country, with 58 nuclear plants constructed to date, as depicted in Figure 7 (Le Gros, 2020; WTS Energy, 2023).

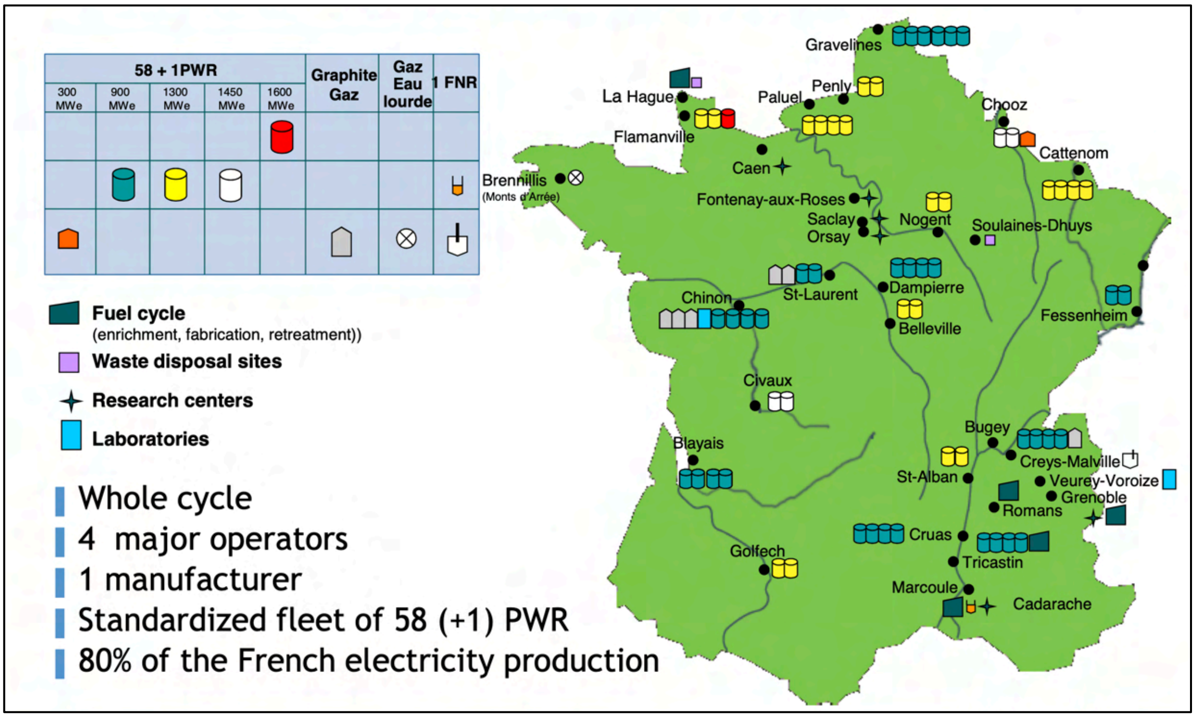

Figure 7: Map of France's nuclear facilities. Source: (Guimier, 2014)

Two of these reactors have since been decommissioned, leaving the country with 56 operable reactors scattered across different nuclear facilities (mostly operated by EDF). Currently, one more reactor is under construction in Flamanville, Normandy (World Nuclear News, 2024c). The nuclear power produced by these reactors cumulatively amounts to 61,370 MW(e) of the country's electricity mix, placing France in the top 3 list of nuclear power-generating countries globally (International Atomic Energy Agency, 2022).

As outlined by WTS Energy (2023) and shown in Figure 8, the number of projected nuclear reactors in France by 2030 demonstrates a planned increase in production capacity.

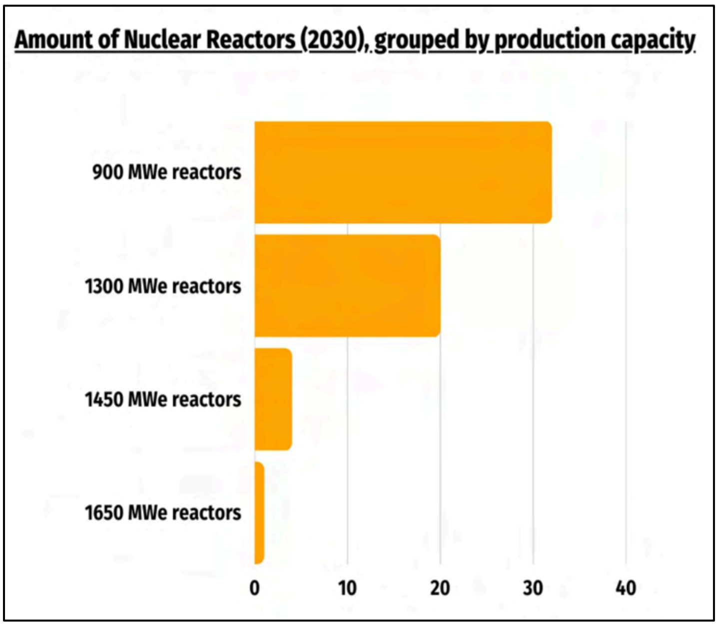

Figure 8: Number of nuclear reactors in France projected for 2030. Source: (WTS Energy, 2023)

Furthermore, Figure 9 illustrates the evolution of France's energy consumption by source from 1965 to 2020 and highlights the shift from fossil fuels to nuclear and renewable energy over time.

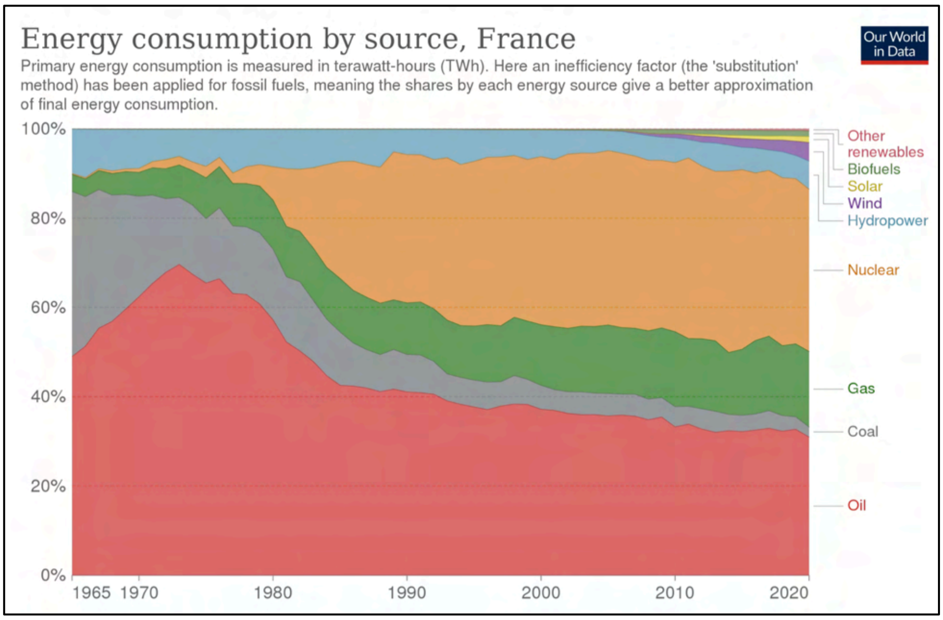

Figure 9: Energy consumption in France over the years. Source: BP Statistical Review of World Energy

Moreover, nuclear energy accounts for over 70% of the country's domestic energy production, as illustrated in Figure 10, with nearly 65% of that accounting for a portion of the country's electricity mix (IEA, 2024; Statista, 2024).

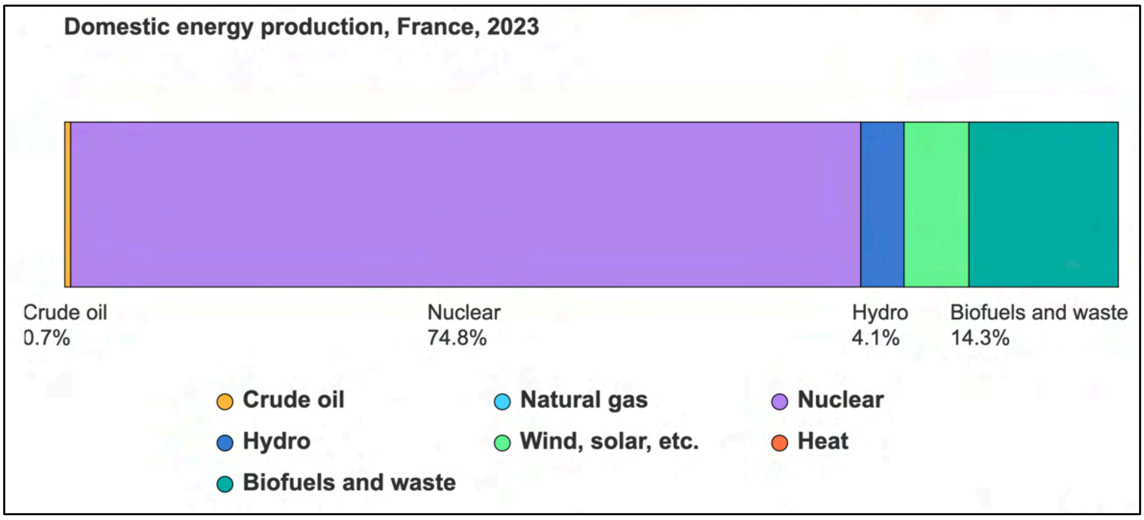

Figure 10: Domestic energy production in France, 2023. Source: IEA

Figure 11 presents the total energy supply in France for 2023, highlighting the share of different energy sources. The figure shows the dominance of nuclear energy, followed by oil and natural gas in the country's energy mix (IEA, 2024).

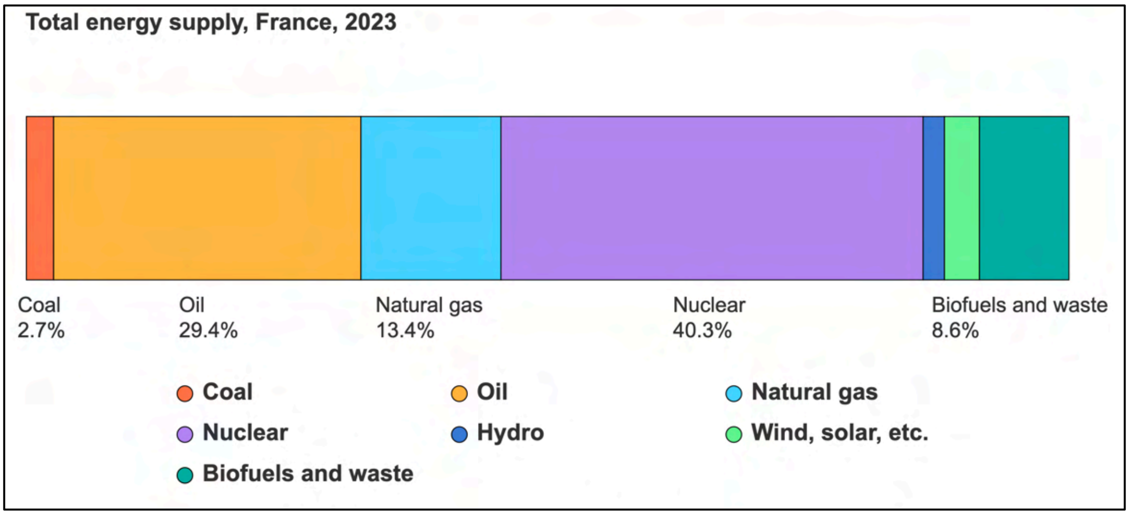

Figure 11: Total energy supply of France, 2023. Source: IEA Licence CCBY 4.0

4.2.3 Regulatory Framework

The regulatory architecture of France's nuclear energy industry is structured in a manner that promotes nuclear safety, transparency, and compliance through the involvement of multiple governmental and independent bodies. Figure 12 illustrates the hierarchical structure of nuclear regulatory frameworks in France, distinguishing between legally and non-legally binding domains. The Figure highlights the roles of Parliament, the executive power, and the French Nuclear Safety Authority (ASN) in establishing laws, decrees, orders, decisions, and guidelines (Guimier, 2014).

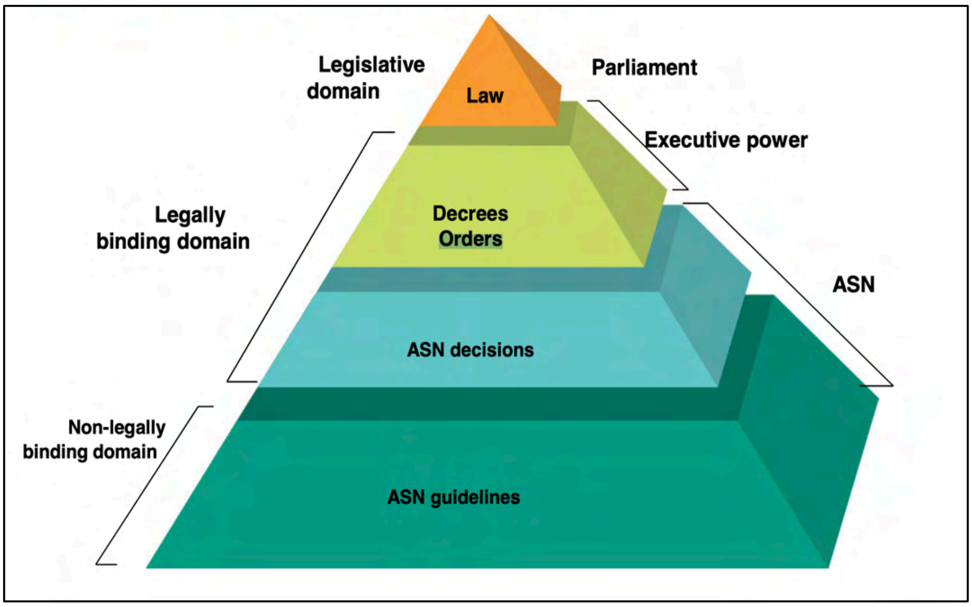

Figure 12: Regulatory architecture of nuclear energy in France. Source: (Guimier, 2014)

4.2.3.1 Primary Responsibilities

Several entities play paramount roles within France's energy systems. For example, the French government is the highest body responsible for the regulatory framework, with tasks that include the issuing of laws, decrees, and ministerial orders. Ministries such as the Ministry of Ecological Transition are delegated the task of implementing and supervising regulations (Guimier, 2014). The government-owned plant operator, EDF, has the primary responsibility for electricity generation and distribution in France. As such, it operates a fleet of 56 nuclear power reactors spread across the country. In addition, EDF ensures safety, reliability, and efficiency in the production of nuclear energy whilst adhering to a strict regulatory framework (Guimier, 2014). There are key regulatory bodies in the country responsible for an independent and well-regulated nuclear sector, and these are discussed in the section below. These entities and their roles are based on information from the International Atomic Energy Agency (IAEA) report on France’s regulatory framework (Guimier, 2014)

4.2.3.2 Key Regulatory Bodies

- Autorité de Sûreté Nucléaire (ASN), commonly referred to as the Nuclear Safety Authority, is an independent body that regulates nuclear safety and radiation protection. Its key roles include proposing or advising on ministerial decisions, issuing legally binding directives (technical rules and guidelines) approved by the government, conducting inspections, granting authorisations, and enforcing compliance. The scope of the ASN also extends to the protection of the environment and the labour force within the industry (ASN, 2024).
- The Institute for Radiological Protection and Nuclear Safety (IRSN) is a technical support organisation that assists ASN through conducting safety analyses and research (IRSN, 2024).

4.2.3.3 Support and Advisory Structures

- Advisory Committees of Experts (GPE): This group is comprised of experts across seven (7) different specialities (nuclear waste, nuclear reactors, transport, laboratories & plants, nuclear pressure equipment, medical exposure, and radiation protection). These experts are nominated based on their competencies (Guimier, 2014). They provide input on these specified specialities.
- Local Information Committees (CLI): These exist for each nuclear site. They serve to facilitate local stakeholder management and disperse public information regarding nuclear (Guimier, 2014).

- High Committee for Transparency and Information on Nuclear Security (HCTISN): They serve to advise the government and Parliament regarding nuclear safety and public communication issues (Guimier, 2014).

The expansion of France's nuclear industry can also be attributed to the nature of decision-making that existed within the French government in the 1970s. France's nuclear policies were outliers (compared to other countries) in the sense that they outlasted major changes in governments over the years. How the government was structured then allowed the President and the government branches it controlled to implement the *Messmer Plan* without much debate from the National Assembly or Parliamentary vote (Andersson & Finnegan, 2024). The plan was carried out by presidential decree, thereby allowing it to bypass the parliamentary debate/voting process. As such, the plan could not be delayed or obstructed by any opposition parties, lawmakers, the private sector, etc. The strong executive branch of government was able to implement the *Messmer Plan* with full commitment (Andersson & Finnegan, 2024; Fagnani & Moatti, 1984).

The *Messmer Plan* stood for years since there was no opposition coalition strong enough to challenge it successfully (Andersson & Finnegan, 2024). This environment allowed labour unions and companies with pro-nuclear interests to strengthen to the point of opposing any anti-nuclear policy stances. By the mid-1980s, companies had invested extensively in nuclear, such that phasing it out for whatever reason was not viable. These factors led to the depoliticization of nuclear energy in the country and nurtured the development of a coalition capable of opposing any stance against the nuclear policy embedded in the *Messmer Plan* (Andersson & Finnegan, 2024; Brouard & Guinaudeau, 2015; Nelkin & Pollak, 1980).

The following tables outline key aspects of France's nuclear governance, essential for understanding its success. Table 4 covers international commitments ensuring safety and non-proliferation. It also details national laws that provide regulatory stability and highlights decrees and orders that guide industry operations within the nuclear sector.

Table 4: French Nuclear Legislature.

International Agreements and Norms	
Convention on Nuclear Safety	This is an international treaty that whose purpose is to maintain a particular level of nuclear safety.
IAEA Safety Fundamentals and Standards	The IAEA provides guidelines that serve to ensure nuclear safety.
International Commission on Radiological Protection (ICRP)	This organisation provides recommendations that assist in ensuring protection radiation standards are met by each nuclear facility.
European Regulations	
European Treaty	This treaty is part of the legal basis for the regulation and development of nuclear energy for member nations of the European Union (EU).
European Council Directives	- 2009/71/EURATOM (25/06/2009): This directive establishes a framework regarding the safety of nuclear installations (European Union, 2009). - 2011/70/EURATOM (19/07/2011): This council directive establishes a framework that upholds the responsible and safe management of spent fuel and radioactive waste (European Union, 2011).

