A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the Degree of Master of Science

# Assessing the financial feasibility of Nigeria's 2030 targets for solar and nuclear power



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AUTHOR’S DECLARATION

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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# CENTRAL EUROPEAN UNIVERSITY

**ABSTRACT OF THESIS** submitted by:

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Massive expansion of low-carbon electricity is key for sustainable development and climate change mitigation, especially in developing economies. Nigeria plans to increase the share of renewables in its electricity to 30% by 2030 while simultaneously expanding electricity production and constructing at least one nuclear reactor. Is the financial investment required for these plans feasible? To answer this question, the thesis uses the "feasibility space" approach, comparing the planned energy transition in Nigeria to several "reference cases". The thesis constructs clean energy transition scenarios for Nigeria with installed solar capacity up to 6.5 GW, nuclear up to 1.2 GW and the required investments up to $37 billion ($156 per capita). The thesis shows that these investments exceed the entire Official Development Assistance and Foreign Direct Investment in Nigeria. They make up to 8% of Nigeria's GDP, which is double that of Just Energy Transition Partnerships commitments to Vietnam, two-three times larger than Russia's loans to nuclear power in Bangladesh, and over ten times larger than Germany's renewable energy investments. The thesis recommends that to achieve its targets, Nigeria should advance its relations with key nuclear suppliers backed by respective states while being mindful about geopolitical implications. The best strategy for developing solar power is public private partnerships as in Brazil and Vietnam. The thesis also recommends more research into successful cases and specific mechanisms of attracting public and private investments to clean energy transitions in Nigeria and other developing and emerging economies.

**Keywords:** energy transitions, feasibility assessment, nuclear, solar, financial investments.

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# List of Abbreviations

| Abbreviation | Full text |
|---|---|
| **CCS** | Carbon Capture and Storage |
| **$CO_2$** | Carbon Dioxide |
| **DFIs** | Development Finance Institutions |
| **FGN** | Federal Government of Nigeria |
| **FiT** | Feed-in-Tariff |
| **IAMs** | Integrated Assessment Models |
| **IEA** | International Energy Agency |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IPG** | International Partners Group |
| **IPPs** | Independent Power Producers |
| **IRENA** | International Renewable Energy Agency |
| **KWh** | Kilowatt-hour |
| **LCOE** | Levelized Cost of Electricity |
| **MDBs** | Multilateral Development Banks |
| **NAEC** | Nigeria Atomic Energy Commission |
| **NDCs** | Nationally Determined Contributions |
| **NERC** | Nigerian Electricity Regulatory Commission |
| **NESI** | Nigerian Electricity Supply Industry |
| **NIMBY** | Not In My Backyard |
| **NPP** | Nuclear Power Plant |
| **NREAP** | National Renewable Action Plans |
| **NREEEP** | National Renewable Energy and Energy Efficiency Policy |
| **NZE** | Net Zero Emissions |
| **OECD** | Organization for Economic Cooperation and Development |
| **PPA** | Power Purchase Agreement |
| **PPCA** | Powering Past Coal Alliance |
| **PPP** | Public Private Partnership |
| **PV** | Photovoltaic |
| **RE** | Renewable Energy |
| **SSA** | Sub-Saharan Africa |
| **TWh** | Terawatt-hour |
| **UK** | United Kingdom |
| **UNFCCC** | United Nations Framework Convention on Climate Change |
| **US** | United States |
| **USD** | United States Dollar |
| **VRE** | Variable Renewable Energy |
| **WACC** | Weighted Average Cost of Capital |

# 1 Introduction

## 1.1 Background and significance

Decarbonization of the global energy system is central to achieving global climate goals. The global energy system represents a principal emitting source, inducing climate change and its effects. Reducing emissions from this system to achieve the Paris targets and net zero emissions by 2050 requires a fundamental shift from fossil-based energy sources towards low-carbon or sustainable energy sources (IPCC 2022; Hirth and Steckel 2016). Towards actualizing a 1.5°C or 2.0°C pathway, there are growing commitments at both national and supranational levels in transitioning or diversifying energy sources through energy plans (e.g., US Inflation Reduction Act, EU 2030 Climate Target Plan) and Nationally Determined Contributions (NDCs). Some of these commitments are further evident in energy transition targets (e.g., national renewable energy targets).

Achieving such pledges also requires a shift in investments to low-carbon and renewable energy technologies to aid their deployment (Polzin et al. 2019; Steffen 2020; IPCC 2022; IRENA 2023a). Current investment flows between fossil-based and renewable energy sources are Paris-aligned but insufficient and unequally distributed. While there is a general decrease in fossil fuel investments and an associated increase in renewable energy investment, there remains a wide investment gap to meet the Paris targets (IRENA 2023b; Gielen et al. 2019; Steffen and Schmidt 2018). For instance, there is a deficit of approximately $6 trillion in global investments in energy transition technologies to ensure consistency with the 1.5°C pathway by 2030 (IRENA 2023a). Also, inequality persists in energy investments. Current financial flows are unevenly distributed, with higher flows to the Global North and disproportionately lower investments in the Global South, excluding emerging economies (Ameli et al. 2021; Isah et al. 2023). This dichotomy extends beyond the Global North and South divide to the Global South itself, as future investments are poised to be centred in Asian countries, leaving African nations' energy transition plans potentially underfunded (Afful-Dadzie et al. 2020; IPCC 2022; IRENA 2023a).

This financial condition in developing countries is exacerbated by financial constraints such as tight budgetary allocation, mounting national debt and inflation, yet sub-Saharan African (SSA) countries continue to adopt energy transition targets (Afful-Dadzie et al. 2020). Given the financial constraints in SSA countries and the unequal allocation of investments, the financial capacity of SSA countries to achieve these targets comes into question. For instance, Nigeria adopted a renewable action plan in 2015 but failed to meet its 2020 target due to political and financial constraints (NREAP 2016; Isah et al. 2023). Beyond renewables, Nigeria's energy interests extend to nuclear energy, signalling significant investment requirements for national energy transitions. Two factors are attributable to the nation's interest in renewables and nuclear energy. Firstly, the nation possesses favourable geophysical conditions for solar technology, given the high amount of annual solar irradiation it receives (NREEEP 2015). Secondly, the lack of sufficient and reliable baseload capacity and shortfalls in gas supplies[1], in the face of rising energy demands, has spurred interest in nuclear energy by the Federal Government of Nigeria (FGN) (Adeniyi 2019; Pavanelli et al. 2023; National Energy Mater Plan 2022; Salakhetdinov and Agyeno 2022).



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[1] Electricity from gas-powered plants represents the primary electricity source of Nigeria and accounts for 71% of electricity supply (Adeniyi 2019, 3).

The nation's interest in these technologies is further evident in its adopted 2030 targets through its Nationally Determined Contribution (NDC), National Renewable Action Plans (NREAP), and nuclear roadmap (NDC 2021; NREAP 2016; NAEC 2023). Given the nation's varied targets, different possibilities arise around which targets, or combination of targets, could be achieved. Nevertheless, each possibility requires financial commitments to be actualized. Therefore, this thesis takes a step towards assessing the financial requirements across these possibilities and how feasible these financial requirements are.

Assessing the feasibility of financing energy transition within Nigeria can provide essential insights into energy transitions in the context of sub-Saharan Africa (SSA): a region where huge proportions of future energy demand are to occur but receive the littlest of investments (Afful-Dadzie et al. 2020; IRENA 2023a). Although political support (e.g., Power Purchase Agreement (PPA) and Feed-in-Tariffs (FiT)) may exist for renewables or low-carbon technologies in Nigeria, the ability to deploy them is also contingent on sufficient funds. In a much broader frame, evaluating the financial pathways to nuclear and RE deployment is especially relevant, given their functionality as primary energy sources in most mitigation pathways consistent with global climate targets (Schmidt et al. 2019; IPCC 2018; IEA 2022b).



## 1.2 Problem definition

Overcoming challenges associated with rising energy demands, socioeconomic development, and reduced dependence on carbon-intensive energy sources represent factors driving Nigeria's energy transition (NREEEP 2015; National Energy Master Plan 2022). While the nation's motivations for energy transition are clear through adopted targets, the financial structure to achieve this transition remains unclear. The Federal Government of Nigeria (FGN) recognize that both public and private actors would be instrumental in enabling the nation's energy transition; however, the current financial structure shows an overwhelming dependence on public actors (NREEEP 2015; Isah et al. 2023).

Financial flows into Nigeria's RE sector are principally from development finance channelled by development-related agencies and Multilateral Development Banks (MDBs) (Isah et al. 2023). This current financial structure is inadequate to support the nation's energy transition plan due to its low amount. Investments from these sources are primarily used to undertake technical advisory training or capacity building within Nigeria. Secondly, although these funds are also utilized to deploy RE technologies, it is typically disaggregated and at small-scales (Schwerhoff and Sy 2017; Isah et al. 2023). These activities require lower capital than the deployment of large-scale RE technologies. This contrasts with the nation's energy transition plan, as targets entail on-grid RE deployment, demanding higher financial commitments. Therefore, the investment from the current financial structure is considerably lower than the required investments in Nigeria's energy transition plan.

On the other hand, nuclear technology has conventionally been financed with state funds (IAEA 2021; IAEA 2023). However, adopting this financial structure in Nigeria is challenging given the prioritization of sectors like health and education (Afful-Dadzie, Mallett, and Afful-Dadzie 2020; BudgiT 2023). Moreover, allocated capital expenditure to the Nigerian power sector is often used for bailouts rather than capacity expansion (Adeniyi 2019). While private actors have also been involved in financing nuclear technology, financial guarantees from the nation adopting nuclear energy are essential (IAEA 2023). Such guarantees would be challenging for Nigeria to offer, given its financial constraints around debt servicing and tight budgetary allocations.

Given these considerations, the question of whether the planned energy transition in Nigeria is financially feasible arises. This thesis aims to contribute to answering this question by first quantifying the financial investments required to achieve Nigeria's energy targets and then comparing this to financial flows from a variety of countries and situations that could serve as 'reference cases' (Jewell and Cherp 2023) and benchmarks for feasibility.

## 1.3 Aim and research questions

Given that Nigeria currently has different energy transition targets by 2030, different possibilities could occur where a combination of targets are met. This thesis explores these possibilities through scenarios to evaluate potential installed capacities in Nigeria by 2030 and further translates potential capacities across scenarios into fiscal values. By quantifying the investment requirement across scenarios characterized by different electric capacities, this thesis aims to assess the feasibility of these required investments. The feasibility assessment was conducted through an analytical framework that assesses the feasibility of an option given its relation to historical data (Jewell and Cherp 2023). The following research questions serve as guidelines for achieving this aim:

1. What are the electric capacities and required investments within each scenario by 2030?

2. What financial flows supporting energy transitions in other countries or directed to Nigeria can serve as prototypes (benchmarks or reference cases) for the required investments?
3. How do the required investments in each scenario compare with the identified reference cases?

## 1.4 Ethical considerations

This thesis adheres to the Central European University's ethical research guidelines on conducting quantitative research. Also, a checklist on ethical issues to ensure adherence to these guidelines was duly signed and submitted to the Department of Environmental Sciences and Policy, Central European University.

## 1.5 Thesis structure

Chapter 2 of this thesis reviews the literature on the role and challenges of renewables in achieving global climate targets and how low-carbon financing occurs within developing economies and Nigeria. It also introduces the concept of feasibility and how the feasibility of climate options is assessed. Following this, Chapter 3 describes the theoretical framework and methodology applied for estimating investments and assessing feasibility. The results of these studies are presented in Chapter 4, with Chapter 5 discussing these results. Chapter 6 concludes this study with recommendations for policy and future research.

# 2 Literature review

The literature reviewed for this thesis is classified into four sections. Section 2.1 reviews the literature on RE in developing economies, highlighting its role in delivering global climate targets and deployment challenges in developing countries. The subsequent section (section 2.2) outlines the sources and models for financing low-carbon technologies within developing countries. This section also reviews barriers to RE financing within Nigeria. Section 2.3 introduces the concept of feasibility and its metonyms while mapping out existing approaches to feasibility assessment. The final section (section 2.4) provides a summary of the chapter.