National Laws and Codes	
TSN Act (Act of June 13, 2006)	This is a national law that focuses on transparency and security within the nuclear energy sector, it is incorporated in the Environment Code too (Nuclear Safety Authority, 2006a).
Waste Act (Act No. 2006-739, June 28, 2006)	This act pertains to the sustainable radioactive waste and materials management (Nuclear Safety Authority, 2021b).
Public Health Code	Has radiation protection provisions.
Environment Code	Includes nuclear transparency and safety regulations.
Labour and Defence Codes	Has necessary provisions for nuclear activities.
Regulatory Decrees and Orders	
Decree of November 2, 2007	Relates to basic nuclear installations (BNI) along with control in nuclear safety, transport and radioactive material (Nuclear Safety Authority, 2021a).

4.2.4 Economic and Financial Factors

Alongside energy security, the French government's objectives with the *Messmer Plan* were to foster an environment that would breed internationally recognised nuclear specialists in efforts to win over global exports, thus assisting France in becoming a global leader in the nuclear industry. Moreover, other benefits also included creating employment within the nuclear industry whilst encouraging competition and thus creating a breeding field for innovation. A benefit that was not initially forthcoming was that of helping France reduce its greenhouse gas emissions (Andersson & Finnegan, 2024).

Furthermore, France viewed the *Messmer Plan* as a national priority due to the economic stability it presented in the long run. As such, the government intensified funding for the plan. Furthermore, the EDF was delegated the task of implementing the plan by managing the construction, operation, and maintenance of the nuclear power plants. EDF was well-supported by the state with ample financial resources made available to them, along with the backing of legislation aimed at nuclear energy capacity growth (Fagnani & Moatti, 1984).

The capital funding required by the EDF for nuclear power expansion came through an array of state loans and loan guarantees that were underpinned by industrial policies (Andersson & Finnegan, 2024). The EDF was able to take out new loans, with the French government as its guarantor. This backing helped to improve the EDF's credit rating and reduce the cost of capital by lowering borrowing costs. Half of this capital came from the USA, whilst the other half came from French investors. By 1976, the EDF was one of the biggest borrowers in the USA capital markets. In the decade that followed the announcement of the *Messmer Plan,* 51 nuclear reactors had been ordered (Andersson & Finnegan, 2024; Jasper, 1990).

As of 2024, France plans to finance the construction of six new reactors through a blend of an array of state support mechanisms (Mallet, 2024). The government intends to issue a zero-interest loan to the EDF so that it may cover a majority of the project's cost. In addition, this plan includes a contract of difference (CfD), a long-term guaranteed price for the electricity to be generated by these reactors that will not only ensure financial stability for the EDF but also attract investors by ensuring a steady revenue stream (Mallet, 2024). This plan is subject to approval by the French finance minister and the EU.

4.2.5 Public Perception and Social Acceptance

It can be argued that the social perception and reception of nuclear energy have been largely influenced by safety, environmental, and economic concerns. France presents itself as a special case since nuclear energy is integral to the country's economic fabric and, most importantly, its energy security. Examining the public opinion of nuclear power in a country with a strong tradition of centralised governance offers an opportunity to gain insights into how this approach affects public involvement in the development of nuclear policies and, consequently, the further development of nuclear power in a country.

A 1990 IAEA bulletin highlighted the importance of the public's confidence in the growth of nuclear power in any country (Chaussade, 1990). This was particularly evident in the aftermath of the 1986 Chernobyl accident, which caused a shift in the public's support of nuclear power. Before the Chernobyl accident, nuclear power was already positively perceived in France, with 62% of the public in support of it by the end of 1985. However, that percentage experienced a sudden drop to 46% by November 1986 (Chaussade, 1990).

Figure 13 depicts survey results conducted by SOFRES, the French Opinion Poll Organization, on public attitudes toward nuclear power in France over three years (IAEA, 1990), Respondents were given three options regarding the future of nuclear power in France. The respondents had to choose between the continued construction of nuclear power plants, maintaining existing plants without new construction, or shutting down all nuclear power plants. The majority of the public favoured maintaining existing plants without new additions, while support for new construction declined slightly over time (Chaussade, 1990).

FRENCH PUBLIC OPINION AND NUCLEAR POWER

Question: Which of these three options would you prefer for France?

	Nov. 1986	*May 1987*	*Oct. 1988*	*Oct. 1989*
Nuclear power plants should continue to be built	19	19	15	14
No new nuclear power plants should be built, but existing plants should continue to operate	63	60	65	67
All nuclear power plants should be shut down	14	16	17	15
No opinion	4	5	3	4
TOTAL	100%	100%	100%	100%

Polls by SOFRES (the French Opinion Poll Organization) reflect the attitudes of the French public to nuclear power plants. Results have been stable for the past 3 years.

Figure 13: French Public Opinions on Nuclear Power in the 1980s (Chaussade, 1990).

In efforts to address public awareness and confidence in nuclear power, the EDF and other relevant nuclear bodies implemented strategies meant to inform, encourage public participation, and reassure the public, especially in times of major nuclear disasters (Chaussade, 1990).

The EDF improved public engagement and education by organising visits to nuclear plants, where they would host over 300 000 visitors each year, 40% of whom were school children. They also established information centres near nuclear power facilities which had teaching aids, models, videos and computers. These information centres attracted at least 200 000 visitors annually. The EDF supplemented this by educational outreach programs that would send information packs to schools across the country (Chaussade, 1990).

Furthermore, the EDF had a targeted professional outreach aimed at medical professionals that addressed the implications of Chernobyl by providing information on the effects of radiation to doctors, pharmacists, nurses, and other health professionals. Teachers and community leaders were given educational packs (Chaussade, 1990).

Another key focus was ensuring transparent communication with the public. The EDF held itself accountable for providing objective information to the public while addressing public questions without any distortion. Part of this communication included outlining the importance of nuclear power to both the environment and the economy. They adopted the International Nuclear Event Scale (INES), which is a tool that can be used to improve public and media understanding of nuclear incident severity (Chaussade, 1990).

It is also important to note that France has continuously taken surveys and polls to gauge the public's attitudes towards nuclear power throughout the 1980s to the present day, with the latest survey conducted by consulting firm Brulé, Ville & Associés (BVA) in partnership with Orano (Brulé, 2019). Understanding public sentiment helps the government and other relevant nuclear bodies to identify concerns about nuclear power, build trust, and be transparent through encouraging public engagement. It also assists in the development of informed policymaking tailored with the consideration of those it affects, the public (Brulé, 2019). Finally, it also helps to avert risks such as protests against nuclear build construction.

Figure 14 below depicts survey results on public sentiment toward nuclear energy in France in 2022. According to Statista (2024a), 60% of respondents expressed a positive outlook on nuclear energy, while 40% held a negative outlook. This data highlights a generally favourable perception of nuclear power among the French public, reflecting ongoing debates about its role in the country's energy future.

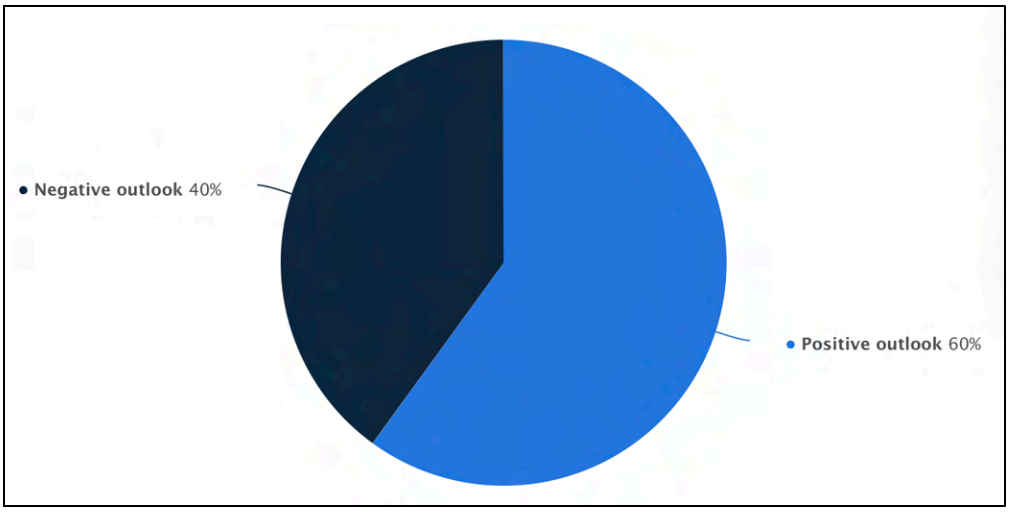

Figure 14: Public Opinion on Nuclear in France, 2022. Source: (Statista, 2024a)

4.2.6 Safety and Security

Between 1940 and 1970, nuclear safety measures were rudimentary and mostly dependent on engineering standards and emerging international standards. Circa 1970s, nuclear safety was overseen by various departments within the Ministry of Industry and the Ministry of the Environment. The construction of the 58 pressurised water reactors following the launch of the *Messmer Plan* was overseen by the IAEA (Autorité de Sûreté Nucléaire, 2006; Hadna, 2017).

As it stands, the French Nuclear Safety Authority (ASN) regulates nuclear safety and radiation protection in efforts to ensure the safety of workers, the public, and the environment. The body was set up by Law 2006-686 of 13 June 2006, also commonly referred to as the TSN law (Nuclear Safety Authority, 2006). The TSN law granted the ASN new legal authority and powers to become more independent and legitimate in overseeing nuclear safety and radiation protection. The ASN plays an impartial and credible role as a regulator that is recognised not only nationally but globally, where it constitutes an international benchmark (ASN, 2024; Nuclear Safety Authority, 2006). As outlined in the French Nuclear Safety Authority's official website (ASN, 2024), the ASN's key responsibilities include the following:

- It is involved in the shaping of nuclear regulations through working together with the government on draft decrees and ministerial orders.
- ASN ensures that installations are compliant with relevant specifications and rules.
- ASN is also responsible for dispersing information on nuclear activities to the public and vital nuclear power industry stakeholders (ASN, 2024).

Following the Chernobyl Disaster of 1986, France strengthened its regulatory and safety framework on nuclear activities (Autorité de Sûreté Nucléaire, 2006). South Africa could enhance the safety, governance, and public confidence in its nuclear energy sector by learning from France's post-Chernobyl improvements, summarised below:

As per the Autorité de Sûreté Nucléaire official website (Autorité de Sûreté Nucléaire, 2006), the following are key lessons learned by France from the Chernobyl disaster:

- Improved reactor design with increased safety factor: France has since introduced systematic research into unforeseen nuclear accident scenarios and, as such, has implemented measures to mitigate risks in nuclear reactor operations (Autorité de Sûreté Nucléaire, 2006).
- Improved organisational factors and human management: The Chernobyl Accident illustrated the impact that poor organisation and human error have on nuclear safety. In response, France developed the concept of "safety culture" and methodically integrated it into all nuclear facility operations (Autorité de Sûreté Nucléaire, 2006).
- Improved emergency preparedness: Off-site emergency plans (PPIs) and internal emergency plans were developed to effectively address potential nuclear incidents. These plans both outline a specific set of actions to be taken in the case of an incident to ensure the protection of the public whilst managing the potential release of radiation from those nuclear facilities (Autorité de Sûreté Nucléaire, 2006).
- Improved public communication and transparency: The confusion that followed the Chernobyl disaster highlighted the need for improved communication with the public regarding nuclear risks. France addressed this by opening a nuclear communication channel on INES, which was able to rank incidents by severity. Today, the ASN media outlets can provide real-time updates on nuclear operations to help ensure transparency and accountability (Autorité de Sûreté Nucléaire, 2006).
- Strengthened global collaboration: France participated and continues to participate in international conferences and conventions that are aimed at preventing accidents whilst effectively managing the consequences that ensue. France also works in collaboration with neighbouring countries in sharing monitoring data to help improve cross-border responses to nuclear incidents (Autorité de Sûreté Nucléaire, 2006).
- Better monitoring and radiation protection: France has since continued to modernise and innovate its radiation monitoring network to better enable

it to detect and effectively respond to any changes in radiation in the environment. Most measurement systems have been automated to trigger alerts in the case of exceeded thresholds. The nation also began distributing stable iodine tablets nationwide. In the present day, those living within a 10km radius of nuclear reactors can collect these tablets from their local pharmacies to use in the case of a nuclear accident (Autorité de Sûreté Nucléaire, 2006).

- Institutional and structural reforms: The French government began reorganising nuclear safety institutions after the Chernobyl incident. This gave rise to the merge of nuclear safety and radiation protection entities to form the General Directorate for Nuclear Safety and Radiation Protection (DGSNR), which has now become the independent body ASN as of 2006. ASN now performs all operator monitoring roles, which include oversight from the design stage to the decommissioning of nuclear facilities. This also covers over 700 inspections that are carried out annually by ASN (Autorité de Sûreté Nucléaire, 2006).
- Engaging in post-accident management: The country contributed to international working groups, including those under the OECD Nuclear Energy Agency, where they work towards optimising their post-accident management strategies (Autorité de Sûreté Nucléaire, 2006).

Ultimately, the Chernobyl Disaster catalysed the changes that France's nuclear industry had to undergo to fortify its nuclear safety framework. These are the same lessons that have ensured that France is viewed as an international benchmark for best nuclear safety practices (ASN, 2024; Autorité de Sûreté Nucléaire, 2006).

Currently, France prioritises advanced regulatory frameworks associated with nuclear safety and security. ASN still plays an integral role in these efforts by ensuring that all nuclear facilities comply with the rigorous standards that are in place to protect the public and the environment (ASN, 2024). For example, in keeping with nuclear safety standards, the country is currently involved in the advancement of nuclear reactor designs, as evidenced by the Flamanville European Pressurised Reactor (EPR) project that is led by the EDF (Hernandez, 2024). The reactor design promises enhanced safety features, which include improved containment systems and passive safety mechanisms. Additionally, the country has invested in research for small modular reactors and next-generation reactors with improved safety features (Hernandez, 2024; World Nuclear News, 2024c).

With most of France's nuclear reactors built in the 1980s, it is paramount that their life extension programmes include regular maintenance, upgrades, and assessments that will be able to identify and address ageing infrastructure-related vulnerabilities that affect safety (Center for Nuclear Studies, 2012). To enforce this, ASN oversees the decisions on the extension of reactor lifecycles. Following the 2011 Fukushima incident, France implemented additional safety measures that included the creation of emergency response centres and reinforcements of cooling systems that would be able to withstand extreme events (Center for Nuclear Studies, 2012; Crellin, 2023).

4.2.7 Radioactive Waste Management and Environmental Considerations

France is reported to have nearly 1200 radioactive waste producers across the following sectors: nuclear power generation, research, defence, medicine, and other non-nuclear power industries (Orano, 2024a). The French National Agency for Radioactive Waste Management (ANDRA) is a state-owned entity that coordinates long-term radioactive waste management by developing tailor-made waste management solutions for all waste groups in the country and other French territories (ANDRA, 2024b). These solutions are governed by the National Radioactive Materials and Waste (PNGMDR) national plan. Operator EDF is responsible for the management of radioactive waste generated by nuclear power plants in France (EDF, 2024b; Orano, 2024a).

According to the EDF, 90% of the radioactive waste produced from the operation, maintenance, and decommissioning of nuclear plants has low radioactivity levels and half-lives that are limited. The remaining 10% is said to be highly radioactive, with a half-life that can reach ranges of tens of thousands of years (EDF, 2024b). Further classification of radioactive waste in France is shown in Figure 15 below.

<table>
<tr><th></th><th>Very short lived
(T < 100 days)</th><th>Short lived
(T < 31 years)</th><th>Long lived
(T > 31 years)</th></tr>
<tr><td>Very low activity level (VLL)</td><td rowspan="3">Natural radioactive decay on production site</td><td colspan="2">Surface storage
(CIRES waste collection storage and disposal facility)
VLLW</td></tr>
<tr><td>Low activity level (LL)</td><td rowspan="2">Surface disposal
(CSA waste disposal, Aube)
LILW-SL</td><td>Subsurface disposal
(research ongoing)
LL-LLW</td></tr>
<tr><td>Medium activity level (ML or IL)</td><td>ILW-LL</td></tr>
<tr><td>High activity level (HL)</td><td></td><td colspan="2">Reversible deep geological disposal
(research ongoing under the Act of 28 June 2006)
HLW</td></tr>
</table>

Figure 15: Radioactive Waste Management and Environmental Considerations. Source: (Radioactivity EU, 2024).

From Figure 15, it can be observed that radioactive waste is categorised based on its activity level and half-life, which determine its potential hazards and required disposal methods. In France, ANDRA classifies radioactive waste into several categories to ensure safe handling, storage, and disposal (Radioactivity EU, 2024). According to ANDRA, the main waste classifications include the following:

High-level waste (HLW) is placed in immediate storage at Orano La Hague after it has been conditioned in containers that are made of stainless steel (Orano, 2024a). HLW is derived from the reprocessing of nuclear fuels that are unloaded from nuclear reactors. France uses a reprocessing strategy at facilities such as La Hague to recycle usable plutonium and uranium in efforts to reduce waste volumes. Even though HLW accounts for 0.2% of all radioactive waste, it contains 96% of all the radioactivity in the total volume of nuclear waste (Orano, 2024a; Radioactivity EU, 2024).

Very Low-level waste (VLLW) is less risky compared to HLW. The volume of VLLW is expected to increase as more old nuclear power stations are decommissioned. Examples of this type of waste include filters, resins from nuclear power plants, and waste from labs, hospitals, and other industries. This type of waste makes up 63% of the total waste volume but only 0.02% of the radioactivity (Orano, 2024a; Radioactivity EU, 2024).

Intermediate-level waste (ILW) has moderate radioactivity. It includes reactor components and reprocessing residues that require containment but do not generate significant heat. Due to long-lived radionuclides, ILW is typically stored in deep geological repositories (Orano, 2024a; Radioactivity EU, 2024).

High-level waste (HLW) is highly radioactive, mainly from spent nuclear fuel and reprocessing residues. It generates intense heat and requires cooling before deep geological disposal. Due to its long-lasting radioactivity, HLW warrants strict containment for safe long-term storage (Orano, 2024a; Radioactivity EU, 2024).

Figure 16 presents a classification system for radioactive waste based on two key factors: half-life (short-lived vs. long-lived) and activity level (very low, low, intermediate, and high). The classification is structured as follows:

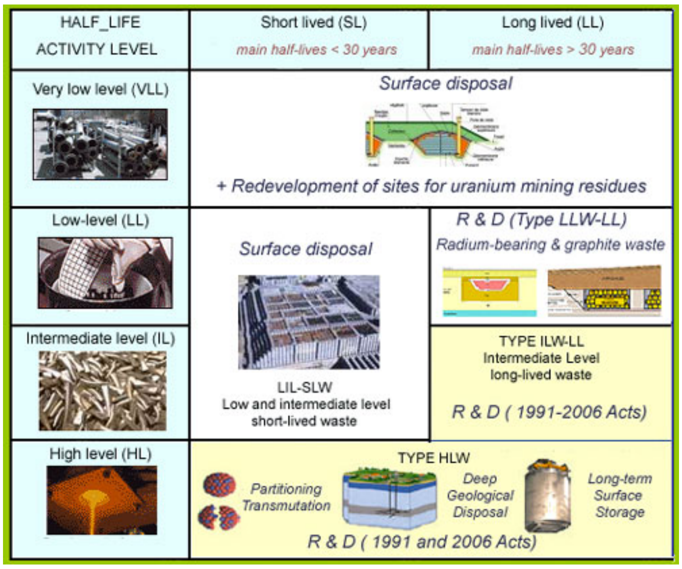

Figure 16: Management of Radioactive Waste in France Source: (Radioactivity EU, 2024)

Additionally, France has had its hand in pioneering the design of the European Pressurized Reactor (EPR), which embeds improved safety mechanisms, increased efficiency, and reduced waste produced during operations, as depicted in Figure 17 below. This design is currently being rolled out at the Flamanville 3 plant and in other countries (Leverenz et al., 2004).