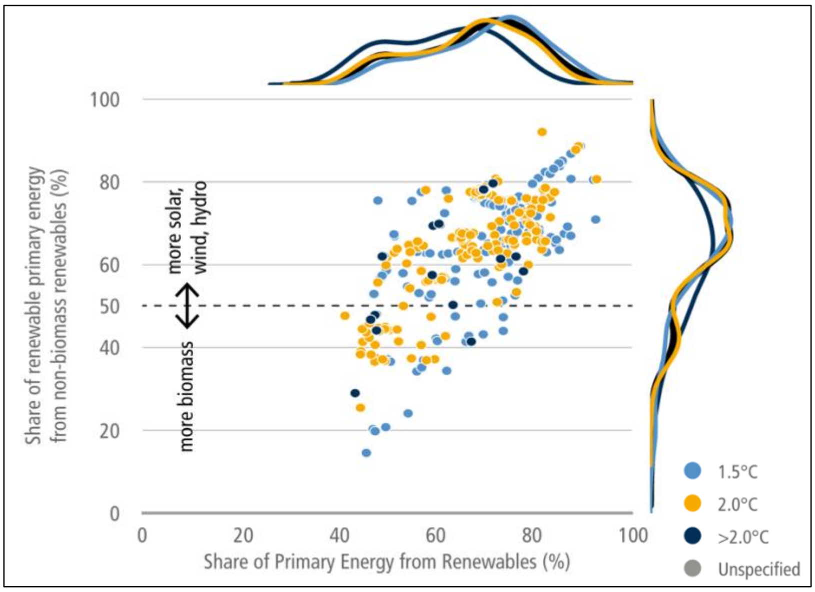
## 2.1 Renewable energy in developing countries

### 2.1.1 The role of renewable energy in achieving Net Zero emissions and climate targets

Preventing global average temperature increase above the 2.0°C or more ambitious 1.5°C Paris target requires $CO_2$ emission reductions in the energy sector to near or net zero by 2050 (IEA 2022b; IPCC 2022). Although different pathways to achieving the climate targets exist – given variations across scenarios about technological deployment and socioeconomic factors – a commonality across pathways is the essential role of renewable energy (IPCC 2022; Cherp et al. 2021; Steffen 2020; Wilson et al. 2013). Figure **2.1** illustrates the share and source of renewables under scenarios with global warming levels of 1.5°C (*light blue*), 2.0°C (*orange*), and >2.0°C (*dark blue*). In the Paris consistent scenarios in Figure **2.1**, medium to large proportions of primary energy are generated from renewables (solar, wind and hydro sources). These energy sources enable sectoral decarbonization within the global energy system, particularly in the power sector. Also, the declining cost of solar and wind power in many parts of the world will place them at the vanguard of renewables deployed in the power sector

(Schmidt et al. 2019; Gielen et al. 2019; Egli 2020; IPCC 2022). In the IEA's Net Zero Emission (NZE) scenario, for instance, solar and wind power account for about 70% of the ~90% of electricity generated from renewable sources in 2050 (IEA 2022a; IEA 2022b; Renné 2022).

Figure 2.1: Share of renewable energy resources across IPCC scenarios.




Source: IPCC (2022)

Across other sectors (i.e., transport, building, and industrial), the growth of direct and indirect uses of renewables contribute to realizing net zero emissions (Gielen et al. 2019; IEA 2022a). On the one hand, end-use electrification[2] enables the incorporation of variable renewable energy (VRE) sources[3], mitigating emissions from these sectors (IPCC 2022; IEA 2022b). For

[2] A process whereby the end-use or final use of energy is supplied from electricity. For instance, cooking with electric burners rather than fuel wood or gas.

[3] Variable renewable energy are energy sources that only function with the availability of certain natural resources e.g., sunlight or wind.

example, for road transportation[4], substituting internal combustion engines with electric vehicles under a decarbonized electricity sector (i.e., higher shares of VRE in electricity supply) indirectly reduces emissions (IEA 2022a). On the other hand, direct use of renewables e.g., bioenergy, solar thermal, and geothermal, is to serve residential (water and space heating/cooling), transportation (liquid biofuel), and industrial (heat) demands (IEA 2022a; Ahmed et al. 2022).

Nevertheless, the use of renewable energy sources is not without its challenges. The large share of VRE sources in the power sector in net zero or Paris-consistent pathways (Figure **2.1**) raises issues about the intermittency of electricity supply (Kroposki 2017). Offsetting shortfalls to ensure adequate electricity supply will require VRE sources to be complemented with dispatchable generation[5] (such as nuclear, fossil fuels with Carbon Capture and Storage (CCS), geothermal, and concentrated solar power); and energy storage (Davis et al. 2018; Kroposki 2017; IEA 2022a). However, capital costs for some of these dispatchable technologies (e.g., nuclear, CCS) and energy storage remain high, posing deployment challenges (Davis et al. 2018). Also, the use of direct renewables (biofuels) to mitigate emissions in hard-to-abate sectors (long-distance transportation, aviation, shipping) requires finite resources (arable land, water, nutrients). This induces land use competition, placing it at odds with food security and ecosystem services. Furthermore, the current lack of competitive prices of biofuels against fossil fuels impedes the renewable from being widely adopted (Davis et al. 2018).



[4] The defined scope of this statement is limited to short distance road transport as electrification for long distance transport remains a challenge (Davis et al. 2018; IPCC 2022).
[5] Dispatchable generation refers to electricity sources that can be provided on demand.

### 2.1.2 The challenges of renewable energy systems in developing countries

The developing world has an essential role in delivering global climate targets but faces challenges in achieving this role. The region must meet rising energy demands without following the carbon-intensive pathways of the developed world to mitigate climate change (Fankhauser and Jotzo 2018; Garlet et al. 2019). Renewable energy technologies are often promoted to address both challenges, as it is a clean energy source with high potential in developing countries (Gujba et al. 2012; Schwerhoff and Sy 2017; Mungai, Ndiritu, and Da Silva 2022). Nevertheless, the overwhelming share of RE adoption has occurred in developed and emerging economies (Cherp et al. 2021; Afful-Dadzie, Mallett, and Afful-Dadzie 2020). The pace of adoption and diffusion of these technologies to developing countries, however, is slow and inadequate to meet climate or development priorities, despite the high potential (Cherp et al. 2021; Bishoge, Kombe, and Mvile 2020; Vanegas Cantarero 2020). This dissonance between high potential and low adoption indicates the presence of barriers impeding renewable uptake in developing countries. In the context of the developing world, studies often emphasize economic (financial) challenges as an essential barrier to RE adoption (Ramalope et al. 2022; Ohunakin et al. 2014; Mungai, Ndiritu, and Da Silva 2022; Mahama, Derkyi, and Nwabue 2021; Shahsavari and Akbari 2018).



Utility scale RE technologies are capital-intensive technologies due to the infrastructure size and long lifespan of these technologies (Hirth and Steckel 2016; Sweerts, Longa, and Van Der Zwaan 2019; Polzin et al. 2019). Deploying RE thus requires high initial investment costs (Egli, Steffen, and Schmidt 2018; Schwerhoff and Sy 2017). These investment costs tend to be significantly higher in developing countries because of higher risk perceptions from investors (Ohunakin et al. 2014; Steffen and Schmidt 2018; Ameli et al. 2021). Some scholars also suggest that the lack of financial instruments (e.g., FiTs, tax relief subsidized loans, guarantees etc) keeps costs high (Asante et al. 2022; Mahama, Derkyi, and Nwabue 2021). Other scholars, however, claim that the absence of financial instruments has little effect on RE adoption (Barnea, Hagemann, and Wurster 2022). The high investment cost for RE is also reflected in electricity prices, with higher prices for renewables than fossil fuels (Egli, Steffen, and Schmidt 2018; Steffen 2020). Sweerts, Longa, and Van Der Zwaan (2019) assessed the Levelized Cost of Electricity (LCOE) for renewable and fossil fuel technologies in 46 African countries. The authors found that the median LCOE for renewables[6] ranged from 0.1 – 0.35 USD/kWh and 0.05 – 0.25 USD/kWh for fossil fuels[7] (Sweerts, Longa, and Van Der Zwaan 2019). The relatively lower LCOE for fossil fuels has led to its preference for energy production within developing countries (Schwerhoff and Sy 2017; Afful-Dadzie, Mallett, and Afful-Dadzie 2020).

Technology diffusion theories can also help to explain the challenges of RE development in developing economies. Technological development has primarily occurred in developed economies or core markets before diffusing to developing economies or periphery markets (Cherp et al. 2021; Wilson et al. 2013). The growth of these technologies in core markets is often slow, given the volatilities associated with initial high costs, uncertainties, learning and experimentation (Cherp et al. 2021). In periphery markets, however, growth tends to be faster due to the benefits of technological learning (Cherp et al. 2021; Wilson et al. 2013; Grubler, Wilson, and Nemet 2016). Despite this rapid growth, saturation levels are often lower than core



[6] The RE technologies considered were geothermal, hydro, solar PV, onshore wind, and concentrated solar power (CSP).
[7] The fossil fuels considered included coal, natural gas, and diesel.

regions due to the inadequate political and technical systems within peripheries (Cherp et al. 2021; Wilson et al. 2013).

In terms of political barriers, Bishoge, Kombe, and Mvile (2020) argue that insufficient political will to promote RE policies or incentives impedes the adoption of RE. Barnea, Hagemann, and Wurster (2022) support this, revealing that both will and skill (a state's capacity) have "significant positive correlations […] to the expansion of renewable energy" (8). Other studies attribute impediments to bureaucratic procedures and the absence of enabling policies or regulatory frameworks in developing countries (Ouedraogo 2019; Asante et al. 2022; Schwerhoff and Sy 2017). Although RE policies exist in some countries, scholars have found that their design limits effectiveness (Bishoge, Kombe, and Mvile 2020). The inadequacy of skilled professionals, physical infrastructures, and research and development activities are often cited as the technical barriers to RE adoption (Shahsavari and Akbari 2018; Seetharaman et al. 2019; Bishoge, Kombe, and Mvile 2020; Cherp et al. 2021; Asante et al. 2022). These technical challenges also induce economic or financial barriers (Seetharaman et al. 2019; Ibrahim and Ayomoh 2022), resulting in what Sweerts, Longa, and Van Der Zwaan (2019) term "technology premium" (78). For example, a lack of grid integration can deter investors from investing in a RE project (Ouedraogo 2019; Hafner, Tagliapietra, and De Strasser 2018; Cherp et al. 2021).

## 2.2 Financing low-carbon energy in Nigeria

### 2.2.1 Sources and flows of renewable energy finance in developing countries

Mobilizing finance for renewable energy deployment occurs through public or private sources. Private sources account for the highest shares of RE investments within emerging and developing economies (EMDEs) (IEA 2021). Across EMDEs, however, the bulk of private sector investments flows to three countries: Brazil, Chile, and India (IRENA 2023b). These countries receive the most private capital because they possess less risk than other EMDEs. The associated risk and expected return of RE projects represent criteria that determine private sector investments (Donovan 2015; Polzin et al. 2019; Schmidt 2014). Private investors often have high-risk perceptions of RE projects within developing countries (Schmidt 2014; Ameli et al. 2021). These high-risk perceptions create high premiums, influencing RE investment costs (*see section 2.1.2*). However, what influences such high-risk perceptions? Scholars posit that local conditions, such as political stability, business environment and macroeconomic conditions, strongly influence risk perceptions (Ameli et al. 2021; Ragosa and Warren 2019). The less enabling local situations are, the higher the risk perception of private creditors. These risk perceptions are numerically expressed through the Weighted Average Cost of Capital (WACC)[8] (Ameli et al. 2021; Sweerts, Longa, and Van Der Zwaan 2019). A higher WACC value translates into higher perceived investment risk.



[8] WACC is defined as "the expected rate of return that market participants require in order to attract funds to a particular investment expressed as percentage value" (Steffen 2020).

Ameli et al. (2021) assessed disparities in regional WACC values, revealing that developing economies had higher values (6.8% to 12%) than developed economies (2.4% to 5.8%). Their results within the developing world were also insightful, as Africa's WACC (12%) was almost double that of Asia's[9] (6.8%). This variance in WACC between regions can explain why future investments are poised to flow towards Asian and OECD countries (Ameli et al. 2021; IPCC 2022). In other words, private investors perceive lower investment risks in Asia than in Africa. Other studies (Steffen 2020; Sweerts, Longa, and Van Der Zwaan 2019) have estimated WACC values at national levels, similarly concluding higher rates in developing economies than in developed ones. Given the importance of risk (WACC value) in determining private investments, reducing risk (de-risking) is essential to attract private capital to developing countries (Schmidt 2014). Studies find that policy tools like FiTs, subsidies, tax breaks and long-term targets de-risk investment (Polzin et al. 2019; Sweerts, Longa, and Van Der Zwaan 2019; Isah et al. 2023; Brimmo et al. 2017). However, other scholars have revealed that despite implementing such policies, investments in the global South remain low (Afful-Dadzie, Mallett, and Afful-Dadzie 2020). For example, despite Nigeria adopting solar FiTs (0.177 USD/KWh) and long-term RE targets in 2015 and 2016, respectively, investments remain unforthcoming (Adeniyi 2019; NREAP 2016). This reinforces the need to assess the financial feasibility of Nigeria's adopted energy transition targets, as accessing private finance to deliver adopted targets would be challenging due to high-risk perceptions.