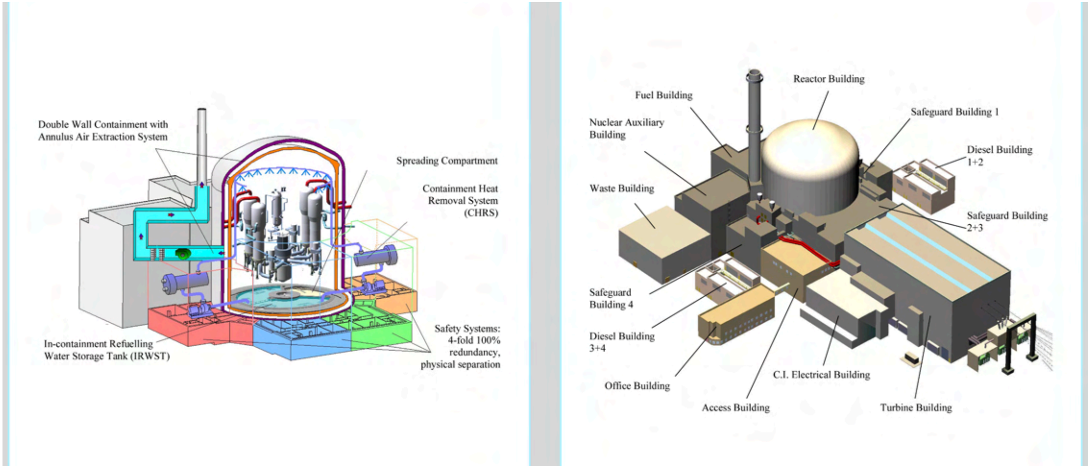

Figure 17: EPR Safety features and main plot of plant, protection from external factors. Source: (Leverenz et al., 2004)

France also hosts world-leading nuclear fuel reprocessing facilities, Orano La Hague and Melox. Both facilities hold a combined 55 years' worth of operational experience in nuclear waste management (Orano, 2024b). France is also involved in advanced research on geological repositories that focus on the long-term storage solution for highly radioactive nuclear waste. An example of this is the Cigeo, The Industrial Centre for Geological Disposal, project (ANDRA, 2024a; Orano, 2024b).

The EDF has identified the potential that small modular reactors (SMRs) have a role to play in curbing the consequences of climate change (EDF, 2024a). As such, France has placed considerable investment in developing SMRs. They are being considered for grid centralisation and integration with renewable energy systems (EDF, 2024a; Hernandez, 2024).

4.3 Case Study 2: India

4.3.1 Overview of the Nuclear Energy Sector in India

India, shown in Figure 18, is a developing country that makes up the bulk of South Asia, with an area covering 3 287 263 square kilometres (Central Intelligence Agency, 2024b). The country has a population of over 1.4 billion, making it the country with the highest human population in the world (Central Intelligence Agency, 2024b; World Bank, 2024).

Figure 18: Map of India. Source: (Central Intelligence Agency, 2024b).

India presents itself as a compelling case study in this research undertaking due to multiple shared energy goals between itself and South Africa. Both countries are emerging economies in the pursuit of reliable energy sources to support base load and meet their growing energy demands. They each have an abundance of indigenous resources to support a thriving nuclear sector: India with thorium and South Africa with uranium. South Africa stands to gain by observing the practices adopted by India in propelling its nuclear energy sector forward.

4.3.2 A Brief History of India’s Nuclear Programmes

India’s nuclear power aspirations firmly took root as early as 1947 following the nation’s independence from British Colonial rule (Central Intelligence Agency, 2024b). Its nuclear programme commenced in 1948 with the establishment of the Atomic Energy Commission (AEC) by the government, following the endorsement by nuclear physicist Dr Homi Bhabha (Sethna, 1979). Following the endorsement, the government enacted the Atomic Energy Act in 1948, establishing the framework for the development and regulation of atomic energy's peaceful use. (Sethna, 1979). The AEC was established in an effort to oversee nuclear energy research and development in the country (Banerjee & Gupta, 2017a; Department of Atomic Energy, 2024c).

At that time, India barely had any industrial infrastructure to support such a vision. There was very little coordinated research on nuclear energy, with few research activities confined to a minute number of university departments across the country. The notion that fundamental research and the development of skills among nuclear energy professionals were essential during the early stages of the nation's nuclear energy programme was upheld (Banerjee & Gupta, 2017a). The programme was intentional in avoiding reliance on international imports; instead, it focused on tapping into the utilisation of indigenous technologies and raw materials available (Banerjee & Gupta, 2017a; Sethna, 1979).

By 1954, the Department of Atomic Energy (DAE) was established to consolidate nuclear research under the supervision of the state (Department of Atomic Energy, 2024a). India’s first nuclear reactor, Aspara, was a pool-type reactor built in 1956 with the assistance of Britain. It was the first Asian research reactor to achieve criticality and was mainly used for research purposes, shielding experiments, neutron radiation and testing (Department of Atomic Energy, 2024e). It was in 1960 that India, in collaboration with Canada, commissioned the Circus 40 MW reactor, which served as a tool to train engineers and scientists in understanding the intricacies of operating a nuclear reactor and performing tests or experiments on it. It was later observed that both Aspara and Circus were shut down in 2010 (Department of Atomic Energy, 2024e).

India’s three-stage nuclear programme is hinged on the fact that the country is well-endowed with thorium reserves. The first stage of the programme involves the use of natural uranium (U-238) to fuel the pressurised heavy water reactors (PHWRs), as illustrated in Figure 19 (Banerjee, 2017). The by-product of the fission process from the first stage, plutonium-239, is used to build up the stockpile for the second stage of the program whilst maintaining focus on energy production (Pasricha, 2024). PHWR is a natural uranium-based reactor that uses heavy cooling and moderation. Multiple PHWRs have since been deployed across the nation, each fulfilling a critical role in supporting India’s nuclear energy programme (Banerjee, 2017; Sinha, 2021).

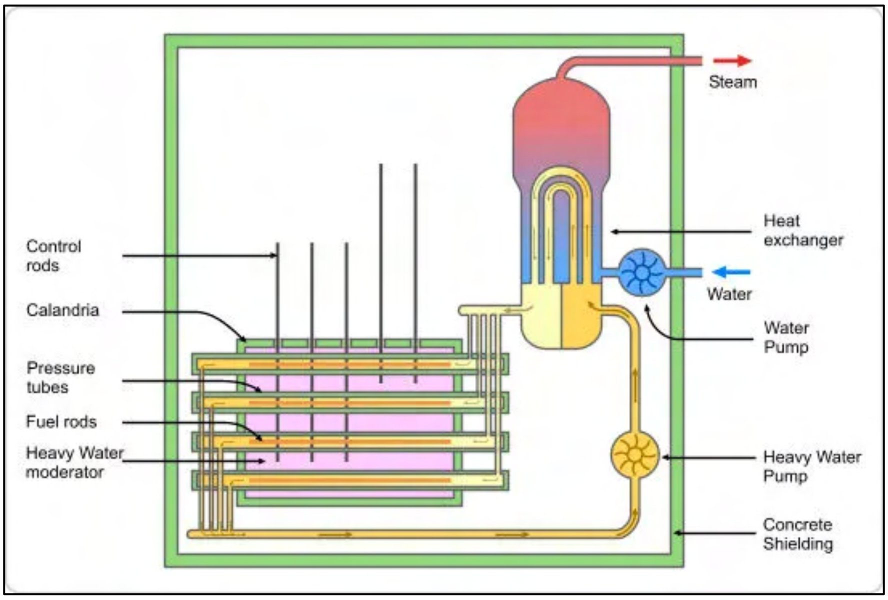

Figure 19: Pressurised Heavy Water Reactor. Source: (Earth Science Australia, 2025)

For stage 2 of the programme, the plutonium-239 from stage 1 is used to generate energy and produce more fissile material (uranium-plutonium mixed oxide fuel). The fast breeder reactors used in this stage also use thorium-232 as fertile material that goes on to absorb neutrons, which form uranium-233, which then becomes fissile material for future use (Pasricha, 2024). This stage is paramount as it introduces thorium into the cycle, and the availability of fissile material is increased. As it stands, the Prototype Fast Breeder Reactor (PFBR) has been developed indigenously by an Indian institution called Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI), which is an enterprise set up in 2003 under the DAE (World Nuclear News, 2024b). Fuel loading began in 2024 for the above-mentioned PFBR in Kalpakkam, Tamil Nadu (Gopalakrishnan, 2002; World Nuclear News, 2024b).

Figure 20 depicts Indian Prime Minister Narendra Modi visiting the Prototype Fast Breeder Reactor (PFBR) site during the fuel loading process in March 2024. This visit underscores India's commitment to expanding its nuclear capabilities and energy security (World Nuclear News, 2024b).

Figure 20: India's Prime Minister on tour at Kalpakkam ahead of reactor fuel loading in March 2024. Source: (World Nuclear News, 2024b).

Finally, the third stage focuses on the extensive use of India’s abundant thorium reserves to sustain the nuclear energy program indefinitely (Pasricha, 2024). Uranium-233 is used as fuel for thorium-based reactors. For this stage, a 300 MWe Advanced Heavy Water Reactor (AHWR) is being designed and developed in the country to use a mix of uranium-233 and thorium (Banerjee & Gupta, 2017b; A. Kumar et al., 2009). Figure 21 depicts the envisioned AHWR plant, designed to utilise thorium-based fuel (BARC, 2021).

Figure 21: 3-D render of the envisioned AHWR plant. Source: (BARC, 2021)

Figure 22 provides a detailed overview of India's nuclear power infrastructure, highlighting existing and upcoming nuclear power plants along with their respective capacities across various states (NPCIL, 2024). It depicts the distribution of nuclear energy projects. As of 2024, India has 23 operable reactors scattered across the nation, totalling 7 425 MWe, with only one 135 MWe reactor having been shut down. Seven reactors are currently under construction, aiming to produce approximately 5 398 MWe of nuclear power (World Nuclear Association, 2024b).

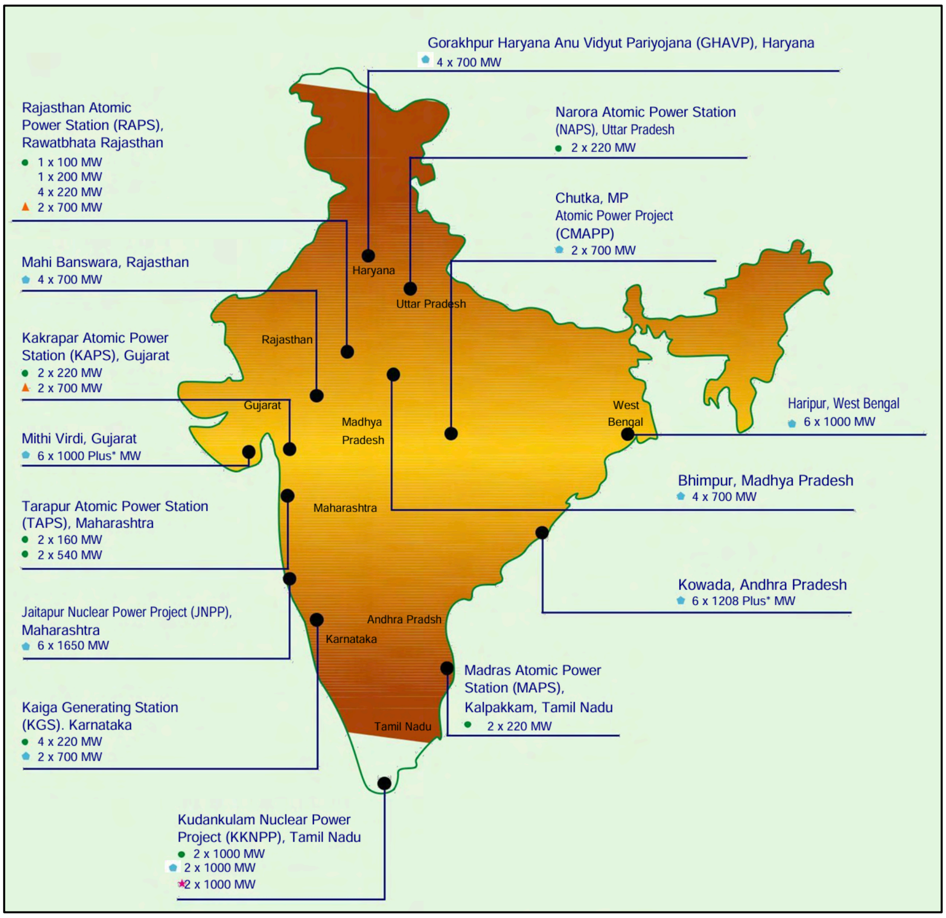

Figure 22: India's Nuclear Reactor Sites. Source: (NPCIL, 2024)

Although diverse, India's electricity mix still shows a heavy reliance on fossil fuel-derived energy, which is complemented by renewables and nuclear energy. Coal accounts for over 70% of the electricity mix, similar to South Africa (International Energy Agency, 2024). This is illustrated in Figure 23.

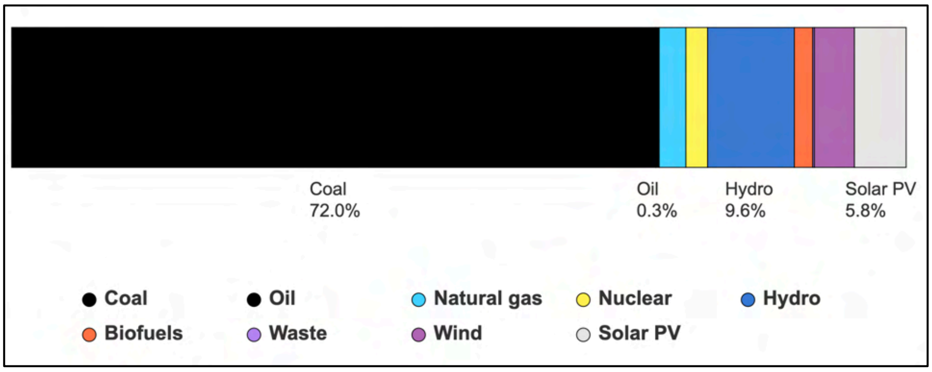

Figure 23: Electricity generation, India as of 2022. Source: (International Energy Agency, 2024)

Nuclear power accounts for 6.78 GW of electricity generation in India, which is only 1.5% of the nation's 452.69 GW of installed electricity generation capacity (World Nuclear Association, 2024c). This still places India in the world's top 15 nuclear energy-generating countries, as shown in Figure 24 (International Energy Agency, 2024; Ministry of New and Renewable Energy, 2024).

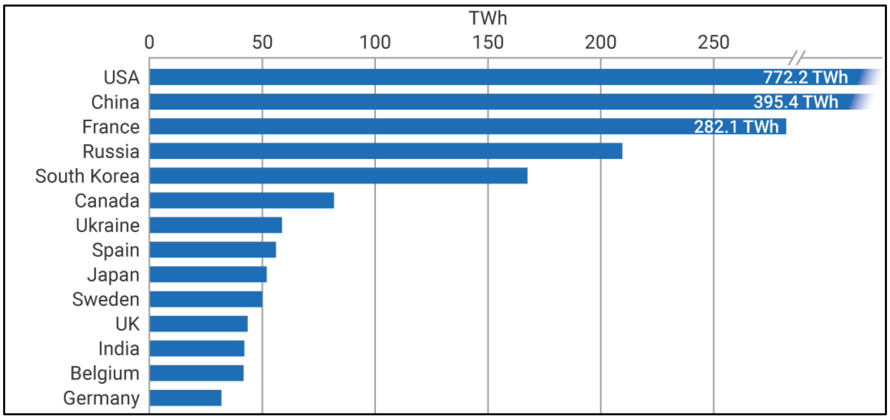

Figure 24: Nuclear Generation by Country Source: World Nuclear Association

4.3.3 Regulatory Framework

Figure 25 depicts the organisational structure of India's nuclear energy framework. It shows the relationships between key institutions that are involved in the functioning of the country's nuclear energy sector.

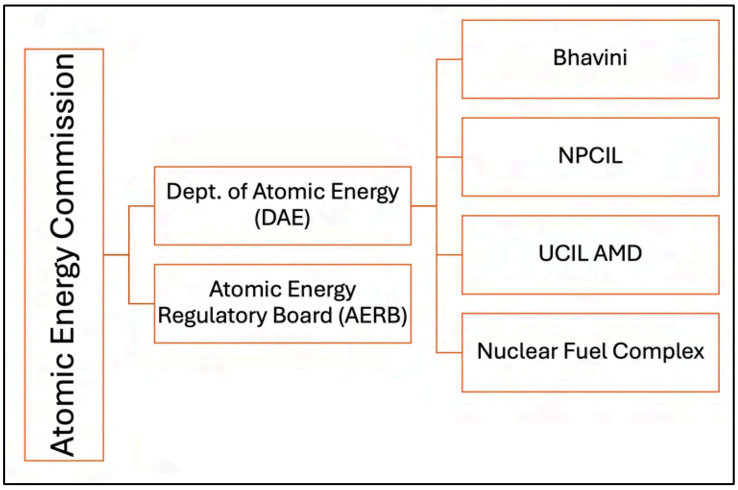

Figure 25: India Nuclear Regulatory Bodies, Source: (Department of Atomic Energy, 2024b)

4.3.3.1 Key Institutions

The AEC is a body established by the Indian Government with full executive and financial autonomy over the country’s nuclear sector. Its primary purpose is to ensure that atomic energy is used for the welfare and peaceful purposes of the Indian population. It is at the apex of India’s nuclear regulatory framework and policy-making body, and as such, it oversees the functioning of the Department of Atomic Energy (Department of Atomic Energy, 2024b).

The DAE operates with the mandate of nuclear energy technology advancement, which includes but is not limited to exploration of uranium resources, fabrication of nuclear fuel, etc. Its responsibilities include supervising all bodies involved in nuclear power generation, fuel processing, and research, along with administering all the facets of nuclear energy production and use (Department of Atomic Energy, 2024b). The DAE has subsidiary entities, as shown in Figure 25, that perform specific roles in the country’s nuclear program. They are listed below (Department of Atomic Energy, 2024b):

- Bhartiya Nabhikiya Vidyut Nigam Limited (BHAVINI): This operational arm focuses on the development and operation of fast breeder reactions and is aimed at improving fuel efficiency and increasing energy production (Department of Atomic Energy, 2024b).

- Nuclear Power Corporation of India Limited (NPCIL): This operational arm manages the construction, commissioning and operation of nuclear power plants, thus enabling generation of nuclear electricity for India's national power grid (Department of Atomic Energy, 2024b).
- Uranium Corporation of India Limited (UCIL) and Atomic Minerals Directorate (AMD): The UCIL is responsible for handling uranium mining-related issues, along with minerals processing, to ensure a consistent supply of raw materials for nuclear facilities (Department of Atomic Energy, 2024b). The AMD has the role of conducting exploration and research in efforts to discover more mineral resources (Department of Atomic Energy, 2024b).
- Nuclear Fuel Complex (NFC): This operational arm is responsible for the manufacture and supply of nuclear fuel bundles. It plays a vital role in the fabrication and processing of reactor components (Department of Atomic Energy, 2024b).

The organisational structure in Figure 25 shows the Indian government's ability to maintain centralised control and supervision over all the nation's nuclear energy operations (Department of Atomic Energy, 2024a, 2024b; World Nuclear Association, 2024b).

The Atomic Energy Regulatory Board (AERB) is an independent regulatory body constituted in 1983 with a mission to safeguard public health and the environment by prioritising the safe use of ionising radiation and nuclear energy in the country. It functions under the DAE (AERB, 2024). Figure 26 illustrates the hierarchical organisation of the AERB, outlining its key components, decision-making bodies, and regulatory functions.

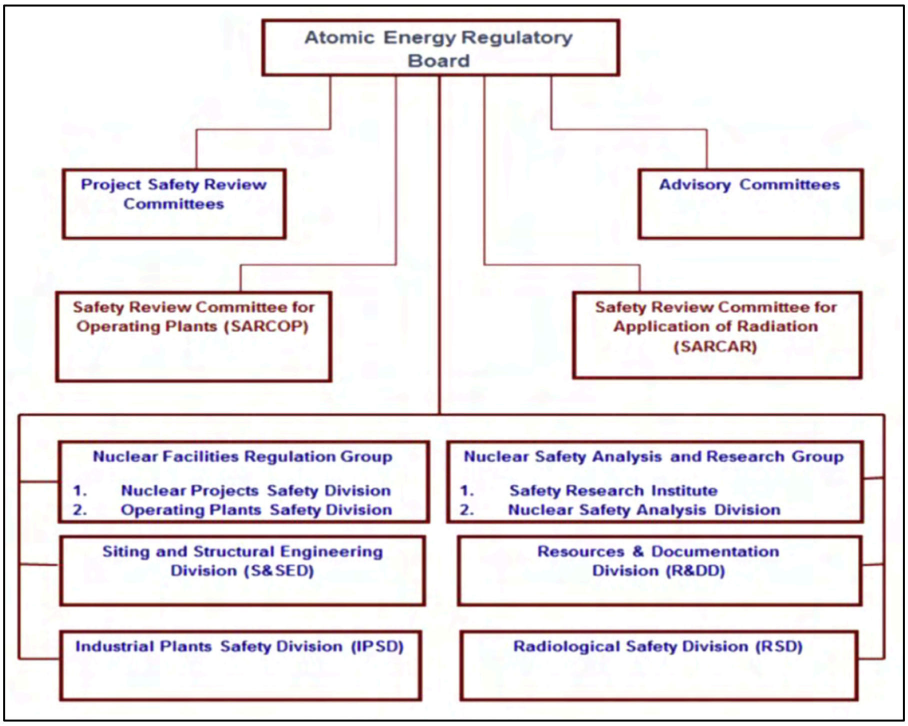

Figure 26: AERB Organisational Structure. Source: (S. Kumar et al., 2017)

The AERB is responsible for ensuring nuclear and radiation safety in India. Its key functions include developing safety standards, codes, and policies, overseeing regulatory compliance at nuclear and radiation facilities, and granting licenses and authorisations for their operation (S. Kumar et al., 2017). AERB also sets radiation exposure limits, ensures emergency preparedness, and engages with the public to promote transparency and awareness of nuclear safety (Atomic Energy Regulatory Board, 2024).

Bhabha Atomic Research Centre (BARC) functions as India's foundational nuclear research and development facility. Its role includes providing technical support to safety regulatory activities. It operates under the DAE.

4.3.3.2 Primary Responsibility

The nuclear energy industry in India is predominantly managed by the public sector and is thus government controlled. The production and use of nuclear energy are governed by the Atomic Energy Act of 1962, which gives an exclusive mandate to the Government of India to perform the above-mentioned roles. The role of the private sector has been limited to supplying specific components (engineering, procurement, and construction involvement only), but beyond that, they are not permitted to own or operate any nuclear power plants (Lamba et al., 2024).

Table 5 provides a comprehensive overview of national laws and codes that govern India’s nuclear sector, as well as the international agreements and norms to which India adheres in the field of nuclear energy. It serves as a valuable reference to understand the regulatory framework, safety protocols, and international commitments that guide India's nuclear activities, ensuring compliance with both domestic and global standards.

Table 5: National Laws, Codes and international agreements pertaining to India’s nuclear sector.

National Laws and Codes	
Atomic Energy Act of 1962	This act provides the legal framework for R & D along with the use of nuclear energy for peaceful purposes. It grants autonomy to the DAE over the nuclear sector, from uranium mining all the way to waste management. It thus governs all avenues of the nuclear energy industry in India (Department of Atomic Energy, 1962).
Civil Liability for Nuclear Damage Act of 2010	This act establishes a legal framework for the compensation of nuclear incident victims and caps the liability of nuclear operators, thus establishing a no-fault liability regime (Department of Atomic Energy, 2010).

Environmental Protection Act of 1986	First introduced in 1986 by the Ministry of Environment and Forests (MofEF), this provides a legal framework that aims to protect the environment and improve it by preventing pollution and addressing hazardous substance management (Ministry of Environment and Forests, 1986).
International Agreements and Norms	
India – USA Civil Nuclear Agreement of 2008	This agreement allows India to access civilian nuclear technology and fuel from the global market without having signed the Non-Proliferation of nuclear weapons (NPT) thus helping the nation integrate into the international nuclear community (US Department of State Archive, 2008).
Safeguards Agreement with the IAEA in 2009	An agreement between India and the IAEA for the application of safeguards to civilian nuclear facilities (IAEA, 2008).

4.3.4 Economic and Financing Factors

In the past, India has employed traditional government-led financing on its nuclear power projects. These nuclear power projects were mainly financed by state-backed and government-regulated utilities. This entailed the use of public funds, sovereign guarantees, and financial support from government financial institutions. India has also relied on foreign aid initially, as evidenced by its first two reactors, Aspara and CIRCUS (Tellis, 2024). These reactors exist through the collaboration India had with the United Kingdom and Canada. Despite these collaborations, India has always been intentional about reducing its reliance on the international community with regard to propelling its nuclear sector (Tellis, 2024; Terlikowski et al., 2019).

Furthermore, intergovernmental loans have also proved to be key for India. An example of this government-to-government financing can be seen with India and Russia entering an arrangement to help finance a nuclear power project (Express News Service, 2023). The Kudankulam Nuclear Power Plant (KNPP) in Tamil Nadu, India, was developed under a bilateral agreement between India and the Soviet Union in 1988 (The Hindu, 2021). Russia kept supporting India beyond the dissolution of the Union, even extending state credit to the value of $2.5 billion for the construction of the first two reactors (Press Trust of India, 2023). Another form of financial assistance from Russia came through vendor financing, with Russia's State Atomic Energy Corporation (Rosatom) facilitating financing the plant along with other Russian companies playing the role of supplying equipment, fuel, etc, through long-term contracts. Russia continues to support India to this day, with plans to assist with the ongoing construction of KNPP's units 3 to 6 (The Hindu, 2021; Vanaik, 2020).

In recent times, most nuclear power plants are funded through the country's government budget allocation, with supplements through vendor financing from international vendors and other countries (Barkatullah & Ahmad, 2017). This includes loans that are usually arranged by vendors and or vendor equity participation (this is a form of financing where, in exchange for an entity's stock/shares, a vendor will provide goods or services) (Barkatullah & Ahmad, 2017; Terlikowski et al., 2019). An example of this would be the Gorakhpur Nuclear Power plant, where the Indian government has already approved over $5bn for phases 1 and 2 of the building and commissioning of four reactors at the power plant (Power Technology, 2023). Engineering companies have been awarded contracts by the NPCIL for various tasks, ranging from civil works and provision of steam turbines to earthwork. These joint ventures between private vendors and the NPCIL also form Public-Private Partnerships (PPPs) being promoted by the Indian government (Power Technology, 2023).

Another model is investor financing, which entails pooling funds from a diverse set of investors that ranges from commercial banks, bilateral banks, export credit agencies, and private funders (Nuclear Business Platform, 2024). In 2024, India aimed to invite private firms to invest approximately $26 billion in its nuclear energy endeavours (Singh, 2024). It is reported that India has held multiple meetings with various private companies to discuss the investment plans aimed at building 11 MW of new nuclear build programmes by 2040 (Singh, 2024). However, despite the call for private investments, all the rights to build and operate nuclear power plants will remain under the NPCIL, which functions under the DAE. Furthermore, the Indian government is also reported to be in engagements that would lead to the possibility of foreign direct investment into the nuclear energy sector in hopes of encouraging competition and innovation (Nuclear Business Platform, 2024; Singh, 2024).

India has also started exploring emerging financing models. Some of these models include Purchase Power Agreements (PPAs), where host governments/utilities agree to purchase power at a particular price, which in turn reassures financial stability for potential investors (Nuclear Business Platform, 2024). Such agreements secure long-term revenue by guaranteeing that the electricity produced by a nuclear power plant will be purchased by a certain buyer over a specified period (Terlikowski et al., 2019). Another emerging financing model is hybrid financing, where corporate finance, loans, and public sector funds are combined in efforts to distribute (and mitigate) the associated risks and ensure project viability (Nuclear Business Platform, 2024; Terlikowski et al., 2019).

4.3.5 Public Perception and Social Acceptance

Nuclear public perception in India has been shaped and formed by multiple historical events, policy development decisions, social movements, and various international factors.

During the country's nuclear programme infancy, a period that lacked significant incidents, public perception was largely positive (Srinivasan et al., 2005). Nuclear energy was viewed as a symbol of progress and embracing modernity for the young nation. Before the 1970s, multiple educational campaigns called for the peaceful use of atomic energy throughout varying industries ranging from agriculture to medicine to electricity generation (Srinivasan et al., 2005). India's perception of nuclear power reached new heights when they successfully conducted the Pokhran Tests in 1974. At this point, national pride surged whilst there were growing concerns about the militarisation of nuclear technology from the intellectuals and nuclear-for-peace activists (The Hindu, 2024).

It is also important to note that India faced condemnation from the international community, especially the USA and the Soviet Union, after conducting the Pokhran Test (1974), which it deemed a peaceful nuclear explosion (Kamath, 1998). Other countries feared that India might perpetuate a regional nuclear arms race. This led to sanctions imposed in the form of the suspension of foreign aid from the USA and restrictions on the trade of certain nuclear equipment (Bureau of Economic and Agricultural Affairs, 1998). India did not sign the NPT, viewing it as discriminatory. In 1998, India performed a second round of nuclear tests that were nicknamed code name Shakti II in Pokhran. Following these tests, India faced more sanctions and condemnation from the global nuclear community (Bureau of Economic and Agricultural Affairs, 1998; Kamath, 1998). These sanctions harmed the economy of the country and the public perception that was reserved for nuclear technology.

Despite sanctions and international backlash, India remained steadfast, using isolation as a catalyst for self-reliance. It advanced indigenous nuclear technology, forged strategic alliances, and secured the 2008 civil nuclear deal with the U.S., reshaping global perceptions (US Department of State Archive, 2008). This resilience cemented India's role as a key player in nuclear energy and security.

The 2011 Fukushima incident renewed the scepticism that the public had on nuclear energy and caused multiple countries, including India, to rethink their nuclear energy programs along with their approach to nuclear safety (World

Nuclear Association, 2024a). In India specifically, the Kudankulam protests in Tamil Nadu, which were driven by locals concerned about the safety and environmental impact of the plant, gained momentum following this disaster (Khan, 2022). Although the Indian government reassured the protesters that stringent safety measures were being taken, the local protesters were not convinced. They cited that lack of transparency in past decision-making is one of the major reasons for this mistrust (Khan, 2022; Vaidyanathan & Kale, 2022).

Although there is a renaissance to the support of nuclear, there still exists opposition to nuclear by environmentalist groups and locals who are weary of displacement caused by nuclear build programmes in India (Bhattacharya et al., 2024).

4.3.6 Safety and Security

Figure 27 outlines India's nuclear security framework based on the Ministry of External Affairs. It highlights five key elements: governance, security culture, international cooperation, technology, and institutions. These components ensure regulatory oversight, adherence to safety norms, global collaboration, technological advancements, and institutional enforcement, reinforcing India's commitment to nuclear security (Ministry of External Affairs, 2024).

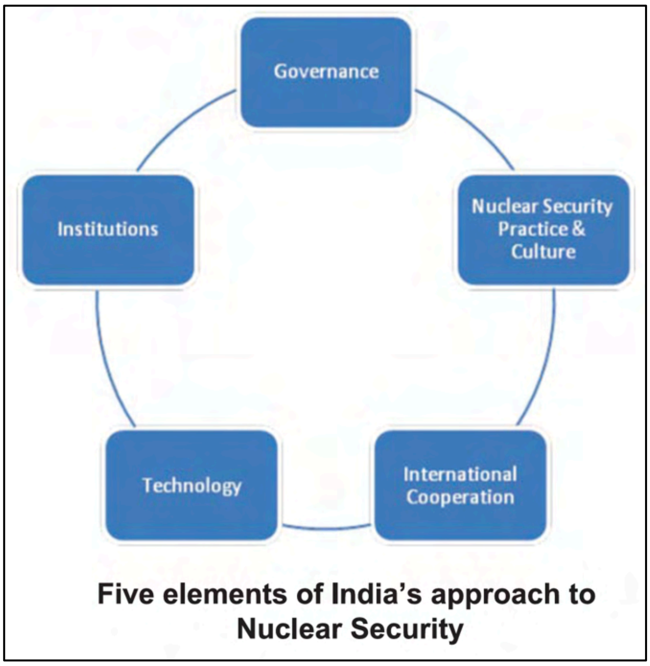

Figure 27: India's Nuclear Security. Source: (Ministry of External Affairs, 2024)

The AERB is the institution that oversees nuclear safety in India and ensures that the sector is not only compliant with the Atomic Energy Act of 1962 but with other relevant legislation such as the Environmental Protection Act of 1986 (Ministry of External Affairs, 2024). In 2013, the DAE created the Nuclear Controls & Planning Wing (NC&PW) that performs the function of integrating the DAE’s safeguards along with other security activities. Additionally, each nuclear facility is required to devise its own Design Basis Threat (NBT) document that outlines the security system that a particular facility has in place in the event of saboteurs, terrorists, and other malicious threats posed to the facility (Ministry of External Affairs, 2024).

India strictly adheres to the IAEA’s safety standards by having its heavy water reactors integrate multiple safety barriers and by adding advanced safety features in its newer reactors (the fast breeder and light water reactors) (Ministry of External Affairs, 2024). Concerning nuclear security, India works together with the IAEA to ensure that its civilian nuclear facilities perpetuate the peaceful use of nuclear technologies. This is achieved through the application of IAEA safeguards to several reactors as per the Indo–USA Civil Nuclear Agreement (Tellis, 2023; US Department of State Archive, 2008).

4.3.7 Radioactive Waste Management and Environmental Considerations

In India, nuclear and radioactive waste management involves the handling of all waste produced throughout the nuclear fuel cycle. This ranges from the extraction of uranium, making fuel, to its use in reactor operations and the reprocessing of spent fuel (Pasricha, 2024). In keeping with its nuclear programme objectives, the spent fuel is reprocessed in efforts to recover uranium and plutonium to be used for subsequent phases of the program (Wattal, 2013). This contrasts with countries such as Canada and South Africa, where the spent fuel is stored without further processing (Ministry of External Affairs, 2024; Wattal, 2013).

Figure 28 shows India's closed nuclear fuel cycle, as described by Wattal (2013). It depicts the various stages, beginning with uranium mining and milling, followed by conversion to oxide and fuel for reactor use. The cycle also includes reprocessing, where plutonium and recovered uranium are extracted for further use, with by-products utilised in medicine, agriculture, and industry. This closed-loop system highlights efforts to optimise resource use and minimise nuclear waste (Pasricha, 2024; Wattal, 2013).

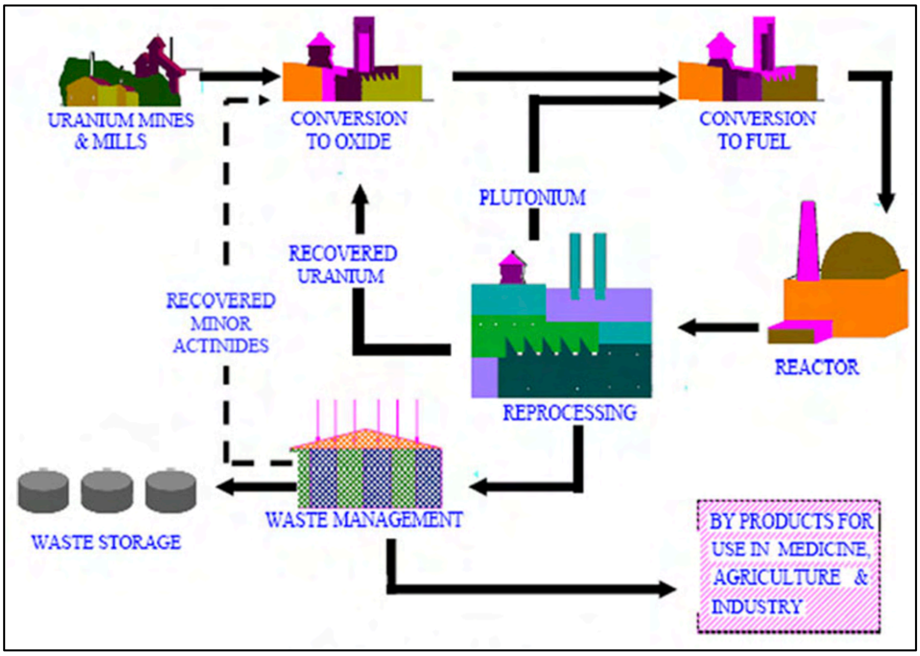

Figure 28: Fuel cycle, source: (Wattal, 2013).