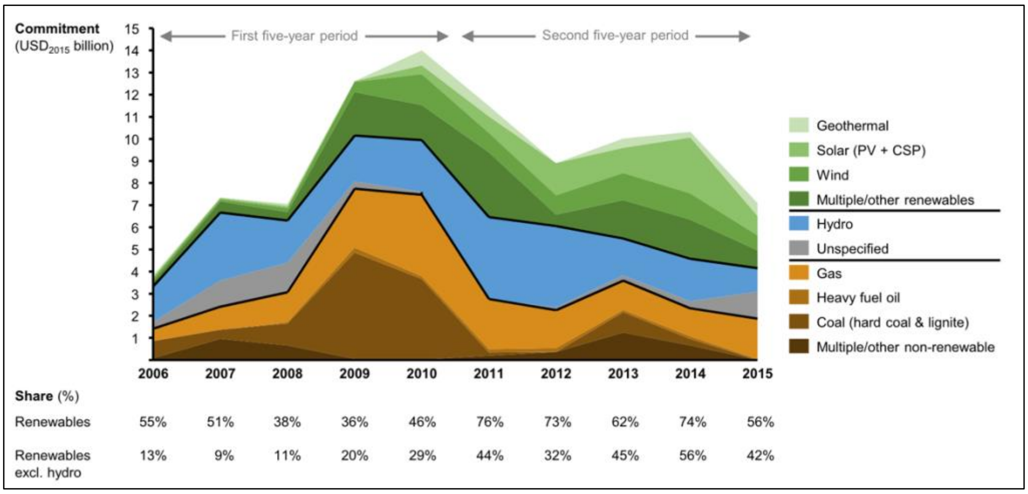
[9] Developing countries within Asia, excluding emerging economies like India and China.

Given the high investor risks as well as budgetary constraints within developing regions[10], particularly SSA, public finance, through Development Finance Institutions (DFIs), has been essential in deploying RE technologies (Afful-Dadzie, Mallett, and Afful-Dadzie 2020; Gurara, Presbitero, and Sarmiento 2020; Steffen and Schmidt 2018). Within DFIs, Multilateral Development Banks (MDBs) account for most financial flows into RE development within the developing world (Steffen and Schmidt 2018; Isah et al. 2023). Although MDBs finance other power generation technologies (i.e., fossil-based energy sources), their investment portfolio has evolved to largely comprise RE technologies (Steffen and Schmidt 2018). Figure **2.2** illustrates that between 2006 and 2010, finance from MDBs was mainly channelled to high-carbon technologies, peaking at ~$7 billion in 2009. From 2011 onwards, however, financial commitments were diverted towards renewables, with as high as ~$9 billion in 2011. Increments in non-hydro renewable shares of the total renewable share are also evident, rising from a low of 9% to > 50% over time (Figure **2.2**).



[10] The use of developing regions or countries in this paragraph excludes emerging economies like Brazil, India, and China.

Figure 2.2: Annual financial commitments to power-generation technologies by 10 MDBs[11] between 2006 – 2015




Source: Steffen and Schmidt (2018).

However, the role of MDBs in RE deployment in developing countries extends beyond financial assistance. These banks serve as catalysts in mobilizing private capital as MDBs stimulate factors attractive to private investors: credibility, macroeconomic stability and growth (Steffen and Schmidt 2018; Broccolini et al. 2021; Ragosa and Warren 2019). These factors help to de-risk private investments within developing countries. Nevertheless, if renewable energy technologies are to deliver development and climate priorities in developing economies, both sources of finance, particularly private finance, must be scaled up (IEA 2021; IEA 2022a).



[11] The 10 MDBs: the World Bank (International Bank for Reconstruction and Development (IBRD), the International Development Association (IDA), the International Finance Corporation (IFC), the Multilateral Investment Guarantee Agency (MIGA)); African Development Bank (AfDB); the Asian Development Bank (AsDB), the European Bank for Reconstruction and Development (EBRD); the European Investment Bank (EIB); the Inter-American Development Bank (IADB); the Development Bank of Latin America (CAF); and the Islamic Development Bank (IsDB).

### 2.2.2 Barriers to financing renewable energy in Nigeria

Nigeria possesses sufficient potential for RE deployment at a utility-scale, particularly for solar PV. Yet, a low-carbon energy transition remains challenging. As highlighted in *section 2.1.2*, financial barriers represent a core challenge to RE adoption in developing countries. However, what are the peculiar barriers impeding RE investment in the Nigerian context? Across the literature, this study identified three distinct factors hindering RE investments in Nigeria: resistive regimes, market performance, and financial development (Osunmuyiwa, Biermann, and Kalfagianni 2018; Adeniyi 2019; Isah et al. 2023; Daggash and Mac Dowell 2021).

Rentier states[12] are often considered to have lower rates of RE adoption due to their dependence on domestic fossil resources (Barnea, Hagemann, and Wurster 2022). Drawing from this, Osunmuyiwa, Biermann, and Kalfagianni (2018) employ an integrated framework composed of the rentier and multi-level perspective (MLP) theories[13] to show how politico-economic[14] and socio-technical[15] regimes interact to impede RE investments in Nigeria. According to the authors, interactions between these regimes "create a recursive path that allows politico-economic actors to divert material and financial resources of the state using socio-technical actors" (Osunmuyiwa, Biermann, and Kalfagianni 2018, 146). These financial resources – which could be invested in renewables – represent subsidies petroleum resources receive due



[12] Rentier states represent states that derive majority of their national income through the renting of resources (particularly oil) to foreign entities.
[13] MLP theory explains energy transitions through technological innovation and user practices, while assessing the social factors present in transition pathways (Osunmuyiwa, Biermann, and Kalfagianni 2018).
[14] Actors within this regime: federal, state, and local governments, petroleum producers and importers, civil society coalitions.
[15] Actors within this regime: Nigerian power sector (e.g., electricity distribution companies), oil and gas ministry, science, and technology institutes.

to lobbying and vested interests of politico-economic actors (Osunmuyiwa, Biermann, and Kalfagianni 2018). However, the authors fail to recognize that certain actors within Nigeria's politico-economic regime, such as gas companies, possess little imperative to impede RE investments. Gas companies[16] in Nigeria's electricity sector have mandatory gas supply quotas to Nigerian GenCos[17] at fixed prices lower than export market prices (Adeniyi 2019). Going by market rationality and the core imperative of private organizations, these gas companies would prefer to export the gas they produce to maximize profits. Hence, politico-economic actors like gas companies may not necessarily oppose RE investments as more electricity generated would reduce mandatory quotas placed on them.

In an opposing view, Adeniyi (2019) argues that a multi-level perspective theory falls short in explaining the constraints of RE investment in Nigeria. The author attributes RE investment barriers to the conduct of actors[18] within the Nigerian Electricity Supply Industry (NESI) (Adeniyi 2019). These actors interact in a manner that leads to an underperformance of the NESI, impeding revenue generation. For instance, to maintain public support, the Nigerian government favour consumers through protectionist actions that prevent the Nigerian Electricity Regulatory Commission (NERC)[19] from setting cost-reflective tariffs (Daggash and Mac Dowell 2021; Adeniyi 2019). Furthermore, there is a distrust[20] between consumers and



[16] Gas companies supply natural gas to gas-fired power stations through generation companies (GenCos). These companies comprise both public and private organizations, but the scope of this statement is limited to the latter (Adeniyi 2019).
[17] GenCos: Generation Companies responsible for producing electricity through natural gas.
[18] These actors include the Federal Government of Nigeria (FGN), electricity distribution companies, and electricity consumers.
[19] The NERC is Nigeria's power sector regulator responsible for setting electricity tariffs (Daggash and Mac Dowell 2021).
[20] This distrust is driven by the estimated billing process distribution companies employ, making consumers believe they are overcharged.

electricity distribution companies, which triggers energy theft and results in commercial losses (Adeniyi 2019). These unfavourable interactions between actors reduce revenues from the NESI that could be reinvested to improve infrastructure and performance. It also reflects an unattractive business environment, leading to high-risk perceptions from private investors (*see section 2.2.1*).

Scholars have found that financial development within a nation aids the deployment of RE technologies (Egli, Steffen, and Schmidt 2018; Dimnwobi et al. 2022; Ameli et al. 2021; Iyabo 2021). Robust financial systems provide access to low-cost finance, reducing the cost of capital for capital-intensive technologies like renewables (*see section 2.1.2*) (Ameli et al. 2021). However, Nigeria's level of financial development is low, limiting access to low-cost capital. Isah et al. (2023) conducted a comparative assessment of the RE financing landscape between Nigeria and Brazil, revealing adequate financing conditions within Brazil, contrary to Nigeria. According to the authors, the diversification of financial instruments has contributed to improving Brazil's RE financing landscape (Isah et al. 2023). However, such diversification remains a challenge in Nigeria. As Adeniyi (2019) illustrates, despite 14 solar Independent Power Producers (IPPs) receiving competitive FiT of 0.115 USD/KWh, the lack of guarantees for the solar IPPs has prevented financial close. Isah et al. (2023) also recognized that the implementation of RE policies in Brazil signalled the government's commitment to RE deployment. This aided the development of Public Private Partnerships (PPP) that improved Brazil's RE financing landscape through access to private capital. Despite Nigeria's adoption of a national renewable policy (NREEEP 2015) for nearly a decade, the nation has failed to implement the policy, virtually missing all stated targets (Pavanelli et al. 2023; NREAP 2015).

The previous sections have highlighted the essential role of finance in enabling sustainable energy transitions due to the capital intensity of RE technologies. Given these considerations, studies have assessed the financial challenges of RE deployment by identifying barriers to capital access or factors influencing high investment costs. Nevertheless, assessing the financial challenges of energy transitions from a feasibility lens, contrary to identifying barriers, is missing from the energy transition literature in Nigeria. Specifically, quantifying the financial requirements for energy transitions within Nigeria and evaluating the feasibility of these financial values remains a gap in the literature. Considering this knowledge gap, this thesis aims to bridge it by conducting a quantitative study that assesses the feasibility of required investments for energy transitions in Nigeria.

### 2.2.3 Prospects and financial pathways of nuclear power in Nigeria

Sufficient and stable electricity production and supply remain a challenge in Nigeria. Electricity demand and production have grown disproportionately, with rapidly increasing demand and stagnant growth in production. Rising population and economic growth drive the surge in demand, which remains unmet due to insufficient capacity in the power sector (Adeniyi 2019). In over a decade, Nigeria has installed only 6 GW of electric capacity from predominantly natural gas (Pavanelli et al. 2023). Furthermore, being the rentier state it is, over 70% of electricity production comes from fossil sources, illustrating a lack of diversity and high dependence on fossil fuels (Osunmuyiwa, Biermann, and Kalfagianni 2018; Adeniyi 2019). In view of needed energy diversification and independence, the FGN through the National Energy Masterplan (2022) recognizes nuclear energy as a potential energy source that can facilitate the nation's climate and development priorities.

Nuclear energy interests in Nigeria date back to 1976 when the Federal Government of Nigeria (FGN) established the Nigeria Atomic Energy Commission (NAEC) (National Energy Masterplan 2022). The commission was to serve as the national agency mandated with developing the framework and pathway for a nuclear energy program that enabled socioeconomic development (Salakhetdinov and Agyeno 2022; Kessides 2014; Ejiogu 2013). However, the successive years following the development of NAEC were characterized by political instability, hindering the advancement of a nuclear energy program (Salakhetdinov and Agyeno 2022). Consequently, NAEC failed to be inaugurated and activated until 2006 (National Energy Masterplan 2022; Lowbeer-Lewis 2010). The inauguration of NAEC in 2006 rekindled the nation's interest in nuclear energy, marked by the commission's release of a nuclear roadmap in the following year (Ishola et al. 2019; Lowbeer-Lewis 2010; NAEC 2023). The nuclear roadmap represented a three-phase technical framework to develop Nigeria's nuclear energy program (NAEC 2023). These phases included human capital development; site selection, design certification and regulatory approval; and construction (Ejiogu 2013; Lowbeer-Lewis 2010). The roadmap also set nuclear capacity targets of 1,000 MWe and 4,000 MWe by 2017 and 2027, respectively (Brimmo et al. 2017; NAEC 2023; Kessides 2014). However, the 2017 target failed to be met, with the 2027 target similarly unlikely given the timeframe, technical and financial constraints as well as the political insurgency in Nigeria (Salakhetdinov and Agyeno 2022; Kessides 2014; Lowbeer-Lewis 2010).