The national policy of radioactive waste management in India focuses on ensuring that radioactive waste is safely and efficiently handled with much consideration of various factors (social and economic). The aspects listed below are part of the breakdown of the national policy (Raj et al., 2006):

- Minimising discharges: Radioactive substances released through gases, liquids, and solids are kept at reasonably low levels.
- Near-surface disposal for low and intermediate-level solid waste in shallow land repositories.
- High-level waste is solidified and temporarily stored in cooled and monitored facilities before being moved underground (geological repositories) for long-term disposal (Raj et al., 2006).
- Alpha-contaminated waste is disposed of in deep geological repositories.
- Spent radiation sources are either returned to the supplier or given to a waste management agency for further handling (Raj et al., 2006).
- Several waste disposal facilities are located near nuclear facilities/installations for increased efficiency and better transport management (Raj et al., 2006).
- Reprocessing spent fuel is seen as a vital resource. It is reprocessed to recover uranium and plutonium. These reprocessing plants are usually located near vitrification plants that then solidify the waste.
- Long-term monitoring and control for waste buried in shallow land repositories is in place. For the first 100 years, active control is maintained by the waste management agency. For the next 200 years, the central government will then passively control the sites whilst awaiting the waste to decay to safe levels (Raj et al., 2006).

Figure 29 presents an overview of India's radioactive waste management system, as described by Raj et al. (2006). It categorizes waste into low-level (LL), intermediate-level (IL), and high-level (HL) types, outlining treatment methods for liquid, solid, and gaseous waste (Raj et al., 2006).

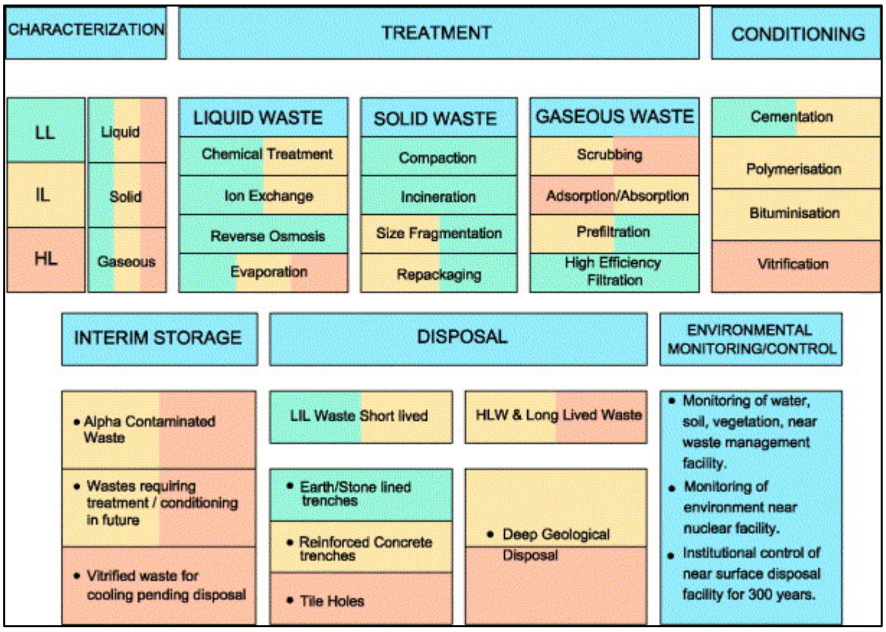

Figure 29: Stages of nuclear waste management in India. Source: (Raj et al., 2006)

4.3.8 Technological Advancement and Skills Development

India's commitment to honing indigenous skills early on has helped the nation make significant strides in its nuclear skills development programs and technological advancements within the industry. This is evidenced by the fact that India will become the second country in the world to have a 500 MWe sodium-cooled commercial fast breeder reactor once it is commissioned in Kalpakkam, Tamil Nadu (World Nuclear News, 2024b). Furthermore, Indian scientists and engineers at the Bhabha Atomic Research Centre are working on developing indigenous pressurised water reactors (Department of Atomic Energy, 2024d). This presents an opportunity for skills development for future nuclear scientists, researchers, and engineers in the country (Department of Atomic Energy, 2024d).

The DAE set up the Global Centre for Nuclear Energy Partnership (GCNEP) to help promote and advance the peaceful use of nuclear energy. Its primary purpose is to serve as a platform for research and training in the fields of nuclear energy, safety, and security (Global Centre for Nuclear Energy Partnership, 2024). It also serves to facilitate collaboration between India and other nations where they can share information on nuclear policy frameworks, research advancements, and best practices. The GCNEP plays a role in skills development in India through its provision of specialised training programs, workshops, and courses for nuclear scientists, enthusiasts, engineers, and others alike. It is a centre of capacity building and knowledge transfer (Global Centre for Nuclear Energy Partnership, 2024).

The National Power Training Institute (NPTI), under the Ministry of Power, offers training programs that help complement the skills of professionals within the power and energy sector of the country (The Tribune India, 2024). This is supplemented by the NPCIL corporate social responsibility initiatives that include projects that are focused on skills development, an example of this being the Kudankulam Nuclear Power project to train the locals in various nuclear skills (NPCIL, 2024; The Tribune India, 2024).

4.4 Comparisons and Lessons from the Case Studies

France and India were chosen as case studies for this research for their contrasting yet instructive history with nuclear energy. France is a developed nation, whilst India is considered a developing nation. This dual case study approach mirrors South Africa's current developmental stage and its aspirations to transition to an energy-secure country. France is considered an international leader in nuclear energy, with most of its baseload supported by nuclear. India is a maverick when it comes to combining indigenous nuclear power skills with global partnerships in advancing its nuclear sector. Both countries offer valuable lessons that could inform South Africa's future nuclear energy endeavours.

As stated previously, the key themes that were analysed in the case studies include the regulatory framework of each country, economic and financing factors, safety & security, radioactive waste management, environmental factors, public perception & acceptance, and the history behind each nuclear energy sector. These case studies aimed to draw recommendations that could inform policy development and other factors that influence the nuclear energy sector in South Africa.

4.4.1 History of Nuclear Energy Sector Lessons

South Africa's nuclear energy sector is a product of a government that adopted a centralised approach to its decision-making processes. This was before 1994 when the then government tapped into its uranium reserves and previous research on nuclear to pave the way for Koeberg power station, commissioned in 1984. This positioned the country as a regional leader in nuclear technology. However, South Africa has since not increased its nuclear energy capacity.

It then prompts the question of whether South Africa should follow a centralised model going into the future or whether it should work on developing a hybrid approach that allows it to balance the state control of the nuclear energy sector with the involvement of the private sector and international players. A centralised approach, similar to that of the French government, offers stability and allows a long-term commitment to nuclear energy. Centralised regulatory and policy decision-making can help to secure funding for new power plants/reactors through offering policy certainty. Both India and France have nuclear programmes championed through a centralised decision-making approach by their respective governments. These nuclear programs are well supported and anchored by sound policy frameworks to ensure their implementation. Both governments allocate resources to these programs to increase their success.

To provide a clear comparison of different governance models in the nuclear sector, Table 6 contrasts France's centralised approach to policy framework and regulatory decision-making with India's hybrid model. This comparison highlights the strengths and challenges of each system, offering insights into potential lessons for South Africa's nuclear sector.

Table 6: Key differences between France and India.

France	India
<u>Centralised & state-driven decision making</u> - Centralised decision-making allowed France's government to rapidly scale up its nuclear infrastructure through state entities such as EDF and Orano. - The state has been able to invest in research and infrastructure throughout the years. Its nuclear success has been rooted in institutional stability, and the state's incredible hold on nuclear policy framework development. - It was able to curb opposition to nuclear projects early on in its nuclear program.	<u>Hybrid (Local + International Influences)</u> - India's nuclear sector has been shaped by a combination of domestic needs and international partnerships. - India's nuclear program is tailor-made to make use of its high thorium reserves and eventually reduce dependence on imported uranium. - India has faced restrictions on nuclear trade and has used that isolation to promote indigenous developments within its nuclear power sector.

Based on these observations, it can be argued that South Africa's nuclear strategy should consider the successes and downfalls of both the centralised and hybrid models from France and India. This might result in South Africa finding an optimal balance between state control over the nuclear sector, private sector involvement through public-private partnerships, and international collaborations or influences.

4.4.2 Policy Framework and Regulatory Dispensations

France's nuclear policy framework demonstrates strong state control, centralised governance, and a clear regulatory structure. This is evidenced by the establishment and implementation of *Plan Messmer* following the 1970s oil embargo, as discussed in France's case study. By adhering to the plan, France was able to build a massive network of nuclear reactors that would go on to help meet the country's growing energy demands and help it gain energy independence. The French government set a clear target and rallied all stakeholders around that goal, resulting in the construction of most of its nuclear reactors within 15 years by following a clear roadmap driven by consistent decision-making and alignment with its national energy objectives. They were able to rapidly build and expand the nuclear reactor network because the reactor designs were standardised, and the construction process was streamlined.

On the contrary, India combines a centralised government's initiatives with international and private sector partnerships, which does come with its own set of challenges. India's nuclear programme owes its success to a strong, clear, and unified policy framework that has ensured consistent implementation of nuclear project plans supported by the Atomic Energy Act of 1948 and 1962. This reinforces the centralised control of the nuclear sector by the government, where the DAE oversees all nuclear activities in the country. In addition, the country decided to uphold indigenous expertise in its nuclear sector, thus improving the set of nuclear skills in India significantly. They managed to develop and carry out the country's three-stage nuclear plan in efforts to use thorium, an indigenous resource. India also leverages its partnerships with countries such as Russia to advance their nuclear reactor designs. India is also actively seeking to cultivate public-private partnerships in its nuclear sector and is open to funding from the private sector.

South Africa may adopt a hybrid policy framework that blends France's centralised governance for regulatory oversight & safety with India's strategy on public-private partnerships to increase chances of securing adequate funding. Developing a clear long-term energy strategy that aims to gradually reduce South Africa's coal dependency by considering energy sources that emit less GHGs may be beneficial. The use of nuclear as a dispatchable energy may be complemented by the use of VRE in light of its intermittency challenges. Once the strategy has been developed, the government may create appropriate legislation to anchor the plan so that it is not easily challenged by various stakeholders. The government should ensure and maintain accountability and transparency from the implementation of the plans to the commissioning and operation of future nuclear power builds.

4.4.3 Economic and Financial Factors

France's nuclear sector has always relied on public funding and state investment. This approach prioritised energy security over cost implications. Cohesive planning and rapid implementation are the result of this centralised approach. By standardising the design of nuclear reactors and streamlining construction, the government could reduce construction timelines and eventually lower the costs of nuclear projects. On the other hand, India's three-stage nuclear programme and upholding of indigenous expertise have helped it avoid the high cost of importing nuclear technology and skills. Creating and using indigenous supply chains has helped India reduce costs associated with nuclear builds whilst supporting the local industry. The three-stage programme has also facilitated a phased approach to the development of the nuclear sector. The gradual scaling up has minimised financial risks.

Unlike France, which maintains strong state control over its nuclear sector, India has shown increasing openness to private sector participation and international funding. However, the Indian government has not compromised its control over the nuclear sector, even though it has created a space for private players to participate in the nuclear sector. The government maintains strategic oversight.

For South Africa, it is suggested that a balanced approach of combining state investment in key infrastructure with India's model of public-private partnerships to help attract foreign investment, whilst spreading the financial risks, be implemented. Moreover, exploring other avenues of innovative funding from other countries with newer nuclear power plants may also assist in finding the right financing solutions. Furthermore, the South African government should consider developing policies that incentivise private sector participation. Similar to India, indigenous technology can be leveraged for funding.

The South African government may consider using PPAs as a tool for securing long-term funding and ensuring stable profit, similar to the model employed by the NPCIL in India. Additionally, investor financing and vendor financing arrangements can be explored to reduce nuclear capital costs, with vendors potentially providing financing options tied to the procurement of reactor technology. Moreover, intergovernmental loans, akin to those utilised by India and Russia, offer another viable avenue for securing funding for nuclear build programmes. By combining these funding mechanisms, South Africa can build a robust financial framework that supports the development and expansion of its nuclear energy sector while mitigating risks and fostering international collaboration.

4.4.4 Public Perception and Social Acceptance

As presented in the case study, France has invested a tremendous amount of effort and time into improving the public perception held by its population regarding nuclear, especially on the heels of several historic nuclear incidents. They have achieved this through improving and upholding an outstanding safety record, transparency in all nuclear-related decision-making, and excellent nuclear public awareness initiatives. Public awareness in France has shaped a generally favourable public perception of nuclear power. In contrast, India has a mixed public perception. This can be attributed to the government's lack of transparency, disregard for safety concerns about nuclear power plants in some regions, and the displacement of communities caused by nuclear power plant construction.

Drawing from France's approach to nuclear public perception, South Africa should prioritise transparent communication with a focus on safety and the long-term benefits of nuclear energy. South Africa should build trust through community engagement and involvement in decision-making. Public awareness campaigns that are tailored to address various stakeholders must be made. This will help to fight against the resistance that nuclear power faces in South Africa. Some of the steps that France took after the Chernobyl incident can be adopted in South Africa to improve nuclear public perception. These include improvement on public communication, transparency, and preparedness for nuclear disasters.

4.4.5 Radioactive Waste Management and Environmental Factors

France is a global leader in nuclear waste management with its advanced recycling technologies that aim to reduce waste volumes. The country has invested heavily in long-term waste storage solutions, as discussed in the case study. For example, the Cigeo project and Orano highlight the need for strong regulation, public engagement, and innovation in nuclear waste management. France's approach emphasizes deep geological disposal and recycling to minimize waste and ensure long-term safety. India's approach to waste management has been reprocessing spent nuclear fuel to recover plutonium and uranium for future use. However, India lacks a comprehensive long-term disposal plan.

For future nuclear power plants, South Africa should invest in recycling and reprocessing technologies similar to those in France. From India, waste minimisation can be adopted, especially since South Africa has plans to grow its nuclear energy sector, which might signal an increase in nuclear waste.

4.4.6 Technological Advancements and Skills Development

France has excellent nuclear skills development programs that are deeply embedded throughout its research institutions, where continuous innovation is encouraged. India places special focus on indigenous capacity building and leveraging domestic skills whilst collaborating with the international community in technology transfer activities. Both nations are steadfast in developing a highly skilled workforce that will continue to support their nuclear sectors.

South Africa should continue to fund its existing nuclear research institutions so that they can carry out different research activities that will inform future decision-making and policy development. Additionally, nuclear research must not be limited to a few research universities. Instead, the government must ensure that the nuclear industry continuously works closely with academia. Taking a leaf out of India's book, South Africa can use international partnerships to their benefit by arranging for technology transfer activities, which can be enriching. They can also create initiatives that promote local capacity building through establishing specialised training programs.

4.4.7 Archetype of Nations favouring Nuclear Power

In Chapter 2, Sovacool and Valentine's theory suggests that countries with successful nuclear programmes typically show socio-technical traits (Sovacool & Valentine, 2012). These traits include central governance, strong institutional frameworks, and an alignment between societal values and government priorities. Furthermore, these countries depend on technocratic decision-making in an environment where there is a high level of trust by the public in the state.

From the case study, it is evident to note that France exemplifies the technocratic decision-making approach discussed by Sovacool and Valentine in their book. France's nuclear sector shows high state involvement, with the EDF and Orano (both are state-owned) responsible for a majority of all nuclear activities in the country. France's nuclear success is deeply embedded in its national identity, such that public trust in nuclear energy is relatively high. This aligns with part of the theory that focuses on national pride in nuclear energy.

India has pursued and continues to pursue nuclear power as a means to gain energy independence while meeting its growing energy demands. Its nuclear programme decision-making exhibits limited public engagement and involvement. The case study on India brings to light the friction between the country's developmental goals and public resistance with regard to the nuclear energy expansion currently taking place there. The contrast between India and France highlights the institutional and infrastructural challenges that exist in less centralised approaches.

Through Benjamin and Sovacool’s framework, South Africa can learn from France’s centralised governance for policy stability and strong regulatory oversight, ensuring long-term planning and safety. From India, the hybrid approach offers flexibility, fostering innovation and private sector participation. Balancing these models, South Africa should strengthen regulatory consistency while allowing market adaptability to drive investment and technological advancement in its nuclear sector.

4.5 Findings from participants' responses

This subsection presents the key findings derived from the thematic analysis of the semi-structured interviews conducted with eleven (11) energy experts in South Africa. The analysis zones in on identifying the major barriers that have hindered the establishment of new nuclear build programmes in the country, with the experts also providing potential recommendations for overcoming these challenges. Please note that the words *interviewees* and *experts* have been used interchangeably.

4.5.1 Profile of Study Participants

The selection criteria for research participants required individuals to have a minimum of three years of experience in a mid-level position within the nuclear sector or a nuclear-adjacent field in South Africa. The profile of research participants is summarised in Table 7 below:

Table 7: Profile of research participants.

Participant ID	Nuclear Field	Years of Experience
P1	Policy Development and Planning.	27
P2	Nuclear Advocacy.	13
P3	Nuclear Security, Safety, and Engineering	9
P4	Nuclear Regulation, Licensing and Procurement.	5
P5	Nuclear Science, Research and Development.	23
P6	Nuclear Engineering Design.	7
P7	Nuclear Engineering and Strategic Planning.	20
P8	Project Financing and Energy Specialist.	15
P9	Project Financing and Energy Specialist.	15
P10	Nuclear Waste Management.	50+
P11	Policy Development and Planning.	20

4.5.2 Policy and Regulatory Dispensation Challenges

All of the interviewees said that they do not have any qualms with the existing nuclear policy and regulatory dispensations in the country. Sixty-three percent of them showed their satisfaction with how the nuclear policy has developed post-1994 and the regulatory dispensations that have been established.

4.5.2.1. Challenges about policy and regulatory dispensations expressed by interviewees:

- No new policies (beyond integrated resource plans) on nuclear since the white paper.
- Flawed procurement process:
    - In past nuclear procurement processes, there was a lack of transparency. Some interviewees provided evidence to support their claims regarding the lack of transparency and parliamentary oversight, citing the agreements between the South African government and Russia's Rosatom for the procurement of nuclear reactors. Additionally, six participants referenced the unsuccessful procurement of 9,600 MW of nuclear capacity, as outlined in the Integrated Resource Plan (IRP) 2019, as further evidence. This failure led to legal challenges that caused delays in the procurement process, highlighting non-compliance with constitutional and legal requirements. The incident raised concerns about the government’s capacity to manage large-scale projects in a manner that is both lawful and transparent (Vásquez-Maignan et al., 2024).
    - The failed procurement of 9 600 MW of nuclear power has highlighted the lack of public engagement that has existed in decision-making when it comes to nuclear energy (Vásquez-Maignan et al., 2024).
    - Environmental and safety concerns have added to the delays in nuclear procurement, raised by NGOs.

- Ever-changing plans that the government seldom sees to completion. Interviewees highlighted the severe lack of continuity when it comes to the plans that are put forth by the government regarding nuclear build programmes. One participant highlighted the inconsistency in the government's implementation of nuclear energy plans across successive Integrated Resource Plans (IRPs). Specifically, they noted that with each change in administration, the plans were revised, leading to a lack of continuity in the country’s nuclear energy strategy. This lack of stability has resulted in the absence of additional nuclear capacity being integrated into the national grid, according to the interviewees.
- It was expressed that there is a lack of a comprehensive set of policies designed to incentivise private investors in the nuclear sector.
- Lack of public participation in nuclear policy development is a recurring challenge that draws criticism from environmental groups, civil society, and legal entities. For example, interviewees P2, P5, and P6 expressed concerns regarding the government's poor stakeholder engagement, all emphasising a lack of access by the public to information on nuclear power. They also noted the limited availability of platforms for meaningful engagement among various stakeholders in the nuclear sector. This was observed recently when a court ruled against a ministerial determination on nuclear, which was endorsed without public consultation (Vásquez-Maignan et al., 2024).
- Concerning the independent nuclear regulator, NNR, some interviewees expressed the lack of prescriptive regulation. Interviewee P5 mentioned that this lack of clear guidance from the regulator hinders nuclear industry professionals from adequately planning their projects, particularly in the design phase, where ensuring safety is crucial before submitting them to the NNR for licensing. The participant advocated for the NNR to provide clear timelines, enabling professionals to work efficiently without delays during the licensing process.
- One issue raised is the political framework not tailormade to South Africa. Some interviewees expressed that the nuclear political framework considers too many outside voices, which in turn takes away from the

quality of it being specifically made to suit the needs of the nation. Furthermore, the political landscape has been mentioned as something that has significantly affected and continues to affect the growth and development of nuclear energy in the country. The issues that were cited include leadership changes, misuse of state funds, governance challenges, political resistance from various parties, influence of interest groups, etc.

- Interviewee P8 expressed concerns that the Government of National Unity (GNU) in South Africa may influence future procurement processes, given the differing opinions of the various parties involved, and warned relevant stakeholders to take heed. They emphasised the importance of the NNR playing a proactive role in ensuring impartiality and fairness throughout these future procurement processes.

4.5.3 Recommendations by Interviewees on Policy and Regulatory Dispensations

Based on the above responses, the interviewees also provided recommendations as follows:

- Policy certainty must be ensured through the government's full and firm commitment to nuclear energy expansion within the country's energy mix. Long-term plans must be backed up and anchored by legislation to avoid inconsistency. These plans must include timelines that are rooted in feasibility studies and phased approaches that are tailored to what the government can afford.
- Interviewees have suggested that the IRPs must include a clear roadmap for nuclear projects, with well-defined milestones and deadlines. This will ensure that proper planning that includes workforce development and budget allocation is done. Furthermore, departures from one IRP draft to the next must be avoided. The interviewees suggest that there must be continuity between successive IRP drafts; otherwise, suitable justifications must be made for each departure. This assists with the notion of policy framework certainty.

- NNR regulations should be prescriptive. This way, stakeholders will have clarity on the process of applying for and obtaining licensing since there will be little room left for ambiguity or misinterpretation. Furthermore, it would help to reduce the time it takes to obtain a license. Participant P5 suggested that the NNR look at other nations, such as Russia, where they use prescriptive regulations that ensure robust oversight and observe the effect they have had on those countries' nuclear industries.

4.5.4 Financing Challenges

The participants were asked about financial challenges within South Africa's nuclear energy. They highlighted the following:

4.5.4.1. High Capital Costs in Financing New Nuclear Build Programmes

One of the key themes that emerged from the interviews is the significant challenge of securing financing for nuclear build programmes in South Africa. This sentiment was echoed by eighty percent of the interviewees who pointed out the challenge of high upfront capital costs of nuclear being a deterrent towards the establishment of nuclear build projects. Fifty-four percent of them commented on the effects of the long payback period and associated risks that these capital costs come with. Interviewee P5, for example, mentioned that these long payback periods are exacerbated by the fact that projects are seldom completed on time in South Africa. The views of participants are echoed by a 2022 article that asserts that nuclear power requires high capital expenditure to build (Stewart & Shirvan, 2022).

4.5.4.2. Lack of Innovative Funding Models and Financial Support for Auxiliary Services

Participant P3 expressed that the success of South Africa's nuclear power expansion is contingent on the government being able to find and implement innovative funding methods for future nuclear build programmes. Thirty-six percent of the interviewees spoke about the lack of innovative financing models that are specifically tailored to nuclear build projects. Additionally, forty-five percent of the interviewees highlighted that the lack of financial support in auxiliary services had been a hindrance in the nuclear sector.

For example, interviewee P10, an expert involved in supporting the operations of the Vaalputs nuclear waste disposal facility, shared their challenges in securing financial support from the government for essential site visits crucial to their research. They further mentioned instances where they had to personally fund these visits for their researchers. This situation underscores the pressing need for greater government support for auxiliary services that support the nuclear sector in South Africa, as well as the necessity to fund research programs dedicated to fostering innovation within the nuclear industry.

Another point highlighted by participants was that of digitally archiving important research work that can potentially be used in future nuclear build programmes. This is an activity that can be fast-tracked by generous funding to those research departments. Participants also spoke on the shortage of skilled personnel at the Vaalputs waste disposal facility. For example, participant P10 mentioned that the staff at the disposal facility do not get paid competitively, which increases their chances of not only leaving the institution but also potentially leaving the country.

4.5.4.3. Poor Financial Planning

Seventy-two percent of the interviewees expressed that how public funds are allocated towards different nuclear activities needs to be reviewed. Interviewees P6 and P8 called for transparent financial planning and showed their scepticism towards how the government comes up with the perceived cost of nuclear build programmes.

4.5.5 Recommendations made by Interviewees on addressing Financial Challenges

The participants suggested the following about South Africa's financial challenges associated with nuclear funding:

- It was suggested that the government could look into innovative nuclear energy project financing models. Participant P10 suggested club deals, debt plus equity, and other forms of private funding. They mentioned that these types of funding methods offer the benefit of spreading financial risks amongst different stakeholders whilst reducing the risk that would be incurred by the government. Participant P10 encourages the government to take lessons from the El Dabaa Nuclear Power Plant in Egypt, whose funding is structured using debt and equity, with a majority of the debt being provided for by a loan from Russia whilst the remainder of the funding is covered by Egypt through equity (Lorenzini, 2023; World Nuclear News, 2024a).

- Improved transparency in financial planning. All nuclear activities must be funded accordingly. Institutions researching various aspects covering nuclear energy must be adequately funded, and so should entities such as the Vaalputs Waste Disposal Institute. That way, participants P6 and P10 suggest that the government can ensure that they will always have skilled staff and can retain highly skilled and experienced professionals. Other factors, such as the digital archiving of past nuclear research work, must be considered and catered for.
- Participants urged the government to develop and publish a detailed investment plan as it did with the Just Energy Transition Investment Plan. Interviewees P7 and P8 suggest that special consulting panels made up of experienced nuclear energy experts under the Presidency may be created for this specific process.

4.5.6 Role of Civil organisations in the Nuclear Sector

Over half of the interviewees spoke about the role that civil organisations have played in hindering the growth of nuclear energy in South Africa. Interviewees believe that some of these groups are funded and backed by international players seeking to influence the energy landscape in the country. Examples highlighted by participants include:

- Environmental Advocacy Groups: Interviewees P2 and P6 expressed that these groups oppose nuclear energy based on environmental, safety, and waste management. They have successfully challenged procurement agreements in courts, completely nullifying them. In addition, they have a better hold on the perception of nuclear energy held by the public in comparison to the state itself through their organised campaigns to raise public awareness of the perceived dangers of nuclear energy. Participant P6 noted that these groups are funded by players who are keen to grow the renewable energy industry. They, as argued by participant P6, marginalise nuclear power in the energy policy debate in efforts to redirect public and private investment towards sources such as VRE.

- The interviewees also mentioned that nuclear opposition groups have called out government procurement processes on their lack of transparency, accountability, and public participation. Thereby introducing public scepticism regarding nuclear energy and slowing down the procurement of nuclear energy.

4.5.7 Recommendations made by Interviewees on Addressing Concerns made by Civil Organisations

To manage the influence of civil organisations, the participants suggest the following:

- Transparency: Interviewees suggest that the government must ensure that all nuclear energy decision-making, policy development, and procurement processes are publicly documented and accessible. Public participation must be encouraged. This can be achieved through open-access digital platforms.
- Enhanced Public Participation: Increased public participation channels in policymaking (broad-based consultation).
- Follow prescribed procurement processes to the tee and not skip certain stages (consult all stakeholders) to avoid litigation.
- Interviewees suggested that the government improve its stakeholder management by better outreach programmes. The government should conduct public awareness campaigns on nuclear energy and educate the public on the pros and cons of this technology without bias and not allow the narrative to be overtaken by anti-nuclear groups.

- Some interviewees were of the view that for nuclear to grow, nuclear energy plans must be made into law. This would be beneficial in the sense that it can help to provide a structured, transparent, and enforceable framework for energy policy. It also curbs the issue of the lack of continuity in nuclear energy plans that have been witnessed in the past. Additionally, it would make nuclear plans less susceptible to political shifts and other political interferences.

4.5.8 Lack of Public Awareness and Poor Stakeholder Engagement

Seventy-two percent of the interviewees mentioned how the government had neglected its role in spreading awareness of nuclear energy as a pathway that can support the baseload. Interviewees P2 and P11 expressed that this negligence has given lobby groups an edge over the state when it comes to the public perception of nuclear energy. The interviewees suggested that when the public is not well informed, it becomes difficult to have public participation and buy-in from communities.

Interviewees expressed that the government's stakeholder engagement in the nuclear sector has been poor and marred by the lack of transparency in important decision-making processes, coupled with insufficient consultation in the past.

4.5.8.1. Recommendations by Interviewees on Improving Public Perception and Stakeholder Engagement

- The government must proactively initiate communication and/or engagement channels to educate the public and let them know of different ways that they can be involved in pivotal decision-making on nuclear energy and related policies in the country. Interviewees P2, P8, and P11 have expressed that the public must be included in this attempt to lift the veil on the nuclear energy industry.
- Government and relevant institutions must adopt proactive engagement strategies that involve regular consultations with all stakeholders, transparent communication, and acceptance (and incorporation) of feedback into policy decisions.

4.5.9 Skills Development

Interviewees' responses show that more support from the government is required in efforts to align the country's plans on nuclear energy and the skillset being offered by institutions of higher learning. On top of that, adequate funding is required to support research departments that are dedicated to work related to this technology in South Africa (this includes the geological sciences about nuclear waste management).

Interviewees also spoke on the departure of experienced nuclear professionals to other countries. They express that these world-class professionals are usually lured to other countries by higher pay and better working conditions that are marred by bureaucracy and thus contribute to brain drain. The interviewees suggested the following to the government to help develop nuclear skills in the workforce:

- Provide adequate funding to research institutions that research nuclear energy.
- Allocate an appropriate budget for the salaries of professionals in the nuclear sector.

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the concluding remarks of the research study where the findings are integrated into the research objectives that were stated in Chapter 1. The research objectives will be revisited individually to address them systematically. A comprehensive set of answers based on the data gathered through expert interviews and case studies will be provided.

5.2 Research Objective 1: Recommendations from Case Studies

The first research objective aimed to form and provide recommendations that were derived from the case studies based on countries with successful nuclear energy sectors.

5.2.1 Summary of Recommendations

5.2.1.1 Policy and Regulatory Framework Improvement

Adopting a centralised government approach to decision-making, the South African government should create a regulatory framework and nuclear energy policies that are stable and consistent. They must commit to long-term nuclear energy plans so that they increase the chances of attracting investments into nuclear energy projects through policy certainty. In addition, South Africa should learn from countries with successful nuclear programmes.

5.2.1.2 Nuclear Project Financing

Financing options that include public-private partnerships and other innovative funding models must be thoroughly explored and adapted to the South African context. Additionally, partnerships with private investors help mitigate and spread risk by sharing it. To reduce financial strain, the government may consider phased nuclear project implementation. These considerations can help make nuclear build programmes feasible.

5.2.1.3 Public Perception and Social Acceptance

The government must invest in targeted nuclear energy public awareness campaigns that will educate the public on the benefits and cons of nuclear energy. That way, the government will be able to demystify the nuclear energy sector and highlight the role that nuclear energy could play in reducing the country's carbon footprint. This will ensure that the public opinion of nuclear energy is not controlled and skewed by anti-nuclear groups. Inclusive consultations with the public and other nuclear stakeholders will assist in building trust. The government's transparency, inclusion, and accountability in its decision-making processes will help improve nuclear public perception and help it garner support.

5.2.1.4 Nuclear Safety and Security

The nuclear sector can benefit from the National Nuclear Regulator adopting a prescriptive regulatory approach. This type of approach aims to provide detailed requirements for nuclear safety, security, and operational practices. This will reduce ambiguity, help to improve compliance and reduce the timelines for obtaining licensing.

5.2.1.5 Skills Development

Expanding and improving South Africa's nuclear energy workforce is an important aspect to consider before expanding the nuclear infrastructure in the country. South Africa must focus on local capacity building by investing in the development of local skilled professionals. This can be achieved through a collaboration between the country's higher institutions of higher learning (academia) and the government. The establishment of centralised training institutions can help to ensure specialised training for nuclear professionals. Participating in knowledge/information sharing activities, such as international nuclear energy conferences with other countries, is helpful in skills development.

5.3 Research Objective 2: Identifying Factors that Have Hindered Nuclear Growth in South Africa

The second research objective aimed to identify the factors that have hindered the growth of South Africa's nuclear energy sector and the uptake of new nuclear build programmes. Based on interviews conducted, case studies, and a review of relevant literature, multiple key barriers were identified and analysed.

5.3.1 Summary of findings

5.3.1.1 Policy Uncertainty

Frequent changes in government plans, coupled with the lack of long-term energy plans/policies, have hindered the growth of the nuclear energy industry in South Africa and have negatively affected the uptake of new nuclear build programmes in the country. These frequent changes have brought about policy uncertainty in the nuclear sector, making it an unstable investment sector. Without clear and consistent nuclear plans/policies, long-term planning for nuclear is not feasible, and delays in the expansion of the country's nuclear capacity will persist.

5.3.1.2 Financial Challenges

South Africa's limited financial resources, coupled with the high upfront capital cost of nuclear power plants, serve as yet another hindrance to nuclear growth in the country. Nuclear power build programmes require large amounts of foreign investments and government funding, which are both difficult to secure. The severe lack of affordable options continues to stall multiple proposed nuclear projects in South Africa.

5.3.1.3 Civil organisations and Lobby Groups

South Africa's nuclear build programme ambitions have been previously thwarted by lobby groups and anti-nuclear organisations with an emphasis on environmental, safety, and financial concerns. Beyond that, these lobby groups and anti-nuclear groups have a large stake in controlling the public perception of nuclear power in South Africa. Their involvement and activism in the sector have continuously delayed nuclear procurement processes whilst also negatively affecting the perception of nuclear power in the country.

5.3.1.4 Lack of Public Awareness and Poor Stakeholder Engagement

The lack of public awareness campaigns around nuclear power by the government has not only given lobby groups the upper hand in terms of controlling the public perception of nuclear power, but it has also impeded the social acceptance of nuclear power in South Africa. The government, in its nuclear procurement processes, has exhibited poor communication and inadequate engagement with key stakeholders (especially the public and local communities). Without targeted public awareness campaigns and inclusive consultation processes, the challenge of garnering nationwide support for nuclear energy will persist.

5.3.2 Conclusion

The study shows that policy uncertainty, project financing challenges, lobbying by anti-nuclear groups, lack of public awareness by the government, and poor stakeholder engagement have collectively contributed to hindering the growth of nuclear energy in South Africa. Policy uncertainty discourages foreign investments in nuclear projects and affects long-term energy planning and security. The high capital costs of nuclear and limited government funds exacerbate the financial challenges of funding nuclear build programmes, especially considering the country's fiscal constraints. On the other hand, the perception of nuclear is heavily influenced by civil organisations, the political landscape, and lobby groups. They also play a large role in delaying nuclear procurement processes. Poor stakeholder engagement and inadequate public awareness feed into the scepticism and resistance against nuclear energy.

Although some of these findings align with existing literature, they further provide an additional nuance by considering the South African context. Study participants provided insights that are based on first-hand experience. This study further identifies a critical gap in the South African government's lack of proper public awareness and stakeholder engagement strategies. The study further shows that policy certainty, innovative funding mechanisms, better public awareness campaigns, and stakeholder engagements could catapult South Africa’s nuclear sector.

Table 8: Consistency table: research objectives, conclusions, and contribution to knowledge

RO #	State Research Objective	State literature-based proposition	State conclusion or answer based on own research	Highlight key differences between your initial propositions and your findings – this is your contribution to knowledge
1	Analyse international case studies pertaining to countries with successful nuclear power programmes to draw comparison between their nuclear power strategies and South Africa's.	Countries such as France that have had successful nuclear build programmes lend themselves as perfect case studies to draw learnings from that will later form the recommendations.	The recommendations formed from France and India's case studies, interviews with nuclear energy experts in South Africa include improving the policy and regulatory framework by adopting a centralised governance approach, exploring innovative financing models, embarking on targeted nuclear awareness campaigns and focusing on creating skills development activities to improve nuclear workforce.	The French and Indian case studies provided valuable insights that were used to form recommendations for South Africa.

RO #	State Research Objective	State literature-based proposition	State conclusion or answer based on own research	Highlight key differences between your initial propositions and your findings – this is your contribution to knowledge
2	Identify and expand on the factors that have hindered the growth of South Africa's nuclear power programmes through the consideration of socio-political, environmental, economic and leadership aspects.	South Africa has had opportunities that could have led to new nuclear build programmes; however, they all fell through due to lack of investment and limited customer interest (in the case of the PBMR) Other factors that came up within the global perspective include active nuclear opposition coalitions exacerbated by negative public attitudes towards nuclear health and safety.	The factors that have hindered nuclear power build programmes in South Africa include policy uncertainty, project financing challenges, lobby groups, anti-nuclear groups, lack of nuclear public awareness and poor stakeholder engagement.	The initial proposition was based on limited literature that was based on observations and news reports on the South African nuclear sector. The findings are based on nuclear energy experts who have experienced these factors first hand. The issue of policy uncertainty is expanded upon by the expert interviewees. Another departure made by the findings is the that of poor stakeholder engagement exhibited by the government with regards to the procurement of nuclear energy in the country.

5.4 Recommendations

Numerous challenges have arisen in South Africa concerning achieving energy diversification whilst ensuring that energy demands are met. These challenges require urgent and sustainable solutions. The country has greenhouse gas emission reduction targets to meet by 2030, as evidenced by its commitment to the Paris Agreement. As such, South Africa is embarking on a just energy transition in efforts to step away from coal to less carbon-intensive energy source technologies. It then becomes imperative for the government to find suitable replacements for coal power plants.