Despite the challenges facing nuclear power deployment, Nigeria has maintained its interest in nuclear energy, taking steps to advance this interest (Sah et al. 2018; World Nuclear Association 2023a). In 2015, the nation reached phase 2 of the three required phases for developing the infrastructure necessary to support a nuclear power programme (IAEA 2022;

IAEA 2015). Table **2.1** illustrates the phases of nuclear power infrastructure development with the corresponding milestones. These milestones mark the completion of activities within a particular phase towards advancing to the next phase (IAEA 2015). Nigeria being in phase 2 means it is undertaking preparatory requirements for contracting and constructing a Nuclear Power Plant (NPP). Such preparations are evident through interactions with Russia's state-owned nuclear energy program, Rosatom (Szulecki and Overland 2023). For example, in July 2011, the Nigeria Atomic Energy Commission (NAEC) and Rosatom completed a draft agreement to collaborate on the design, development, operation, and retirement of an NPP (World Nuclear Association 2023a). In the subsequent year, a memorandum of understanding was signed between both parties to establish a comprehensive plan for NPP construction in Nigeria (World Nuclear Association 2023a). These interactions signal steps towards the second milestone to progress into the third phase. However, can Nigeria advance to the third phase towards commissioning its first nuclear power plant (NPP)?

Table 2.1: Phases and milestones for nuclear power infrastructure development.

| ***Phase 1*** | ***Phase 2*** | ***Phase 3*** |
|---|---|---|
| Considerations before a decision to launch a nuclear power programme is taken | Preparatory work for the contracting and construction of a nuclear power plant after a policy decision has been taken | Activities to implement the first nuclear power plant |
| ***Milestone 1*** | ***Milestone 2*** | ***Milestone 3*** |
| Ready to make a knowledgeable commitment to a nuclear power program | Ready to invite bids/negotiate a contract for the first nuclear power plant | Ready to commission and operate the first nuclear power plant |

Source: IAEA (2015).

Studies have assessed the feasibility of nuclear energy in so-called “newcomer countries”. These newcomer countries represent countries interested in initiating or developing their first nuclear power program (Jewell 2011). Jewell (2011) evaluated the feasibility of nuclear power development in 50 newcomer countries by benchmarking the capacities[21] and motivations[22] of these newcomers against countries with existing nuclear energy programs. Based on the new entrants’ capacities and motivations, Jewell (2011) classified each newcomer into one of four taxonomies:

I. *Nuclear power development unlikely*
II. *Nuclear power development possible through international cooperation*
III. *Nuclear power development uncertain*
IV. *Nuclear power development most likely*

Nuclear power development in Nigeria was categorized as uncertain as although the nation possessed strong motivation, its capacities (technical, institutional, and financial) were low (Jewell 2011). In other words, the feasibility of attaining the third milestone in Nigeria was unknown (Table **2.1**). Interestingly, Bangladesh, which had similar characteristics to Nigeria, has been able to deploy a nuclear power plant with support from the Russian government (Szulecki and Overland 2023; World Nuclear Association 2023b). Building upon Jewell (2011), Sah et al. (2018) concluded that the adoption of smaller and more advanced nuclear technologies (i.e., small modular reactors) could make nuclear development achievable in



[21] The study evaluated capacity across four dimensions: technical, political, institutional, and financial.
[22] Motivations were assessed based on energy demand and energy security. Newcomer countries with an imperative to meet energy demand or achieve energy security were deemed more motivated than other new entrants with low demand or energy dependency.

Nigeria. These smaller nuclear technologies reduce technical and institutional constraints[23] that contributed to the uncertain outcome of Nigeria's nuclear development in Jewell's study (Jewell 2011; Sah et al. 2018).

Along a similar stream of literature, Brutschin, Cherp, and Jewell (2021) sought to identify factors that influenced the adoption of the first sizable[24] nuclear power plant in 79 countries. The authors revealed that contextual (i.e., proximity to core nuclear vendors, electricity demand growth and insecurity) rather than technology characteristics (i.e., competition from alternate energy sources, nuclear accidents, and proliferation) were more influential in determining nuclear uptake. Certain contextual variables identified reflect Nigeria's current condition. Rapid population and economic growth have increased electricity demand, with the country seeking to diversify its electricity sources beyond natural gas and hydro (National Energy Masterplan 2022; Owebor et al. 2021; Pavanelli et al. 2023). This should suggest suitable conditions for nuclear energy adoption in Nigeria. Yet, Brutschin, Cherp, and Jewell (2021) also uncovered that major fossil fuel exporters rarely deploy nuclear technology[25]. The causality of this situation is often attributed to the rentier characteristics of such nations. These nations provide subsidies for fossil fuels making electricity prices from fossil-based energy sources cheaper, inhibiting competition from alternate energy sources like nuclear (Barnea, Hagemann, and Wurster 2022; Osunmuyiwa, Biermann, and Kalfagianni 2018). However,



[23] The technical constraints are associated with the grid capacity of Nigeria. Nuclear technology must account for less than 10% of the total capacity in a nation to sufficiently control the electricity system's frequency (IAEA 2015). Jewell (2011) considered the deployment of large-scale nuclear technology (1GW), which accounted for over 10% of Nigeria's 2011 electricity capacity of 6GW (Pavanelli et al. 2023). Institutional constraints, on the other hand, refer to stable and reliable regulatory procedures (Jewell 2011).
[24] Nuclear power plants with high capacities and deployed for commercial rather than experimental use.
[25] This situation can also be applied to Nigeria with the country being a major fossil fuel exporter.

while rentier states have conventionally failed to adopt nuclear technology, the landscape seems to be shifting, with prominent fossil exporters like the United Arab Emirates (UAE) commissioning a nuclear power plant in 2021 (IAEA 2022).

Nuclear Power Plants (NPPs), like renewable energy technologies, are capital-intensive infrastructures (IAEA 2023; IAEA 2021). The high upfront investment required for NPPs is attributable to the technical and managerial complexities that NPPs demand (IAEA 2021). Besides these complexities, NPPs are subject to certain risks that drive up the investment cost (Terlikowski et al. 2019). These risks include ambiguities about construction expenses or delays, and market[26], political and regulatory risks (Terlikowski et al. 2019; IAEA 2021). Conventionally, these risks were borne by customers as NPPs were primarily financed by governments under regulated utility markets[27] (Brutschin, Cherp, and Jewell 2021; IAEA 2008; IAEA 2021). In essence, the state or state-owned utilities provided funds for building NPPs, where the impact of these risks (if manifested) increased electricity prices for customers (Terlikowski et al. 2019; IAEA 2008; IAEA 2021). However, following the liberalization of electricity markets and the evolution of financial markets, new financial models beyond the traditional paradigm emerged, shifting risk from consumers to electricity generation companies and investors (Brutschin, Cherp, and Jewell 2021; Terlikowski et al. 2019; IAEA 2021).



[26] Market risk refer to future revenue risk. Often the deployment of NPPs are structured in ways that consumers pay for the NPP project by purchasing the electricity generated from the NPP. However, electricity prices might fall considerably, lowering the revenues expected from customers (IAEA 2021).

[27] This meant that the state or rather state-owned utilities had monopoly over electricity generation and distribution and as such, were responsible for setting electricity prices.

These new financial models include government-to-government, corporate, and vendor financing[28] (Terlikowski et al. 2019; IAEA 2021). The government-to-government model represents an approach where governments with established nuclear experience finance the construction of NPP in countries with limited financial resources (Terlikowski et al. 2019; IAEA 2021). This financial aid mostly takes the shape of intergovernmental loans (IAEA 2021). In this approach, mutual benefits are realized between the host and exporting nation. The former accesses financial resources and technical know-how for nuclear energy, while the latter enters a new market. Countries like Russia and Bangladesh adopted this model to develop the Rooppur 1 and 2 NPPs (IAEA 2021; World Nuclear Association 2023b). In the corporate model, public or private organizations finance the construction of NPPs through equity or debt or a combination of both funds (IAEA 2021). Mainly organizations with robust balance sheets[29] adopt this model, given their capacity to take on the risks and high investment costs associated with NPPs (IAEA 2021). Within this model, organizations could also partner to share the risk and generate sufficient capital for nuclear energy deployment. For instance, several large industrial electricity consumers partnered up and invested in the Olkiluoto-3 NPP in Finland (IAEA 2008). The vendor paradigm takes after its name i.e., the nuclear vendor is involved with financing the NPP through equity or short-term loans (Terlikowski et al. 2019; IAEA 2021). The Barakah NPP in the United Arab Emirates is modelled after vendor financing, as it raised capital through equity financing with the Korean Energy Corporation (KEPCO) (IAEA 2021).



[28] It should be noted that this study does not provide an exhaustive list of all financial models but rather highlights common models.
[29] Financial statement that identifies an organization's assets, liabilities, and capital at a given period.

Among these financial models, the Federal Government of Nigeria's (FGN) preference leans towards the government-to-government model due to the nation's fiscal and technical limitations (Salakhetdinov and Agyeno 2022; Kessides 2014; World Nuclear Association 2023a). As highlighted above, Russia and Nigeria have established bilateral relationships through Rosatom and the Nigeria Atomic Energy Commission (NAEC). Consequently, Russia could serve as the exporting nation within the government-to-government model, given its established nuclear experience (Salakhetdinov and Agyeno 2022). Rosatom's confirmation that Russian financing options would be accessible to Nigeria reinforces the possibility of adopting the government-to-government model (World Nuclear Association 2023a). Therefore, Nigeria's nuclear development pathway could trail that of Bangladesh but with a different ownership structure. While the Rooppur 1 and 2 NPPs in Bangladesh will operate under a Build-Operate-Transfer (BOT) structure, the FGN prefer the Build-Own-Operate (BOO) structure[30], initially introduced in Turkey by Rosatom (World Nuclear Association 2023a; World Nuclear Association 2023b; Szulecki and Overland 2023).

The literature shows that the feasibility of nuclear energy development has been assessed from a financial dimension, unlike renewable energy in Nigeria. Nevertheless, this financial dimension has been based on the financial capacity of a state (i.e., Jewell (2011) employed GDP and GDP per capita of Nigeria) as opposed to the financial cost of deploying nuclear energy. The current literature falls short in evaluating feasibility based on the required cost for



[30] In the build-own-transfer (BOT) structure a private or non-private organization is authorized by the public sector to finance, **build**, **own**, operate, and maintain the NPP over a defined period. Over this period the authorized organization **owns** the NPP, retaining both the risks and income generated from the NPP. After the defined period, NPP ownership is **transferred** to the public sector. Build-own-operate (BOO) functions similarly to BOT, however, the authorized organization owns the NPP and retains the risk and revenue forever (IAEA 2008).

nuclear energy development in Nigeria. Specifically, studies that quantify the cost of nuclear energy development in Nigeria and assess the feasibility of this cost are scant in the literature. Therefore, this study offers another dimension of financial feasibility by evaluating the feasibility based on the financial cost of nuclear energy development rather than a state's financial capacity.

## 2.3 Feasibility of climate action

### 2.3.1 What is feasibility?

Different climate actions have been proposed to deliver global climate targets. These often span technological (rapid deployment of renewables, negative emission technologies), socioeconomic (low-energy demand) and geophysical (land-based climate mitigation or adaptation) solutions (IPCC 2022; Cherp et al. 2021; Jewell and Cherp 2023; Semieniuk et al. 2021). However, these solutions have respective challenges, which may hinder their use in mitigating or adapting to climate change. As highlighted in section 2.1.1, the intermittency of renewables requires these technologies to be complemented with other often costly energy sources. Assumptions about high energy efficiency levels often underpin low-energy demand solutions, potentially triggering a rebound effect (Van Benthem 2015; Semieniuk et al. 2021; Jewell and Cherp 2023). Likewise, land-based climate mitigation measures are scrutinized for their impacts on food security (Fujimori et al. 2022). These challenges raise questions about the feasibility of climate actions in delivering global climate targets. Therefore, assessing the feasibility of climate actions is vital for understanding which solutions can be prioritized to achieve global climate targets. Nevertheless, how can studies evaluate the feasibility of a climate action to deem it feasible or infeasible? Moreover, before assessing the feasibility of a solution, what does "feasibility" itself mean?