Nuclear and natural gas have been lauded as viable options to support the baseload in light of the intermittency challenges brought about by renewables. However, this study focuses on nuclear energy as a possible solution towards replacing coal as a dispatchable energy source that can support baseload.

This study has explored the South African nuclear sector in a quest to identify the factors that have hindered the adoption of nuclear build programmes in the past. In addition to identifying these factors, the study also sought to form recommendations to help improve the South African nuclear sector. This improvement can then go on to create an enabling environment for the successful adoption of nuclear build programmes in the country. Thereby serving as a tool that may potentially help the country transition from a coal-fuelled and less carbon-intensive future that considers nuclear energy technology.

This study provides valuable insights to the South African government to help assist in nuclear planning and policy decision-making. This includes the Department of Mineral Resources and Energy (to be split into the Department of Electricity and Energy and the Department of Mineral and Petroleum Resources), the National Nuclear Regulator, and Eskom. This study may also serve as a valuable tool to nuclear research and development institutions such as NECSA and academic institutions. The study may be valuable to educational and training institutions geared at improving the nuclear sector’s workforce.

REFERENCES

Adamantiades, A., & Kessides, I. (2009). Nuclear power for sustainable development: Current status and future prospects. *Energy Policy*, *37*(12), 5149–5166.

AERB. (2024). About AERB. In *AERB*. AERB.

Andersson, J. J., & Finnegan, J. J. (2024). Industrial Policy and Decarbonization: The Case of Nuclear Energy in France. In *Stockholm School of Economics*. Stockholm School of Economics. https://www.juliusandersson.com/Industrial_Policy_and_Decarbonization_Andersson_Finnegan.pdf

ANDRA. (2024a). Cigeo. In *ANDRA*. ANDRA. https://international.andra.fr/solutions-long-lived-waste/cigeo

ANDRA. (2024b). Our Missions. In *ANDRA*. https://international.andra.fr/about-andra/our-missions

Arent, D., Arndt, C., Miller, M., Tarp, F., & Zinaman, O. (2017). *The Political Economy of Clean Energy Transitions* (1st ed., Vol. 1). Oxford University Press. www.wider.unu.edu

ASN. (2024). ASN overview. In *ASN*. Nuclear Safety Authority. https://www.french-nuclear-safety.fr/about-asn/asn-overview#introduction

Atomic Energy Regulatory Board. (2024). Functions of AERB. In *Atomic Energy Regulatory Board*. Atomic Energy Regulatory Board.

Autorité de Sûreté Nucléaire. (2006). Chernobyl What has been achieved over the past 20 years. In *Autorité de Sûreté Nucléaire*. Autorité de Sûreté Nucléaire.

Banerjee, S. (2017). Pressurised Heavy Water Reactor. In *Press Information Bureau*. Press Information Bureau.

Banerjee, S., & Gupta, H. P. (2017a). The evolution of the Indian nuclear power programme. *Progress in Nuclear Energy*, *101*, 4–18. https://doi.org/10.1016/j.pnucene.2017.02.008

Banerjee, S., & Gupta, H. P. (2017b). The evolution of the Indian nuclear power programme. *Progress in Nuclear Energy*, *101*, 4–18. https://doi.org/10.1016/j.pnucene.2017.02.008

BARC. (2021). BARC Newsletter. In *Bhabha Atomic Research Centre Journal*. Bhabha Atomic Research Centre.

Barkatullah, N., & Ahmad, A. (2017). Current status and emerging trends in financing nuclear power projects. *Energy Strategy Reviews*, *18*, 127–140. https://doi.org/10.1016/j.esr.2017.09.015

Basias, N., & Pollalis, Y. (2018). Quantitative and Qualitative Research in Business & Technology: Justifying a Suitable Research Methodology. In *Review of Integrative Business and Economics Research* (Vol. 7, Issue 1, pp. 1–15). GMP Press and Printing.

Bearman, M. (2019). Focus on Methodology: Eliciting rich data: A practical approach to writing semi-structured interview schedules. *Focus on Health Professional Education: A Multi-Professional Journal*, *20*(3), 1–11.

Bhattacharya, S., Banerjee, R., Ramadesigan, V., Liebman, A., & Dargaville, R. (2024). Bending the emission curve — The role of renewables and nuclear power in achieving a net-zero power system in India. *Renewable and Sustainable Energy Reviews*, *189*, 113954. https://doi.org/10.1016/j.rser.2023.113954

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Britannica. (2024a, April). *Types of reactors*. Encyclopedia Britannica.

Britannica. (2024b, April 5). *atomic bombings of Hiroshima and Nagasaki*. Encyclopedia Britannica. https://www.britannica.com/technology/nuclear-reactor/Types-of-reactors

Brook, B. W., Alonso, A., Meneley, D. A., Misak, J., Blees, T., & van Erp, J. B. (2014). Why nuclear energy is sustainable and has to be part of the energy mix. *Sustainable Materials and Technologies*, *1*, 8–16. https://doi.org/10.1016/j.susmat.2014.11.001

Brouard, S., & Guinaudeau, I. (2015). Policy beyond politics? Public opinion, party politics and the French pro-nuclear energy policy. *Journal of Public Policy*, *35*(1), 137–170. https://doi.org/https://doi.org/10.1017/S0143814X14000221[Opensinanewwindow]

Brulé, V. & A. (2019). Press release French people and nuclear energy: knowledge and perceptions. In *Orano*. Orano. https://www.orano.group/en/news/news-group/2019/june/french-people-and-nuclear-energy-knowledge-and-perceptions

Brynard, H. J., Ainslie, L. C., & Van der Merwe, P. J. (1988). Uranium in South Africa : 1987. In *Atomic Energy Corporation*. Atomic Energy Corporation.

Bureau of Economic and Agricultural Affairs. (1998). Fact Sheet: India and Pakistan Sanction. In *US Department of State*. US Department of State. https://1997-2001.state.gov/regions/sa/fs_980618_india_pak.html

Burkett, J. (2009). Direct Action and the Campaign for Nuclear Disarmament, 1958–62. In *NGO's in Contemporary Britain* (pp. 21–37).

Cardis, E., & Hatch, M. (2011). The Chernobyl Accident - An Epidemiological Perspective. *Clinical Oncology*, *23*(4), 251–260. https://doi.org/10.1016/j.clon.2011.01.510

Carter, N., Bryant-Lukosius, D., DiCenso, A., Blythe, J., & Neville, A. J. (2014). The Use of Triangulation in Qualitative Research. *Oncology Nursing Forum*, *41*(5), 545–547. https://doi.org/10.1188/14.ONF.545-547

Caulfield, J. (2019, September 6). *How to Do Thematic Analysis | Step-by-Step Guide & Examples*. Scribbr; Scribbr.

Cavendish, L. M. (2011). Stories of international teachers: A narrative inquiry about culturally responsive teaching. In *University of Iowa*.

Center for Nuclear Studies. (2012). France: A Study of French Nuclear Policy After Fukushima. In *Columbia University*. Columbia University. https://k1project.columbia.edu/news/french-nuclear-policy-after-fukushima

Central Intelligence Agency. (2024a). France Details - The World Factbook. In *The World Factbook*. Central Intelligence Agency. https://www.cia.gov/the-world-factbook/countries/france/map/

Central Intelligence Agency. (2024b). India Details: The World Factbook. In *Central Intelligence Agency*. Central Intelligence Agency. https://www.cia.gov/the-world-factbook/countries/india/map/

Chater, J. (2005). A History of Nuclear Power. In *Focus on Nuclear Power Generation* (pp. 28–37). Focus on Nuclear Power Generation.

Chauke, R. E. (2018). Forging resistance: An analysis of opposition to nuclear energy in South Africa. In *University of Witwatersrand* (pp. 1–60).

Chaussade, J.-P. (1990). Public confidence and nuclear energy. In *International Atomic Energy Agency* (Issue 2). International Atomic Energy Agency. https://www.iaea.org/sites/default/files/publications/magazines/bulletin/bull32-2/32204790709.pdf

Clark, G., & Jacks, D. (2007). Coal and the Industrial Revolution, 1700-1869. In *European Review of Economic History* (Vol. 11, Issue 1, pp. 39–72). Oxford University Press. https://about.jstor.org/terms

Crellin, F. (2023). French nuclear watchdog ASN issues first lifespan extension to 40-year-old reactor. In *Reuters*. https://www.reuters.com/business/energy/french-nuclear-watchdog-asn-issues-first-lifespan-extension-40-year-old-reactor-2023-08-22/

Crippa, M., Guizzardi, D., Banja, M., Solazzo, E., Muntean, M., Schaaf, E., Pagani F., Monforti-Ferrario, F., Olivier, J. G. J., Quadrelli, R., Risquez Martin, A., Taghavi-Moharamli, P., Grassi, G., Rossi, S., Oom, D., Branco, A., San-Miguel, J., Vignati, E., & European Commission. Joint Research Centre. (2022). CO2 Emissions of all World Countries. In *JRC Publications Repository*.

Department of Atomic Energy. (1962). The Atomic Energy Act, 1962. In *Atomic Energy Regulatory Board*. Department of Atomic Energy. https://www.aerb.gov.in/images/PDF/Atomic-Energy-Act-1962.pdf

Department of Atomic Energy. (2010). The Civil Liability for Nuclear Damage Act, 2010. In *India Code*. India Code.

Department of Atomic Energy. (2024a). About DAE. In *Department of Atomic Energy*. Department of Atomic Energy.

Department of Atomic Energy. (2024b). Atomic Energy Commission. In *Department of Atomic Energy.* https://dae.gov.in/atomic-energy-commission/

Department of Atomic Energy. (2024c). History - Nuclear. In *Department of Atomic Energy*. Department of Atomic Energy. https://dae.gov.in/history/

Department of Atomic Energy. (2024d). PM witnesses the historic “Commencement of Core Loading” at India’s first indigenous Fast Breeder Reactor (500 MWe) at Kalpakkam, Tamil Nadu. In *Department of Atomic Energy*. Department of Atomic Energy.

Department of Atomic Energy. (2024e). Research Reactors in BARC. In *Bhabha Atomic Research Centre (BARC)*. Department of Atomic Energy.

Department of Energy. (2015). Progress with the Nuclear New Build Programme. In *Department of Energy* (pp. 1–2). Department of Energy.

DME. (1998). White paper on the energy policy of the Republic of South Africa. In *Department of Minerals and Energy* (pp. 1–110). Dept. of Minerals and Energy.

DMRE. (2019). *Integrated Resource Plan* (pp. 1–100).

DMRE. (2022). South African Gas Master Plan: Basecase Report. In *Department of Mineral Resources and Energy*. Department of Mineral Resources and Energy.

DMRE. (2023). Integrated Resource Plan. In *Department of Mineral Resources and Energy* (pp. 1–48). Department of Mineral Resources and Energy.

Du, Y., & Parsons, J. E. (2009). Update on the Cost of Nuclear Power. In *Center for Energy and Environmental Policy Research*. Center for Energy and Environmental Policy Research.

Earth Science Australia. (2025). Earth Science Australia: Nuclear Reactors. In *Earth Science Australia*. Earth Science Australia.

EDF. (2024a). An SMR solution to build a carbon free world. In *EDF*. EDF. https://www.edf.fr/en/the-edf-group/producing-a-climate-friendly-energy/nuclear-energy/shaping-the-future-of-nuclear/smr-solution

EDF. (2024b). Management of radioactive waste. In *EDF*. EDF. https://www.edf.fr/en/the-edf-group/producing-a-climate-friendly-energy/nuclear-energy/edf-unique-expertise-in-nuclear-power-creation/management-of-radioactive-waste

Eisenhower Presidential Library. (2024, April). *Atoms for Peace*. Eisenhower Presidential Library. https://www.eisenhowerlibrary.gov/research/online-documents/atoms-peace

Eskom. (2022). *Koeberg Nuclear Power Station*.

European Union. (2009). Council Directive 2009/71/Euratom of 25 June 2009 establishing a Community framework for the nuclear safety of nuclear installations. In *European Union*. European Union. http://data.europa.eu/eli/dir/2009/71/oj

European Union. (2011). Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste. In *European Union*. http://data.europa.eu/eli/dir/2011/70/oj

Express News Service. (2023). India, Russia sign pacts on future units of Kudankulam plant. In *The Indian Express*. The Indian Express. https://indianexpress.com/article/india/india-russia-construction-power-kudankulam-nuclear-plant-jaishankar-9083865/

Fagnani, J., & Moatti, J.-P. (1984). The Politics of French Nuclear Development. *Journal of Policy Analysis and Management*, *3*(2), 264–275.

Fernández-Arias, P., Vergara, D., & Antón-Sancho, Á. (2023). Bibliometric Review and Technical Summary of PWR Small Modular Reactors. *Energies*, *16*(13), 5168. https://doi.org/10.3390/en16135168

Fig, D. (2010). *Nuclear energy rethink? The rise and demise of South Africa's Pebble Bed Modular Reactor.* https://issafrica.org/research/papers/nuclear-energy-rethink-the-rise-and-demise-of-south-africas-pebble-bed-modular-reactor

Franklin, C., Cody, P., & Ballan, M. (2009). Reliability and Validity in Qualitative Research. In *The Handbook of Social Work Research Methods*. Sage Publications.

Galindo. (2022, November 15). *What is Nuclear Energy? The Science of Nuclear Power*. IAEA Office of Public Information and Communication. https://www.iaea.org/newscenter/news/what-is-nuclear-energy-the-science-of-nuclear-power

George, T. (2022, March 10). *Types of Interviews in Research | Guide & Examples*. Scribbr. https://www.scribbr.com/methodology/interviews-research/

Global Centre for Nuclear Energy Partnership. (2024). Global Centre for Nuclear Energy Partnership. In *Global Centre for Nuclear Energy Partnership*. Global Centre for Nuclear Energy Partnership. https://www.gcnep.gov.in/index.html

Gopalakrishnan, A. (2002). Evolution of the Indian Nuclear Power Program. *Annual Review of Energy and the Environment*, *27*(1), 369–395. https://doi.org/10.1146/annurev.energy.27.122001.083448

Gubrium, J., & Holstein, J. (2002). Handbook of Interview Research: Context and Method. In *Sage Publications* (pp. 2–31). Sage Publications.

Guimier, L. (2014). Regulatory Framework of France. In *Institut de Radioprotection et de Sûreté Nucléaire*. International Atomic Energy Agency.

Gyamfi, S., Derkyi, N. S. A., & Asuamah, E. Y. (2018). The Potential and the Economics of Hydropower Investment in West Africa. In *Sustainable Hydropower in West Africa* (pp. 95–107). Elsevier. https://doi.org/10.1016/B978-0-12-813016-2.00007-1

Hadna, S. (2017). The Nuclear Safety Authority in France: A Dogma of “Independence” and Institutional Fragility. *Journal of Innovation Economics & Management*, *n° 22*(1), 119–144. https://doi.org/10.3917/jie.022.0119

Hanlon, W. (2016). *Coal Smoke and the Costs of the Industrial Revolution* (22921). https://doi.org/10.3386/w2292

Harris, G., Heptonstall, P., Gross, R., & Handley, D. (2012). Cost Estimates for Nuclear Power in the UK. In *Centre for Energy Policy and Technology* (pp. 1–28).

Hernandez, A. (2024). France’s EDF to redraft small modular reactor design amid cost, technology concerns. In *Reuters*. Reuters. https://www.reuters.com/business/energy/frances-edf-drops-plans-develop-its-own-small-nuclear-reactor-technology-2024-07-01/

Herring, H. (2007). Opposition to Nuclear Power: A Brief History. In *Energy, Climate and the Environment Series* (pp. 34–49).

IAEA. (2001). Nuclear power programme planning: An integrated approach. In *International Atomic Energy Agency* (pp. 1–45). International Atomic Energy Agency. https://www-pub.iaea.org/MTCD/Publications/PDF/TE_1259_prn.pdf

IAEA. (2008). IAEA Board Approves India-Safeguards Agreement. In *IAEA.* IAEA.

IEA. (2024). France. In *International Energy Agency*. International Energy Agency. https://www.iea.org/countries/france/energy-mix

International Atomic Energy Agency. (2022). Country Nuclear Power Profiles 2022 Edition: France. In *International Atomic Energy Agency*. International Atomic Energy Agency. https://www-pub.iaea.org/MTCD/publications/PDF/cnpp2022/countryprofiles/France/France.htm

International Energy Agency. (2024). India. In *International Energy Agency*. International Energy Agency. https://www.iea.org/countries/india/electricity

International Institute of Nuclear Energy. (2021). Brief History of Nuclear Energy in France. In *International Institute of Nuclear Energy*. International Institute of Nuclear Energy. https://www.i2en.fr/en/brief-history-of-french-nuclear-energy/

International Monetary Fund. (2023). South Africa Carbon Pricing and Climate Mitigation Policy. *IMF Staff Country Reports*, *2023*(195), 1–48. https://doi.org/https://doi.org/10.5089/9798400245350.002

IRSN. (2024). IRSN| Identity. In *Institute for Radiation protection and Nuclear Safety*. https://en.irsn.fr/about-us/identity

Jasper, J. J. (1990). Nuclear politics: Energy and the state in the United States, Sweden, and France. In *Princeton University Press*. Princeton University Press.

Kamath, P. M. (1998). Indian Nuclear Tests, Then and Now: An Analysis of US and Canadian Responses. *Strategic Analysis: A Monthly Journal of the IDSA*, *23*(5).

Kenan, A., & Chirenje, E. (2014). Uranium in South Africa: Exploration, mining and production. In *International Atomic Energy Agency*. International Atomic Energy Agency. https://www-pub.iaea.org/MTCD/Meetings/PDFplus/2014/cn216/cn216BoA.pdf

Khan, A. (2022). Anti-Nuclear Movement in India: Protests in Kudankulam and Jaitapur. *South Asia Research*, *42*(1), 7–20. https://doi.org/10.1177/02627280211054795

King, N. (2004). Using Templates in the Thematic Analysis of Text. In *Essential Guide to Qualitative Methods in Organizational Research* (pp. 256–270). SAGE Publications Ltd. https://doi.org/10.4135/9781446280119.n21

Kumar, A., Srivenkatesan, R., & Sinha, R. K. (2009). On the Physics Design of Advanced Heavy Water Reactor (AHWR). In *Bhabha Atomic Research Centre (BARC)*. International Atomic Energy Agency.