Across the literature, there fails to be a common approach in defining or evaluating the feasibility of climate actions (Jewell and Cherp 2023). Studies interchangeably use the "feasibility" terminology with synonyms, making it difficult to identify an accepted definition of feasibility (Jewell and Cherp 2023). For example, scholars have used ***plausibility*** (Napp et al. 2017; Pielke Jr, Burgess, and Ritchie 2022) and ***probability*** (Engels and Marotzke 2023) in place of ***feasibility***. However, while these terminologies are characteristics of an unknown future and are interrelated, they are not similar. ***Plausibility*** is considered the occurrence of a situation under internally consistent assumptions; ***Probability*** entails the "likelihood of a future outcome which factors in likely choices of relevant agents" (Jewell and Cherp 2023, 2). Drawing from the IPCC definition of feasibility[31], Jewell and Cherp (2023) describe ***feasibility*** as an action that is "do-able under realistic assumptions" (Jewell and Cherp 2023, 2). Defining these terms enables a better understanding of how the feasibility of a climate action is assessed.

### 2.3.2 Feasibility assessments approaches (solution space, thresholding, forecasts)

Global scenarios help to illustrate how the feasibility of climate actions is assessed as these scenarios comprise climate actions. Scenarios represent "plausible descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about key



[31] The IPCC defines feasibility as "the potential for a mitigation or adaptation option to be implemented". (IPCC 2022, 1802)

driving forces […] and relationships" (IPCC 2022, 1812). Scenarios are constructed with Integrated Assessment Models (IAMs), which are mathematical representations of complex interactions and feedback between the earth's natural system and the socioeconomic system (Jewell and Cherp 2023; Van Beek et al. 2020). Within scenarios, ***solution space, thresholding*** and ***forecasts*** are often used to conduct feasibility assessments. However, how robust are these methods in assessing feasibility? According to Jewell and Cherp (2023), three core principles must be evident for a robust feasibility assessment:

*I.* ***Causal reasoning:*** *Feasibility assessments must be guided by causal evidence i.e., an action that can impede or enable a climate action from being feasible or infeasible.*

*II.* ***Comparability:*** *Feasibility assessments should comprise comparisons between proposed climate actions or a particular action in a different context or at an implementation level.*

*III.* ***Reflexive consideration of agency:*** *Feasibility assessments should consider the level of influence their audience*[32] *have to prevent the overestimation or underestimation of this influence in implementing any climate action.*

IAMs typically combine various assumptions to develop plausible scenarios (comprised of different climate actions) and assess their relationship with the solution space[33] (Jewell and Cherp 2023). The solution space is dynamic, given the influence of political (audience) and



[32] Audience represents individuals that can influence the implementation of a particular climate action, who are often policymakers.
[33] The solution space represents a multidimensional space which hosts climate scenarios that have been explored or unexplored and considered plausible to deliver a climate target (Jewell and Cherp 2023; Du et al. 2022).

biophysical factors that constantly change (Haasnoot et al. 2020; Jewell and Cherp 2023). Climate actions outside the boundary of the solution space are judged infeasible because no causal path enabling its realization exists. Yet not all climate actions within the solution space are ***feasible*** but may be considered ***plausible*** (Jewell and Cherp 2023). This suggests that climate actions within the solutions space have internally consistent assumptions but fail to account for all realistic assumptions. These realistic assumptions embody causalities that can impede climate actions. Failure to identify all relevant causalities limits the constraints on the solution space, preventing the elimination of infeasible climate actions. For instance, IAMs often consider technical and economic constraints but fail to account for political and social constraints, which also influence the feasibility of climate actions (Sweerts, Longa, and Van Der Zwaan 2019; Jewell and Cherp 2023; Stoddard et al. 2021).

A robust feasibility assessment should demonstrate comparability. While comparability occurs during the development of the solution space[34], how can this be extended to climate options after developing the solution space? Thresholding enables this comparison, where implementation levels or contexts of climate actions can be compared (Jewell and Cherp 2023). Model parameters in IAMs define these thresholds to limit the solution space (Jewell and Cherp 2023). For instance, developing a least-cost scenario for net-zero emissions may require limiting nuclear technology deployment[35]. Scenarios closest to the periphery of the solution



[34] Differentiation between climate actions with and without causal paths.
[35] Nuclear technologies are capital-intensive technologies and would thus increase costs in least-cost pathways (*section 2.3.3*).

space[36] are deemed infeasible as they nearly surpass the imposed limit. The primary challenge of this approach is the need for awareness of all the causal drivers of a climate action (Jewell and Cherp 2023). Drawing from the previous example, social impediments to nuclear energy, such as NIMBY[37], that may bring some scenarios closer to the periphery are unaccounted for in IAMs (*see above paragraph*). Another approach distinct from thresholding relies on the idea that more ***probable*** solutions are likewise more ***feasible*** (Jewell and Cherp 2023). Scholars rely on outlook or projection as ***probable*** outcomes for the potential implementation of a climate action. In this approach, scenarios are constructed with assumptions that rely on forecasts, capable of differentiating between more and less likely scenarios given the trajectory of existing trends (Jewell and Cherp 2023). However, assessing feasibility through a probability lens hinders the consideration of uncertainties such as technological disruptions or socio-political shifts (Jewell and Cherp 2023). Also, given that scenarios are exploratory rather than probabilistic, evaluating feasibility through probability indicates an inherent mismatch.

Mutual benefits arise with the development of scenarios through knowledge co-production[38]. On the one hand, climate policymakers gain insight into how to shape policies and agendas. On the other hand, scientists are acknowledged for their contribution, potentially receiving funds (Cointe and Guillemot 2023; Jewell and Cherp 2023). However, this relationship between knowledge co-producers can obstruct rigorous feasibility assessments (Jewell and Cherp 2023). A scenario could consider a target attainable, despite being underpinned by



[36] Scenarios closer to the periphery of the solution space would comprise larger shares of nuclear energy, contrary to those closer to the core of the solution space.
[37] NIMBY (Not in My Backyard) represents social opposition against the development of a particular technology in a community.
[38] Knowledge co-production occurs when two parties with aligned interests work together to develop knowledge.

optimistic assumptions (e.g., large-scale deployment of carbon dioxide removal (CDR) technologies[39]) (Stoddard et al. 2021). Robust feasibility assessments ideally constrain such ambitious assumptions, but performing such comprehensive assessments can prove difficult for scientists involved in knowledge co-production (Jewell and Cherp 2023). Assessing the realism of such optimistic assumptions may require critiquing the role of policymakers in its implementation. This can reveal a need for radical policies, which policymakers may be unwilling to formulate given other priorities. This conflict of interest can prevent scientists from undertaking such assessments to preserve their partnership with policymakers (Jewell and Cherp 2023).

In summary, the three core principles for a robust feasibility assessment identified by Jewell and Cherp (2023) fail to be demonstrated in current feasibility approaches. Identifying all relevant ***causalities*** remains a challenge within the solution space and thresholding approaches, which impedes ***comparative assessments***. Also, the ***agency*** of policymakers may be unconstrained given the conflict of interest arising from their co-dependency with scenario scientists in developing scenarios. The identified approaches to feasibility assessments fall under a broader frame of feasibility assessment called the inside view conceived by Kahneman and Lovallo (1993). Within this view, forward-looking methods are applied to assessing feasibility. Opposing this view is the outside view, where historic analogies, rather than future explorations, are used to assess feasibility. The following section introduces both views and the challenges they face in evaluating feasibility.



[39] CDR technologies are characterized by high levels of uncertainty and have failed to reach deployable scales that could reduce carbon emissions (Stoddard et al. 2021).

### 2.3.3 Inside and outside views of feasibility

The inside and outside views of feasibility represent two distinct notions for conceptualizing feasibility assessments. The inside view conceptualizes any challenge as unique by focusing on the strategies and barriers specific to that challenge and explores the challenge through future scenarios (Kahneman and Lovallo 1993; Jewell and Cherp 2023). This is illustrative in global climate scenario studies, which consider climate change a distinctive challenge often explored through mitigation pathways (Jewell and Cherp 2023). The ***solution space***, ***thresholding***, and ***forecasting*** approaches represent inside views given their forward-looking method (*see section 2.3.2*). Contrarily, the outside view uses historical analogies rather than future scenarios to assess the feasibility of scenarios (Kahneman and Lovallo 1993; Jewell and Cherp 2023). This approach relies on historical precedents to create benchmarks against which climate actions can be assessed. For instance, Cherp et al. (2021) used maximum historical growth rates of wind and solar power deployment in 60 countries to evaluate the feasibility of solar and wind targets consistent with 1.5°C and 2.0°C scenarios. The authors discovered that historical growth rates were inconsistent with rates required to deliver global climate targets (Cherp et al. 2021). The outside approach is, however, faced with criticisms. Among them is the argument that the future will inherently differ from the past, and previous outcomes of precedents may change to hinder or favour a solution (Jewell and Cherp 2023).

Both inside and outside views hold vital roles in feasibility assessments. The future will undoubtedly differ from the past, justifying the need for future scenarios. Nevertheless, some historical forces are strong enough to influence the future, reinforcing the need to account for historical precedents (Jewell and Cherp 2023). Given the importance of both views in feasibility studies, bridging these views can improve feasibility assessment. Jewell and Cherp

(2023) take a step in this direction by proposing a methodological tool that enables a union between both views, a feasibility space. The use of a feasibility space as a feasibility assessment tool relies on reference cases of a climate action. To ensure a solid understanding of the feasibility space concept, the following section introduces reference cases, a core criterion required to develop a feasibility space.

#### 2.3.4 Reference cases

Reference cases represent historical analogies of a climate action or target case[40] that define the bounds of a feasibility space (Jewell and Cherp 2023). Reference cases enable comparative assessments or benchmarking against a target case, facilitating "learning from the past" (Wilson et al. 2013, 383). For an analogy to serve as a reference case to a target case, it should possess similar characteristics to the target case. These characteristics represent the social processes or causal mechanisms influencing the target case (Jewell and Cherp 2023). In other words, reference cases and the target case should be shaped by broadly similar factors. For example, population and economic growth represent factors inducing rising energy demand. Therefore, identifying analogies (reference cases) for energy demand growth (target case) should be guided by the causal factors of population increase or economic development. Accounting for such shared causal mechanisms ensures that insights drawn from comparison between a target case and its analogues are rational (Jewell and Cherp 2023).



[40] The target case represents a particular situation or climate action for which analogies are to be derived to assess its feasibility.

The use of reference cases for comparison has been applied within the energy transition and scenario literature (Pielke Jr, Burgess, and Ritchie 2022; Jewell and Cherp 2023; Semieniuk et al. 2021; Vinichenko, Cherp, and Jewell 2021; Jewell et al. 2019; Wilson et al. 2013; Cherp et al. 2021). Pielke Jr, Burgess, and Ritchie (2022) assessed the plausibility of $CO_2$ emissions in scenarios of the IPCC's fifth and sixth assessment reports (target case). Pielke and colleagues used historical trajectories of $CO_2$ emissions from fossil fuel industries and projected emission trends of IEA's stated policy scenario as benchmarks for the target case, revealing a continuous global mitigation trend but shy of global climate targets. Semieniuk et al. (2021) employed historical observations of global energy demand to evaluate the plausibility of low energy demand scenarios constructed in the IPCC Special Report on Global Warming of 1.5°C (IPCC 2018). The SR1.5°C scenarios assume that absolute decoupling, even in industrializing economies with rising energy demands, is achievable and cost-effective. However, Semieniuk et al. (2021) reveal a contradiction based on historical precedents, as increased economic output has always positively correlated with higher energy demands. Therefore, the scenarios envisioned in SR1.5°C diverge from historical analogies, representing an unprecedented pathway expected of the developing world to achieve industrialization (Semieniuk et al. 2021).

There is no fail-safe approach to identifying reference cases besides looking for causal mechanisms similar to the target case. A rule of thumb is to find analogies with similar outcomes in similar contexts (Jewell and Cherp 2023). The similarity in outcome refers to the expected result of the target case being akin to that of reference cases. As a case in point, studies have used the historical development of established energy technologies as a reference case for emerging energy technologies, given their shared similar outcome in energy transformation and use (Höök et al. 2012; Wilson et al. 2013; Jewell and Cherp 2023). Höök et al. (2012)

employed the historical growth rates of conventional energy systems to compare against the expected growth rates of new energy systems in long-range scenarios. They revealed ambitious estimated growth rates of new energy systems with minor contributions from these systems to global energy supply by 2050, even if rapid growth, comparable to the oil-boom period, occurred (Höök et al. 2012). Wilson et al. (2013) draw similar conclusions showing that low-carbon technologies in IPCC scenarios require a longer timespan to meet similar capacities of conventional energy technologies.

Also, there should be a match in context between reference cases and the target case to prevent incompatibilities when making comparisons. Context similarity further ensures the consideration of implicit causal factors shaping the target case and its analogues. The context of a target could range the scale of implementation (i.e., national or sub-national), the wealth of a nation (i.e., high-income or low-income country), or energy insecurity level (Jewell and Cherp 2023). Thus, assessing a target case centred around RE development in an industrialized economy should ideally be benchmarked against RE development in wealthy nations. Nevertheless, easing the contextual criteria to include diverse contexts can be helpful if the target (or reference) case is unique or only implemented on a smaller scale (Jewell and Cherp 2023). For example, given that reference cases for global RE growth rates are inexistent, Cherp et al. (2021) employed RE growth rates in 60 countries that accounted for ~95% of global electricity production. In instances where the similarity of outcome is met but with high contextual disparities between the reference and target cases, comparative assessments must account for these disparities through normalization[41] (Jewell and Cherp 2023).

A good practice in selecting reference cases is to balance their similarity to the target case and their number. While constraining the similarity criteria increases the validity of insights drawn from comparisons, this may result in few reference cases being identified, impeding robust comparative assessments (Jewell and Cherp 2023). Likewise, relaxation of the similarity criteria may raise challenges in justifying insights from comparisons (Jewell and Cherp 2023). For instance, Wilson et al. (2013), by relaxing the similarity criteria for low-carbon technologies, produced sufficient historical observations from a wide range of energy technologies. However, upon constraining this criterion to power generation technologies alone, only a few analogies could be used for comparison, saturating findings from their study (Wilson et al. 2013).

This sub-section introduced reference cases and the procedures for identifying them. To summarize, reference cases represent historical analogies of a target case and are identified for comparative assessment or benchmarking against a target case. The similarity in shared causal mechanisms represents the approach to identifying reference cases. Nevertheless, they may also be identified through similar outcomes in similar contexts to a target case. Understanding



[41] Normalization entails the adjustment of reference and target cases to a common scale to enable comparisons. For instance, making a comparison between renewable energy targets in Nigeria and Germany requires normalization, given huge differences in electric capacity. German installed electric capacity (228 GW) is much larger than Nigeria's (12 GW). A division between these capacities normalizes the electricity system and enables comparison. A simple interpretation of this normalization is that if Germany carries out any energy-related action, Nigeria could only achieve an outcome that is 20 times lesser (all other considerations being equal) (Aderinto 2023).

the concept and function of reference cases enables a full grasp of the feasibility space concept. The following section introduces the feasibility space, while section 3.1 highlights its tailored application to this thesis.

### 2.3.5 Feasibility space

Jewell and Cherp (2023) proposed the feasibility space as a tool for "assessing the feasibility of a climate option by its characteristics, context, or implementation levels" (Jewell and Cherp 2023, 12). The characteristics, context, or implementation level of the climate option are assessed via benchmarking against the characteristic, context, or implementation level of the climate option's analogues (i.e., reference cases). Therefore, the feasibility space is shaped by historical analogies (reference case) of the climate option or target case under consideration. The position of the climate option or target case relative to the feasibility space determines its feasibility. Feasible climate options fall within the feasibility space, while infeasible options fall outside. The feasibility space is akin to the solution space as it is a multidimensional space that similarly evolves with new information over time (Jewell and Cherp 2023). However, there are three factors differentiating the feasibility from the solution space:

I. *The feasibility space is more constrained than the solutions space. Internal consistency within parameters defines the bounds of a solution space. In the feasibility space, external causal factors from empirical evidence are considered, which further restrains its bounds.*

II. *The solution space assesses scenarios, which comprise multiple climate actions. In contrast, feasibility spaces typically evaluate the feasibility of a single or few climate actions.*

III. *Internal structure: climate actions within the solution space can only be deemed plausible; the feasibility space, however, allows ordering of actions into less or more feasible solutions through "feasibility zones".*

The feasibility space has proven to be a productive tool in assessing the feasibility of climate actions. Vinichenko, Cherp, and Jewell (2021) constructed a feasibility space to evaluate the feasibility of fossil fuel (natural gas and coal) decline in electricity production. Historical precedents of decadal fossil fuel decline larger than 5% in electricity system sizes over 100 TWh served as reference cases. Target cases represented regional and global fossil fuel decline rates in IPCC 1.5°C and IEA Net Zero Emission (NZE) scenarios. Through the feasibility space, the authors illustrated that historical fossil fuel declines were driven by fuel switching, nuclear, renewables, and demand decline. However, historical decline rates were generally lower than envisioned rates in the target cases (Vinichenko, Cherp, and Jewell 2021).

Feasibility spaces can also be separated by feasibility frontiers or grouped into feasibility zones to delineate more feasible from less feasible climate actions (Jewell and Cherp 2023). Jewell et al. (2019) built a feasibility space with a frontier that assessed the prospects of coal18[42] nations in becoming members of the Powering Past Coal Alliance (PPCA). The authors identified coal dependence and the functioning of government as significant causal factors influencing PPCA membership. By quantifying these causal factors in coal18 nations and



[42] The coal18 group represents countries with the highest coal consumption globally. These countries: Australia, China, Czech, Germany, India, Indonesia, Japan, Kazakhstan, Malaysia, Poland, Russia, South Africa, South Korea, Spain, the US, Turkey, Ukraine, and Vietnam.

benchmarking them against PPCA members, the authors induced that the proximity of Australia, Spain, Germany, Japan, and the United States was closest to the feasibility frontier. Consequently, these five nations demonstrated the highest prospects of becoming PPCA members (Jewell et al. 2019). Vinichenko et al. (2023) provide an update to the study by Jewell et al. (2019), revealing an expansion of the feasibility frontier and PPCA membership adoption by Spain and Germany. The expansion of this frontier – due to rising international pressures and competitive cost from alternate technologies – translates into a higher probability of other coal18 nations embracing PPCA membership. As the authors show, majority of coal18[43] nations, excluding China, Kazakhstan, Russia, Turkey, and Vietnam, currently possess a 50% chance of becoming PPCA members (Vinichenko et al. 2023).

The feasibility space tool represents a tool for assessing feasibility through comparative assessment. Analogies (reference cases) of a climate option or target case are identified to develop a feasibility space. The position of the target case relative to the developed feasibility space defines its feasibility. This thesis adopts the feasibility space as its method to conduct a feasibility assessment. In other words, the feasibility space is used to assess the feasibility of required investments for Nigeria's energy transition targets.



[43] It should be noted that this statement excludes Germany and Spain, given that they are members of the PPCA already.

## 2.4 Summary

The literature reviewed highlighted the essential role of RE in decarbonizing the global energy system and the challenges developing economies face in its uptake from a financial, political, and technical lens. This chapter also outlined the sources and models for financing renewables and nuclear energy while illustrating that Nigeria's rentier characteristics, lack of financial development, and market performance of the electricity industry have impeded investments in RE. Current gaps in the literature were also identified, revealing a lack of a feasibility lens for assessing financial challenges to RE deployment in Nigeria. Also, although the feasibility of nuclear energy in Nigeria has been assessed, such assessments have been based on the financial capacity of Nigeria rather than the required cost to deploy nuclear energy.

Furthermore, this chapter introduced the feasibility concept and differentiated it from its metonyms. It presented the principles for a robust feasibility assessment and showed that current approaches to feasibility assessment (solution space, thresholding, and forecasts) fail to demonstrate these principles. Forward-looking approaches (solution space, thresholding, and forecasts) to feasibility assessment represent an inside view, while approaches that employ historical precedents (reference cases) for feasibility assessment represent an outside view. Bridging both views could enhance the feasibility assessment of a climate action, which the feasibility space tool seeks to achieve.

# 3 Theoretical framework and methodology

This chapter outlines the theoretical framework and methodology applied in this thesis. Section 3.1 presents the theoretical framework of this thesis based on the three principles for a robust feasibility assessment (*see section 2.3.2*). This section also provides information on how the feasibility space tool helps to fulfil one of these principles. In the following section (section 3.2), I lay out the methodology employed in answering the Research Questions of this thesis. The three sub-sections within the methodology chronologically illustrate how the three Research Questions were answered (*see section 1.3*). In the final section of this chapter (section 3.3), I identify the limitations of my methodology.

## 3.1 Theoretical framework

This thesis adopts the definition of feasibility by Jewell and Cherp (2023), who define feasibility as an action that is "do-able under realistic assumptions" (Jewell and Cherp 2023, 2). In the context of this thesis, therefore, financing of renewables and nuclear energy is feasible if there are real-world actors who can provide these finances under realistic assumptions. However, what realistic assumptions can be made to ensure that financial flows from these real-world actors are do-able? As an overarching guideline in making these realistic assumptions, I follow the three principles for a robust feasibility assessment identified by Jewell and Cherp (2023): causal reasoning, comparative assessment, and consideration of agency (*see section 2.3.2*).

1. Causal reasoning (*How can financing occur in Nigeria?*):

The principle of causal reasoning addresses how financing can occur in Nigeria. Causal reasoning assumes that an outcome in a particular social setting can happen in a different social setting if similar processes that induced this outcome are present. As such, causal reasoning enables the use of historical analogies to assess if a given situation demonstrates comparable developments to the analogy towards achieving a similar outcome. This thesis applies causal reasoning in two ways. Firstly, by identifying and analyzing reference cases with presumably similar causal mechanisms or social processes under the assumption that "similar things can happen under similar circumstances". Therefore, I seek to identify reference cases with similar outcomes in similar contexts (*see section 4.2*). Secondly, by illustrating what causal processes can lead to the realization of financing energy transitions in Nigeria (*see section 5.2*).

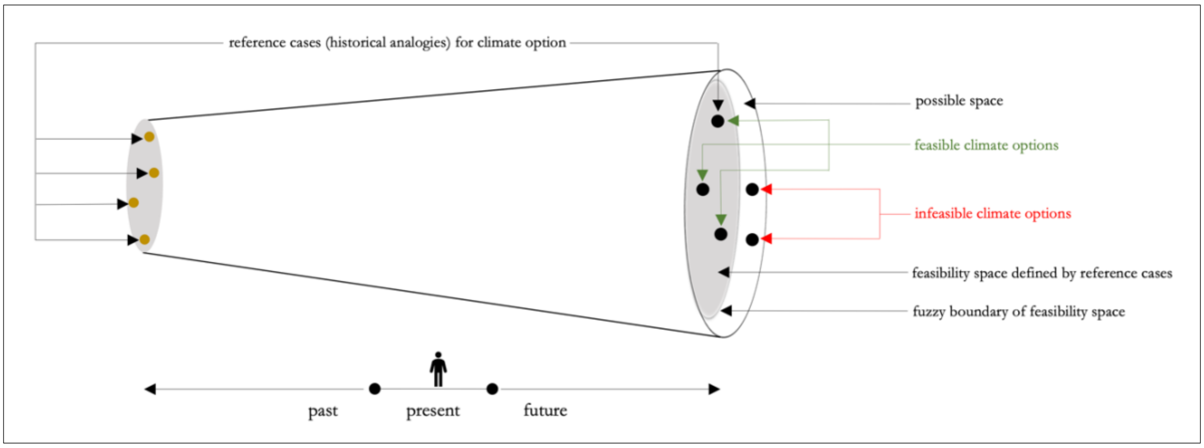
2. Comparative assessment (*How do needed finances compare to historically deployed finances?*):

The target case for this thesis represents the financial values required for actualizing Nigeria's energy transition targets. However, the defined target case must be comparatively assessed against historically deployed finances to align with the principles for a robust feasibility assessment. Therefore, I address the comparative assessment principle through the feasibility space.



As described in section 2.3.5, the feasibility space comparatively judges feasibility by mapping the desired outcome onto a multi-dimensional space where the position of the desired outcome corresponds to its feasibility or infeasibility. Figure **3.1** presents the feasibility space and the underlying processes for its construction. The feasibility space (*large grey oval in Figure* **3.1**) is constructed using reference cases or historical analogies (*brown dots*) of a climate option (*black dots*). These reference cases are identified through similar causal mechanisms, outcomes, or contexts with the climate option (*see section 2.3.4*). The characteristics of the climate option determine its position relative to the feasibility space. Climate options positioned within the feasibility space are feasible climate options (*green arrows*), while those outside are considered infeasible (*red arrows*). As such, a climate option within the feasibility space demonstrates relatively similar characteristics to reference cases, contrary to an option outside the feasibility space (Figure **3.1**). The fuzzy boundary of the feasibility space illustrates the space as a dynamic space that evolves with novel information, such as newly identified causal mechanisms (Jewell and Cherp 2023).