Kumar, S., Harikumar, S., Varghese, C. S., & Shukla, D. K. (2017). Regulatory aspects of nuclear power program in India. *Progress in Nuclear Energy*, *101*, 146–159. https://doi.org/10.1016/j.pnucene.2017.05.006

Kuyper, J., Schroeder, H., Bj¨, B., & Linnér, B.-O. (2018). *Annual Review of Environment and Resources The Evolution of the UNFCCC*. https://doi.org/10.1146/annurev-environ

Lamba, A., Kumar, V., & Gangadharan, B. (2024). Having private participation in India’s nuclear energy. In *The Hindu*. https://www.thehindu.com/opinion/lead/having-private-participation-in-indias-nuclear-energy/article68702460.ece

Le Gros, G. (2020). La naissance du parc nucleaire francais: le plan Messmer. *International Atomic Energy Agency*, *52*(31), 56–59. https://inis.iaea.org/records/czje0-6cv23

Leifeld, P. (2014). Polarization of coalitions in an agent-based model of political discourse. In *Leifeld Computational Social Networks* (Vol. 1). http://www.computationalsocialnetworks.com/content/1/1/7

Leotlela, M. (2017). Evolution of South African nuclear regulatory regime from the British nuclear regulatory system. In *Journal of Nuclear Energy Science & Power Generation Technology* (Vol. 1, Issue 1). Journal of Nuclear Energy Science & Power Generation Technology.

Leotlela, M. (2021). Establishing an Effective Nuclear Regulatory Regime: A Case Study of South Africa. *Science, Technology & Public Policy*, *5*(1), 1. https://doi.org/10.11648/j.stpp.20210501.11

Leszczynska, A. (2023, October 2). *70 Years Later, the Legacy of the "Atoms for Peace" Speech*. IAEA Office of Public Information and Communication. https://www.iaea.org/newscenter/news/70-years-later-the-legacy-of-the-atoms-for-peace-speech

Leung, L. (2015). Validity, reliability, and generalizability in qualitative research. *Journal of Family Medicine and Primary Care*, *4*(3), 324. https://doi.org/10.4103/2249-4863.161306

Leverenz, R., Göbel, A., & Gerhard, L. (2004). The European Pressurized Water Reactor: A Safe and Competitive Solution for Future Energy Needs. In *Nuclear Energy for New Europe*. IAEA. https://inis.iaea.org/collection/NCLCollectionStore/_Public/37/086/37086871.pdf

Lorenzini, M. (2023). Why Egypt's new nuclear plant is a long-term win for Russia. In *Bulletin of Atomic Scientists*. Bulletin of Atomic Scientists. https://thebulletin.org/2023/12/why-egypts-new-nuclear-plant-is-a-long-term-win-for-russia/

Mallet, B. (2024). Exclusive: France is weighing zero-interest loan for 6 nuclear reactors, sources say. In *Reuters*. Reuters.

https://www.reuters.com/business/energy/france-is-weighing-zero-interest-loan-6-nuclear-reactors-sources-say-2024-11-27/

Martin, W. (2024, March 30). *nuclear power*. Encyclopedia Britannica. https://www.britannica.com/technology/nuclear-power

Mazhar, S. A., Anjum, R., Anwar, A. I., & Khan, A. A. (2021). Methods of Data Collection: A Fundamental Tool of Research. In *Journal of Integrated Community Health* (Vol. 10, Issue 1). Journal of Integrated Community Health.

McCombes, S. (2019, September 19). *Sampling Methods | Types, Techniques & Examples*. Scribbr.

Meng, Y., Zhou, R., Dinçer, H., & Yüksel, S. (2021). Analysis of inventive problem-solving capacities for renewable energy storage investments. *Energy Reports*, *7*, 4779–4791.

Middleton, F. (2019, July 3). *Reliability vs. Validity in Research*. Scribbr; Scribbr.

Ministry of Environment and Forests. (1986). The Environmental Protection Act of 1986. In *India Code*. Ministry of Environment and Forests.

Ministry of External Affairs. (2024). Nuclear Security in India. In *Ministry of External Affairs*. Ministry of External Affairs. https://www.mea.gov.in/images/pdf/Brochure.pdf

Ministry of New and Renewable Energy. (2024). India's Renewable Energy Capacity Hits New Milestone. In *Ministry of New and Renewable Energy: PIB Dehli*. Ministry of New and Renewable Energy.

National Nuclear Regulator. (2023). Report on the Status of Nuclear Safety in South Africa. 1 April 2023 - 30 June 2023. In *National Nuclear Regulator* (pp. 1–2). National Nuclear Regulator.

National Radioactive Waste Disposal Institute. (2021). Vaalputs National Radioactive Waste Disposal Facility. In *National Radioactive Waste Disposal Istitute*.

Nelkin, D., & Pollak, M. (1980). Political Parties and the Nuclear Energy Debate in France and Germany. *Comparative Politics*, *12*(2), 127. https://doi.org/10.2307/421698

Nikolopoulou, K. (2022a, September 19). *What Is Confirmation Bias? | Definition & Examples*. Scribbr.

Nikolopoulou, K. (2022b, September 23). *What Is the Hawthorne Effect? | Definition & Examples*. Scribbr. https://www.scribbr.com/research-bias/hawthorne-effect/

NPCIL. (2024). Corporate Social Responsibility at NPCI. In *NPCIL*. NPCIL.

Nuclear Business Platform. (2024). India's Nuclear Regulatory Excellence to Secure $26 Billion in Private Investment. In *Nuclear Business Platform*. Nuclear Business Platform.

Nuclear Engineering International. (2024). HALEU UF6 and SMR Fuel Fabrication. In *Nuclear Engineering International*. Nuclear Engineering International. https://www.neimagazine.com/analysis/haleu-uf6-and-smr-fuel-fabrication/

Nuclear Safety Authority. (2006a). Act No. 2006-686 of 13 June 2006 on Transparency and Security in the Nuclear Field. In *Nuclear Safety Authority*. Nuclear Safety Authority.

Nuclear Safety Authority. (2006b). ACT No. 2006-686 of 13 June 2006 on Transparency and Security in the Nuclear Field. In *Nuclear Safety Authority*.

Nuclear Safety Authority. (2021a). Decree No 2007-1557 of 2 November 2007. In *Nuclear Safety Authority*. Nuclear Safety Authority. https://www.french-nuclear-safety.fr/asn-regulates/regulations/decree-no-2007-1557-of-2-november-2007

Nuclear Safety Authority. (2021b). National plan on management of radioactive materials and waste (PNGMDR). In *Nuclear Safety Authority*. Nuclear Safety Authority.

OECD Nuclear Energy Agency. (2007). Management of Spent Fuel from Nuclear Power Reactors. In *International Atomic Energy Agency*. International Atomic Energy Agency.

Orano. (2024a). All about radioactive waste in France. In *Orano*. Orano. https://www.orano.group/en/unpacking-nuclear/all-about-radioactive-waste-in-france

Orano. (2024b). The world leader in recycling used nuclear fuels. In *Orano*. Orano.

Pasricha, A. (2024). India's 3 stage Nuclear Program: Here's everything you need to know. In *Jargan Josh*.

Petros'yants, A. (1984). A Pioneer of Nuclear Power. In *International Atomic Energy Agency* (Vol. 26, Issue 4, pp. 1–5).

Polit, D. F., & Beck, C. T. (2021). Essentials of Nursing Research. In *Wolters Kluwer* (10th ed.). Wolters Kluwer.

Power Technology. (2023). Gorakhpur Nuclear Power Plant, Haryana, India. In *Power Technology*. Power Technology. https://www.power-technology.com/projects/gorakhpur-nuclear-power-plant-haryana-india/?cf-view

Press Trust of India. (2023). India, Russia ink pacts on construction of future power units of Kudankulam nuclear plant. In *The Hindu*. The Hindu.

Quintão, C., Andrade, P., & Almeida, F. (2020). How to Improve the Validity and Reliability of a Case Study Approach. In *Open Journals in Education* (Vol. 9, Issue 2, pp. 265–275). Open Journals in Education.

Radioactivity EU. (2024). Classification to ensure radioactive waste is managed appropriately. In *Radioactivity EU*. Radioactivity EU. https://radioactivity.eu.com/categories/radioactive_waste/waste_classification#

Raj, K., Prasad, K. K., & Bansal, N. K. (2006). Radioactive waste management practices in India. *Nuclear Engineering and Design*, *236*(7–8), 914–930. https://doi.org/10.1016/j.nucengdes.2005.09.036

Republic of South Africa. (2021). South Africa First Nationally Determined Contribution Under The Paris Agreement. In *UNFCCC* (pp. 1–33). UNFCCC.

Resnik, D. (2020). What Is Ethics in Research & Why Is It Important? In *National Institute of Environmental Health Sciences*. NIH National Institute of Environmental Health Sciences.

Rosenqvist, Å., Milne, A., Lucas, R., Imhoff, M., & Dobson, C. (2003). A review of remote sensing technology in support of the Kyoto Protocol. In *Environmental Science and Policy* (Vol. 6, Issue 5, pp. 441–455). https://doi.org/10.1016/S1462-9011(03)00070-4

Sethna, H. N. (1979). India's Atomic Energy Programme Past and Future. In *International Atomic Energy Agency* (Vol. 21, Issue 5). https://www.iaea.org/sites/default/files/publications/magazines/bulletin/bull21-5/21505090211.pdf

Singh, S. C. (2024). Exclusive: India seeks $26 billion of private nuclear power investments. In *Reuters*. Reuters. https://www.reuters.com/business/energy/india-seeks-26-bln-private-nuclear-power-investments-sources-say-2024-02-20/

Sinha, S. K. (2021). Evolution of PHWR technology: A historical review. In *BARC newsletter*. BARC newsletter. https://barc.gov.in/barc_nl/2021/2021010202.pdf

Snyder, & Hannah. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339.

Sovacool, B., & Valentine, S. V. (2012). *The National Politics of Nuclear Power*.

Srinivasan, M. R., Grover, R. B., & Bhardwaj, S. A. (2005). Nuclear Power in India: Winds of Change. *Economic and Political Weekly*, *40*(49), 5183–5188. http://www.jstor.org/stable/4417490

Statista. (2024). Share of nuclear power in total domestic electricity generation worldwide in 2023, by country. In *Statista*. https://www.statista.com/statistics/270367/share-of-nuclear-power-in-the-power-supply-of-selected-countries/

Statistics South Africa. (2023). Electricity generated and available for distribution (Preliminary) . In *Department of Statistics South Africa*. Department of Statistics South Africa.

Stewart, W. R., & Shirvan, K. (2022). Capital cost estimation for advanced nuclear power plants. *Renewable and Sustainable Energy Reviews*, *155*, 111880. https://doi.org/10.1016/j.rser.2021.111880

Tellis, A. J. (2023). Completing the U.S.-India Civil Nuclear Agreement: Fulfilling the Promises of a Summer Long Past. In *Carnegie Endowment for International Peace*. https://carnegieendowment.org/research/2023/11/completing-the-us-india-civil-nuclear-agreement-fulfilling-the-promises-of-a-summer-long-past?lang=en

Tellis, A. J. (2024). Reclaiming the Promise of Nuclear Power in India. In *Carnegie Russia Eurasia Center*. Carnegie Russia Eurasia Center. https://carnegieendowment.org/research/2024/10/nuclear-power-india-promise?lang=en

Tenny, S., Brannan, J., & Brannan, G. (2022). Qualitative Study. In *National Center for Biotechnology Information*. National Library of Medicine.

Terlikowski, P., Paska, J., Pawlak, K., Kaliński, J., & Urbanek, D. (2019). Modern financial models of nuclear power plants. *Progress in Nuclear Energy*, *110*, 30–33. https://doi.org/10.1016/j.pnucene.2018.09.010

The Hindu. (2021). The story of Kudankulam: From 1988 to 2016. In *The Hindu*. https://www.thehindu.com/news/national/The-story-of-Kudankulam-From-1988-to-2016/article60528215.ece

The Hindu. (2024). Watch | 50 years ago, India conducted its first ever nuclear test. In *The Hindu*. https://www.thehindu.com/news/national/watch-50-years-ago-india-conducted-its-first-ever-nuclear-test/article68187908.ece

The Presidency. (2022). JET Implementation Plan 2023 to 2027. In *The Presidency*. The Presidency.

The Tribune India. (2024). Training programme aims to cut distribution losses: NPTI DG. In *The Tribune India*. The Tribune India. https://www.tribuneindia.com/news/delhi/training-programme-aims-to-cut-distribution-losses-npti-dg/

United Nations. (1992). United Nations Framework Convention on Climate Change United Nations. In *United Nations*. United Nations.

University of Calgary. (2024, April). *Dispatchable source of electricity*. Energy Education. https://energyeducation.ca/encyclopedia/Dispatchable_source_of_electricity

US Department of State Archive. (2008). U.S. - India: Civil Nuclear Cooperation. In *US Department of State Archive*. US Department of State Archive. https://2001-2009.state.gov/r/pa/prs/ps/2008/oct/index.htm

USA EPA. (2023). Significant Discoveries and the History of Radiation Protection. In *United States Environmental Protection Agency*. United States Environmental Protection Agency. https://www.epa.gov/radtown/radtown-radiation-protection-activity-1-

Vaidyanathan, G., & Kale, R. D. (2022). India’s nuclear power program: a critical review. *Sādhanā*, *47*(3), 181. https://doi.org/10.1007/s12046-022-01953-9

Van Wyk, J. (2021). *African perspectives Global insights Nuclear Energy in South Africa Special Report*.

Vanaik, A. (2020). Kudankulam: The Story of an Indo-Russian Nuclear Power Plant. *Journal for Peace and Nuclear Disarmament*, *3*(2), 420–422. https://doi.org/10.1080/25751654.2020.1853930

Vásquez-Maignan, X., Richards, M., & Konig, J. (2024). Latest Plans to Increase Nuclear Energy in South Africa. In *White & Case*. White & Case.

Wattal, P. K. (2013). Indian programme on radioactive waste management. In *Indian Academy of Sciences* (Vol. 38, Issue 5, pp. 849–857). Indian Academy of Sciences.

World Bank. (2024). The World Bank In India. In *World Bank*. https://www.worldbank.org/en/country/india/overview

World Nuclear Association. (2024a). Fukushima Daiichi Accident. In *World Nuclear Association*. World Nuclear Association. https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-daiichi-accident

World Nuclear Association. (2024b). Nuclear Power in India. In *World Nuclear Association*. World Nuclear Association. https://world-nuclear.org/information-library/country-profiles/countries-g-n/india

World Nuclear Association. (2024c). Nuclear Power in India. In *World Nuclear Association*. World Nuclear Association. https://world-nuclear.org/information-library/country-profiles/countries-g-n/india

World Nuclear Association. (2024d, April). *Nuclear Power Reactors*. World Nuclear Association. https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/nuclear-power-reactors.aspx

World Nuclear Association. (2025). Nuclear Power in South Africa. In *World Nuclear Association*. World Nuclear Association. https://world-nuclear.org/information-library/country-profiles/countries-o-s/south-africa

World Nuclear News. (2024a). El Dabaa export loan ratified, as unit 4's core catcher installed. In *World Nuclear News*. World Nuclear News.

World Nuclear News. (2024b). Fuel Loading Begins at Indian Fast Breeder Reactor. In *World Nuclear News*. https://www.world-nuclear-news.org/Articles/Fuel-loading-begins-at-Indian-fast-breeder-reactor

World Nuclear News. (2024c). Fuel loading completed at France's Flamanville 3 EPR. In *World Nuclear News*. World Nuclear News. https://www.world-nuclear-news.org/Articles/Fuel-loading-completed-at-French-EPR

WTS Energy. (2023). France's Nuclear Odyssey. In *WTS Energy*. https://www.wtsenergy.com/frances-nuclear-energy/

Yergin, D. (2023). The 1973 Oil Crisis: Three Crises in One—and the Lessons for Today. In *Center on Global Energy Policy*. Center on Global Energy Policy at Columbia University.

Yin, R. (1994). Case study research: Design and method. In *Sage Publishing*. Sage Publishing.

Yin, R. (2011). Applications of Case Study Research. In *Sage Publications*. Sage Publications.

Zainal, Z. (2007). Case study as a research method. In *Kemanusiaan The Asian Journal of Humanities* (pp. 1–6). Universiti Teknologi Malaysia.

APPENDIX

Appendix (A)

Table 9: Rough outline of Interview Schedule.

Part 1: *Ask questions on the status of nuclear industry in South Africa.*
The aim of these questions is to establish the participants role within the nuclear industry in their own words, where they will share their lived experiences. These questions do not seek opinion, instead they aim to set up a starting point for the interview. This part of the interview will also address the question of what will happen to the information they offer, how it will be interpreted and incorporated into the write-up. The interviewer essentially addresses pertinent points outlined in the cover letter that will be sent to the participants to avoid misunderstanding. 1. In your own words, what is your interpretation of the focus of this study? 2. For how long and in what capacity have you been involved (or employed) in South Africa's nuclear industry? 3. What is current outlook on the nuclear industry?
Part 2: *Questions on Policy Development in South Africa post 1994*
These questions aim to explore the effects of policy development on the industry through the lived experiences of participants. The participants will be industry experts who have interacted with nuclear legislation closely. 4. Which nuclear regulation/policy had an impact on your responsibility within your role? Expand on this impact. 5. What were the implications of that regulation/policy on your responsibility or role? Mention both positive and negative implications.

6. Given the chance, what changes would you make to that regulation/policy to inspire positive effect on your responsibility/role? 7. What recommendations would you make to the relevant government department to assist in the growth of the nuclear industry?
Part 3: *What are the factors they believe have hindered the establishments of new nuclear build programmes?*
This section of the interview is open-ended. It allows the participants to immerse the interviewer freely and fully into their lived experiences in the different facets of the nuclear industry in South Africa. 8. Based on your experience and expertise, what are the factors you believe have hindered the establishments of new nuclear build programmes in South Africa? Expand on those factors.
Part 4*: After working in the industry for x years, what do you believe can be done differently by the government and relevant nuclear energy bodies going forward?*
This section of the interview will help form part of the recommendations, based on experts' lived experiences in the industry. 9. Considering all the facets of the nuclear energy industry (not just policy and regulation), what other recommendations would you make for relevant nuclear bodies going forth?

Appendix B: Ethics Clearance

Graduate School of Business Administration
University of the Witwatersrand, Johannesburg

Wits Business School

Wits Business School Ethics Committee
Constituted under the University Human Research Ethics Committee (Non-Medical)

Ethics Clearance Certificate

Ethics protocol number: WBS/EL1612627/693

This certificate is only valid with a legitimate ethics protocol number and signed by the Researcher (below).

Project title	Assessing factors hindering nuclear power build programmes and nuclear power feasibility in South Africa
Investigator / Researcher	Ms Thendo Masutha
Nature of Project	MM (Energy Leadership)
Decision of the Committee	Approved, provided stakeholders and participants are guaranteed confidentialty.
Issue Date of Certificate	23/07/2024
Expiry date	Date of submission of the project / research report
Chairperson	Dr Ayanda Magida ☎ +27 11 717 3953 ayanda.magida@wits.ac.za

Declaration by Researcher

One copy must be signed by the Researcher and returned to the Chairperson of the Wits Business School Ethi Committee.

I fully understand the conditions under which I am authorized to carry out the abovementioned research an guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I undertake to resubmit the protocol to the Committee.

T.Masutha
Signature

26/08/2024
Date:

Figure 30: Ethics Clearance from the University