Figure 3.1: The feasibility space




Source: Author’s illustration based on Jewell and Cherp (2023)

3. Consideration of agency (*What actors can deploy the required finances for transition?*):

I explore the agency principle by identifying influential actors possessing sufficient capacity and interest in channelling finance to Nigeria. Section 2.2.1 highlighted that renewable energy financing occurs through public and private sources, with the former being more prominent in developing regions like SSA than the latter. Similarly, an adopted model for nuclear financing in countries lacking financial capacity is the government-to-government model, influenced by public actors (*see section 2.2.3*). With these considerations, I consider public actors to hold agency in providing finance for the energy transition in Nigeria. However, investments from public sources like MDBs at the national level are in a lower order of magnitude (millions) than investment requirements for energy transitions in Nigeria (billions). Bridging this investment gap requires private sector investments to supplement public sector investments for energy transitions in Nigeria, extending agency to private actors in the process. As such, when identifying reference cases, I ensure to account for the agency of both private and public actors.

## 3.2 Methodology

This study employs the feasibility space tool to assess the financial feasibility of required investments for Nigeria's 2030 energy transition targets. To utilize this tool, I broadly follow the five steps identified by Jewell and Cherp (2023) for constructing a feasibility space. Also, I ensure that the contextualized principles for a robust feasibility assessment serve as guidance when implementing these five steps (*see section 3.1*). These five steps in developing the feasibility space include:

I. *Define the target case*

II. *Identify relevant reference cases*

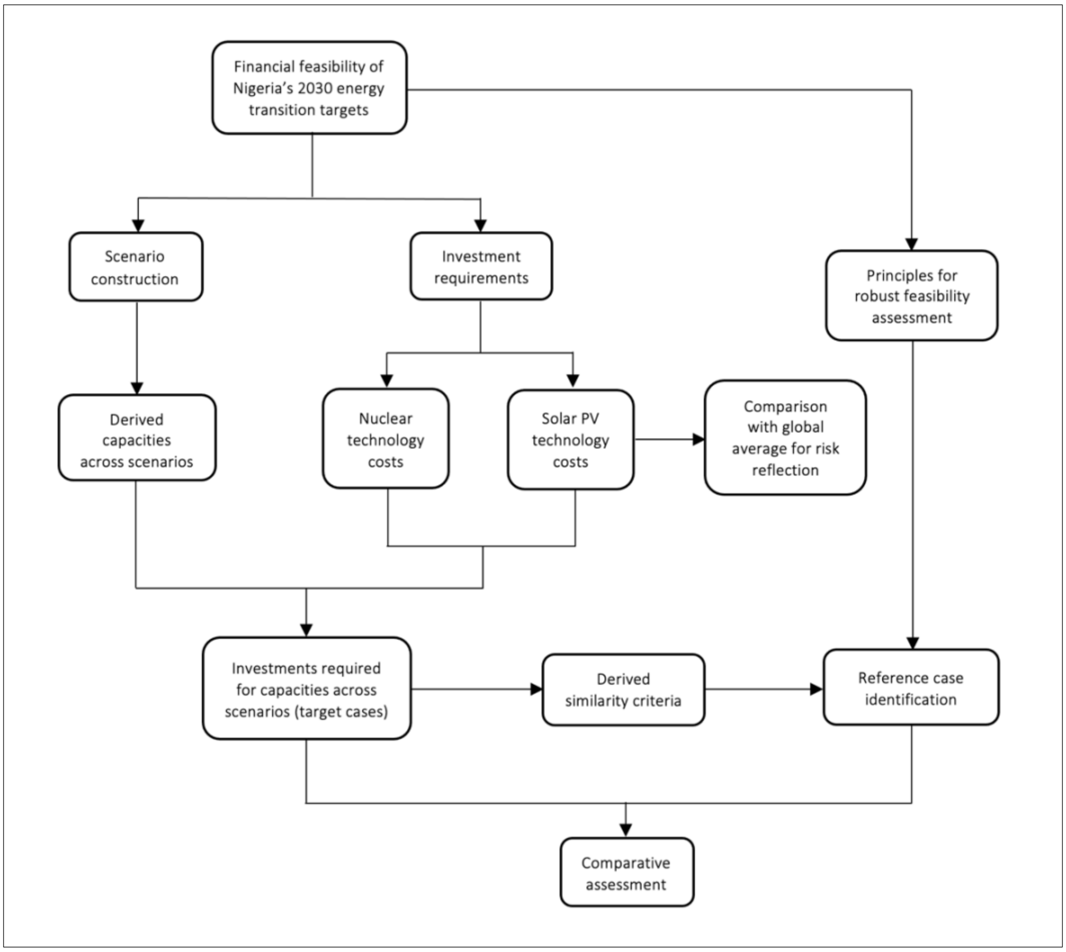
III. *Measure and normalize reference case outcomes*

IV. *Construct feasibility space with distribution of outcomes from reference cases*

V. *Map the target case(s) on feasibility space*

Following these steps, section 3.2.1 defines the target case by conducting a scenario analysis to understand the range of deployable targets by 2030 and the fiscal value associated with each target. In section 3.2.2, reference cases for the target case are identified through guidance from the causal reasoning and consideration of agency principles. Finally, section 3.2.3 maps the target cases onto the feasibility space through a comparative assessment between target and reference cases. The workflow illustrated in Figure **3.2** summarizes the methodology of this thesis.

Figure 3.2: Methodology workflow




### 3.2.1 Scenario construction and estimation of investment requirements

#### 3.2.1.1 Scenario construction

Scenarios are used to explore and evaluate ranges of plausible futures given certain assumptions (Pielke Jr, Burgess, and Ritchie 2022; O'Neill et al. 2020). The IPCC use scenarios to explore plausible levels of future warming given assumptions about population growth, governance efficiency, socioeconomic development, and technological change (Van Vuuren et al. 2014). With Nigeria possessing a range of energy transition targets to be met by 2030, this thesis explores the nation's plausible future energy additions through scenario analysis. I explore Nigeria's plausible future energy additions by employing the scenario matrix architecture, which represents a heuristic tool for categorizing scenarios or guiding the construction of new ones at different scales (Van Vuuren et al. 2014).

The scenario matrix represents a 2-dimensional table comprising two axes: the horizontal or x-axis and the vertical or y-axis. Each axis denotes a pathway that the subject of the scenario analysis could follow. Across each pathway, there are often targets or conditions that shape the characteristics of a scenario. Through the combination or integration of these targets within each pathway, scenarios are produced (Van Vuuren et al. 2014).

Table **3**.**1** presents a simplified representation of the scenario matrix. The pathways (A and B) are highlighted in bold and situated along the x and y axes (*dark grey cells*). The adjacent columns (for pathway A) and rows (for pathway B) represent targets under each pathway (*light grey cells*). Combining these targets under each pathway creates scenarios (*white cells in italics*). For example, achieving A2 and B3 targets within the corresponding pathways produces the *A2B3* scenario. Similarly, attaining A3 and B1 targets results in the *A3B1* scenario.

Table 3.1: Scenario matrix for scenario development

| | | **Pathway A** | | |
|---|---|---|---|---|
| | | Target A1 | Target A2 | Target A3 |
| **Pathway B** | Target B1 | *Scenario A1B1* | *Scenario A2B1* | *Scenario A3B1* |
| | Target B2 | *Scenario A1B2* | *Scenario A2B2* | *Scenario A3B2* |
| | Target B3 | *Scenario A1B3* | *Scenario A2B3* | *Scenario A3B3* |

In the context of this thesis, the two pathways considered for the scenario matrix include the solar and the nuclear pathways. Within the solar pathways, solar PV targets that Nigeria could achieve by 2030 were considered. The four targets (or condition) within the pathway:

I. No solar energy deployed
II. National Renewable Action Plans (NREAP) target
III. Nationally Determined Contribution (NDC) target
IV. Ambitious solar deployment

Nuclear energy represents the energy source considered under the nuclear pathways. Although the Nigeria Atomic Energy Commission (NAEC) set a nuclear capacity target of 4,000 MW by 2027, this study deems the target infeasible, given the short timeframe of four years. Nevertheless, I assume one nuclear power plant to be deployable in Nigeria by 2030. The underlying rationale for this assumption was driven by the nation's contextual characteristics, which Brutschin, Cherp, and Jewell (2021) identify as an influential determinant of nuclear energy development. These contextual characteristics include the nation's electricity demand growth due to its rising population and economic development and needed energy diversification to reduce its high dependence on natural gas (Adeniyi 2019; Pavanelli et al. 2023; National Energy Masterplan 2022). Also, the Nigerian Electricity Supply Industry (NESI) remains largely state-owned, which eases nuclear development, as countries with liberalized power markets are unlikely to adopt nuclear energy due to risk perceptions of private actors (Brutschin, Cherp, and Jewell 2021). Lastly, given that the timeframe for constructing a nuclear power plant (NPP) can range from 7 to over 15 years, I assume only one NPP can be deployed by 2030. With these underlying considerations for the nuclear pathways, I considered two targets:

I. No nuclear energy deployed

II. Nuclear energy target

The combination of targets within each pathway produced the potential installed electricity capacity in each scenario. As an important note, the first targets under both pathways are not necessarily targets and are more of conditions where Nigeria fails to deploy solar or nuclear energy. The following subsection maps out the procedures for estimating investment requirements across the scenarios.

#### 3.2.1.2 Investment requirements in different scenarios

The costs of solar PV and nuclear technologies were obtained from the literature to estimate the required investment across each scenario. I derived solar PV costs from Afful-Dadzie, Mallett, and Afful-Dadzie (2020), who assessed the challenges of electricity generation cost of renewable energy in Ghana. Given the higher risk of RE deployment in developing economies (*see sections 2.1.2 and 2.2.1*), this study ensured risk reflection in obtained solar PV costs. As highlighted in section 2.2.1, risk perception often factors into the cost of deploying renewable energy technologies. Consequently, this study compared the literature-derived solar PV costs to the global average cost of solar PV in IRENA (2021). The global average cost of solar PV has plummeted over the last decade, translating into lower risk perceptions associated with deploying the technology. Therefore, a higher value of the literature-derived solar PV cost than the global average translates into higher risk perceptions and reflects risks in solar PV costs (*see sections 2.1.2 and 2.2.1*). Although a one-year gap exists between the dates of solar PV costs considered (2020 for literature-derived and 2021 for the global average), this study assumes little change in risk perceptions in a year. Also, rather than using the cost range provided by Afful-Dadzie, Mallett, and Afful-Dadzie (2020), the mean value was estimated, as shown in Equation 1.

$$\begin{aligned} &\mathit{Estimated\ solar\ PV\ capital\ cost}\ (\$) \\ &= \frac{\mathit{Upper\ limit\ cost\ range} + \mathit{Lower\ limit\ cost\ range}}{2} \end{aligned}$$

**Equation 1**

On the other hand, nuclear technology costs were obtained from the United States Energy Information Administration (EIA 2022), an agency that collates, analyses, and distributes energy-related information. Although nuclear development was deemed feasible in Nigeria by deploying small modular reactors (Sah et al. 2018), this study acquired costs for light-water reactors due to certain presumptions. Section 2.2.3 of the literature review illustrated that nuclear development in Bangladesh occurred through support from Russia's state-owned nuclear company, Rosatom. The section also highlighted the possibility of Nigeria following the pathway of nuclear development in Bangladesh, given Nigeria's established relationship with Rosatom. If such a trajectory is followed, light-water reactors would most likely be the nuclear configuration adopted as the Rooppur 1 and 2 NPPs in Bangladesh use this configuration. These assumptions underpinned the choice for the light-water reactor over the small modular reactor cost.

Upon deriving the cost for solar PV and nuclear energy, I converted these costs from USD/KW to USD/GW to ensure similarity in the unit of technology cost and scenario electric capacities.

The needed investments were estimated by multiplying capacity across each scenario by the converted cost of the associated technology (Equation 2). In scenarios that simultaneously achieve the targets of nuclear and solar PV technologies, the capacity of each technology was multiplied by its corresponding cost and then summed up to derive the total investments required within the scenario. The estimated investment across each scenario served as the target cases of this thesis and was used to identify reference cases.

$$\begin{aligned} &Required\ investment\ (\$) \\ &\quad = Electric\ capacity\ \ in\ scenario\ (GW)\ \times\ Technology\ cost\ (\$/GW) \end{aligned}$$

**Equation 2**

### 3.2.2 Identification of reference cases for needed investments and constructing feasibility space

Upon deriving the target cases (i.e., required investments across scenarios), I identified reference cases to serve as benchmarks through the following processes:

1. Following the principle of causal reasoning for a robust feasibility assessment (*see section 3.1*), I identified reference cases using the criteria of similar outcomes occurring in similar contexts (*see section 2.3.4*). The similar outcome in similar context criteria was defined as follows:

   ***Similar outcome:*** *The outcome under consideration represents the required investment across scenarios. Thus, reference cases with relatively equal financial amounts defined the similar outcome criterion.*

*__Similar context:__ The target cases of this thesis represents required energy transition investments within Nigeria (i.e., investments within a country). As such, I defined the context criterion as the scale of implementation (i.e., national-level investments).*

2. Also, I accounted for the agency of actors when identifying reference cases. As I established in section 3.1, I consider public and private actors to hold agency in facilitating energy transitions within Nigeria. Therefore, an added dimension to the similar outcome in similar context criteria was ensuring that investment sources where both public and private actors held influence were duly considered.
3. Data on reference cases that met the above criteria were retrieved from the World Bank Open Data platform, OECD website, official government documents (e.g., annual national reports), European Commission website, and the World Nuclear Association website.
4. One of the identified reference cases was given in Euro and to ensure standardization with other reference cases, I made a conversion to US Dollar (USD). Data for the exchange rate was derived from World Bank (2023a). I used the official exchange rate of \$1 = €0.95 on 14$^{th}$ July 2023 at 13:28pm for this conversion.



### 3.2.3 Mapping investment requirements in scenarios onto the feasibility space

#### 3.2.3.1 Estimation of potential investments by 2030 from reference cases with annual investments

With the defined target cases and identified reference cases, the next step entailed mapping the target cases onto the feasibility space. I conducted this process by comparing the required investments across scenarios and the identified reference cases. However, given that some of the reference cases identified were annual investments, I estimated the amount such reference cases could provide till 2030 through two steps. Firstly, I derived the most current financial value of such reference cases and defined it as a base value. Secondly, I assumed that this base value remains constant for seven years (i.e., 2023 – 2030) and that the total value over the seven years represents how much such reference cases could provide (Equation 3). These steps enabled comparison between required investments by 2030 and financial flows from reference cases channelled annually.

$$Total\ financial\ value\ of\ reference\ case\ innvestments\ made\ annually\ (\$) = Current\ financial\ value \times 7$$

**Equation 3**

#### 3.2.3.2 Normalization considerations

As opposed to directly comparing the target (required investments) and reference cases, the financial values of both cases were first normalized and then compared. Normalizing these values enabled more insightful comparison while accounting for inherent disparities between the target and reference cases (e.g., national wealth). I conducted the normalization and comparison in two ways:

1. Certain reference cases had very similar contexts to the target cases. These reference cases represented investments made at the national level and into the Nigerian economy. For such reference cases, I made comparisons through per capita investments. I derived the per capita investments by dividing the financial value of

target cases and reference cases (with very similar contexts to the target cases) by Nigeria's average population size between 2022 and 2030. To derive the average population size, I assumed the current population growth rate remains constant for seven years (Equation 4). Next, I summed up the projected population size from Equation 4 with Nigeria's current population size and took the average (Equation 5). I took this average because the reference cases normalized on a per capita basis were annual investments that would occur over time (2023 – 2030) rather than investments in 2030 alone. Upon estimating the average population size (Equation 5), I derived per capita investment by dividing the financial value of target and reference cases by the average population size (Equation 6). Consequently, I compared the normalized per capita investments of the target and reference cases. I retrieved data on Nigeria's population size and growth rate from the World Bank Open Data platform, which provides free and open access to global development datasets (World Bank 2023b, 2023c).

$$Projected\ population\ size\ (2030) = \left(\frac{Current\ population\ growth\ rate \times 7}{100} \times Current\ population\ size\right) + \ Current\ population\ size$$

**Equation 4**

$$Average\ population\ size = \frac{(Projected\ population\ size + Current\ population\ size)}{2}$$

**Equation 5**

$$Per\ capita\ investments\ (\$) = \frac{Financial\ value\ (target\ or\ reference\ case)}{Average\ population\ size}$$

**Equation 6**

2. Contrarily, other reference cases demonstrated broadly similar contexts to the target cases (investments made at the national level). These reference cases were normalized and compared using Gross Domestic Product (GDP) shares. Firstly, I estimated the share of GDP for target cases from Nigeria's current GDP (Equation 7). Following this step, I quantified the GDP shares across the reference cases, using the GDP values of the country where these investments were made (Equation 8). After these steps, I conducted a comparative assessment between the GDP shares of target and reference cases. Data on GDP for reference and target cases were derived from World Bank (2023d, 2023e, 2023f, 2023g, 2023h, 2023i).

$$Required\ share\ of\ GDP\ for\ scenario\ implementation\ (\%) = \frac{Required\ scenario\ investment}{Nigeria's\ GDP\ (2022)} \times \frac{100}{1}$$

**Equation 7**

$$GDP\ share\ for\ reference\ case\ (\%) = \frac{Investment\ value\ of\ reference\ case}{GDP\ of\ reference\ case\ country\ (2022)} \times \frac{100}{1}$$

**Equation 8**

## 3.3 Limitations

This thesis considered energy transition targets for solar PV and nuclear energy technologies when constructing the scenario matrix. These technologies under consideration have different financial models for their deployment. For instance, nuclear energy is often financed through state funds or the government-to-government model (*see section 2.2.3*), while solar PV has largely been financed through private-sector investments (IRENA 2023b). Nevertheless, when assessing the financial feasibility of scenarios (comprising different technologies), I do not restrict comparisons to the respective financial models. For example, one of the reference cases for this thesis was state loans from a government for nuclear energy development. Rather than restricting this reference case and comparing it to scenarios where nuclear energy is adopted, I extended my comparison to scenarios with solar PV technologies. Such comparisons could be considered a mismatch, given that this financial structure is rarely applied in RE development.

Also, for two reference cases that were annual investments, I assumed their current values remain constant over the next seven years to derive their potential value by 2030. However, a constant value of such investments is unlikely given the volatility of these investment sources and could rise or fall below current levels. Therefore, the risk of potentially overestimating or underestimating investments from these sources arises. Finally, given that I comparatively assess target cases against reference cases representing historical investments, I do not account for discounts or inflation that have occurred over time. Nevertheless, the identified reference cases are relatively recent investments, translating into low discount rates.

# 4 Results

This chapter reports the findings of this thesis. Each subsection addresses one of the Research Questions (*see section 1.3*). Section 4.1 provides my findings on the respective capacities (GW) of solar PV and nuclear energy technologies that could be deployed across scenarios. I also present the required investments needed to deploy the capacities across the scenarios in this section. In the following section (section 4.2), historical analogies with equivalent investments to those required within the scenarios are presented. In the final section (section 4.3), I show the results of the comparative assessment between the required investments and benchmark financial flows.

## 4.1 RQ 1: Installed capacities and required investments across scenarios

### 4.1.1 Installed capacities across scenarios

#### 4.1.1.1 Pathways and targets of scenario matrix

The pathways (solar and nuclear pathways) within the scenario matrix considered six targets in total, revealing that eight scenarios could occur within Nigeria by 2030. Table **4.1** depicts the pathways, targets and eight scenarios. The pathways are the topmost (solar pathways) and leftmost (nuclear pathways) dark grey cells with bold fonts in the scenario matrix. The six targets are the light grey cells that adjoin the solar (adjacent columns) and nuclear (adjacent rows) pathways. The nuclear and solar pathways have two and four targets, respectively. As shown in Table **4.1**, I considered two binary targets under the nuclear pathway in which an assumed nuclear energy target is either achieved or not by 2030. For information about the status of nuclear energy development in Nigeria, I refer readers to section 2.2.3 of the literature review.

Table 4.1: Scenario matrix for the pathways, targets, and scenarios.

| | | **Solar pathways** | | | |
|---|---|---|---|---|---|
| | | No solar energy deployed | National Renewable Action Plans (NREAP) | Nationally Determined Contribution (NDC) | Ambitious solar deployment |
| **Nuclear pathways** | No nuclear energy deployed | *Neither solar nor nuclear energy deployed* | *Solar PV capacity of NREAP deployed* | *Solar PV capacity of NDC deployed* | *Solar PV capacity of NREAP and NDC deployed* |
| | Nuclear energy target | *Nuclear power capacity of one NPP deployed* | *NREAP solar PV capacity and one nuclear power plant deployed* | *NDC solar PV capacity and one nuclear power plant deployed* | *Solar PV capacities (NDC, NREAP) and one nuclear power plant deployed* |

The targets of the solar pathway, on the other hand, include no solar deployed, the National Renewable Action Plans (NREAP), the Nationally Determined Contribution (NDC), and ambitious solar deployment (Table **4.1**). The first target assumes Nigeria fails to install any solar PV capacity, while the last target assumes a high solar capacity installed by 2030. For the other two targets, I provide more information below:

1. National Renewable Action Plans (NREAP)

The National Renewable Action Plans (NREAP) aims to implement the objectives of the National Renewable Energy and Energy Efficiency Policy (NREEEP). The NREEEP serves to develop the right incentives, regulations, and standards that enable RE deployment and alleviate the potential risk that could impede RE uptake in Nigeria (NREEEP 2015, 2). The NREEEP comprises two components: the Renewable Energy Policy (REP) and the Energy Efficiency Policy (EEP). The Renewable Energy Policy (REP) is to function as a “blueprint for the sustainable development, supply and utilization of renewable energy resources within the economy" (NREEEP 2015, 2). The Energy Efficiency Policy (EEP), on the other hand, seeks to ensure the optimal use and conservation of energy by Nigerians (NREEEP 2015, 2). Towards implementing the REP component of the NREEEP, the Federal Government of Nigeria (FGN) developed the National Renewable Action Plans (NREAP).

The NREAP presents the expected development and growth of renewables in Nigeria towards achieving national and regional renewable energy targets (NREAP 2016). According to the NREAP, Nigeria is to have an on-grid RE capacity of 13,800 MW by 2030, comprising solar PV (5,000 MW), large hydro (4,700 MW), small and medium-scale hydro (1,200 MW), biomass (1,100 MW), solar thermal (1,000 MW), and wind (800 MW) technologies (NREAP 2016). While the NREAP considers varied renewable energy sources, the scope of this thesis is limited to the solar PV target.

2. Nationally Determined Contributions to the Paris Agreement

Nationally Determined Contributions (NDCs) represent national plans by countries to reduce national greenhouse gas (GHG) emissions and adapt to the effects of climate change (UNFCCC 2023). It serves as a mechanism that seeks to enable the achievement of the Paris temperature goals (Pattberg and Widerberg 2017). Being a signatory to the Paris Agreement, Nigeria has committed to adaptive and mitigative action via its NDC. According to the FGN, Nigeria's NDC "provides a high-level and strategic vision for climate action in Nigeria" (NDC 2021, 3). Nevertheless, the FGN also recognize that Nigeria's NDC must align with national priorities, including economic growth, national security, health, and nature conservation (NDC 2021).

Hence, the NDC embodies the nation's plan to address climate change and its development priorities.

To contribute to the global mitigation priorities, the FGN pledged unconditional and conditional GHG emission reduction by 20% and 47%, respectively, below 2018 levels by 2030. The Nigerian energy sector represents the principal emitting source, accounting for over 60% of national GHG emissions[44] (Yetano Roche et al. 2020; NDC 2021). Therefore, decarbonizing the energy sector is essential to achieve the nation's NDC commitments. Towards actualizing the needed decarbonization, the FGN committed to 30% of on-grid electricity from RE technologies by 2030. This target is to be delivered by the deployment of 12 GW large hydro, 3.5 GW small hydro, 6.5 GW solar PV, and 3.2 GW wind electric capacities (NDC 2021). Similar to the NREAP, the NDC considers a range of RE sources, but only the solar PV target is of interest to my thesis.

#### 4.1.1.2 Installed capacity in scenarios

The combination of targets under each pathway produced eight scenarios. Table **4.1** highlights the eight scenarios developed from the targets. The scenarios are highlighted in italics and occupy the white cells of the scenario matrix. I discuss these eight scenarios in the following paragraphs.



[44] It should be noted that the energy sector here comprises energy produced for transportation, residential and commercial, manufacturing and construction, and agriculture. It also covers fugitive emissions from oil and gas production (NDC 2021).

In the first scenario, there are no capacity additions to Nigeria's electricity mix from solar or nuclear energy sources by 2030. I consider this scenario a Business-as-Usual (BAU) scenario, given that the nation has never deployed solar PV (on-grid) or nuclear energy in its history. Since its independence in 1960, Nigeria has primarily deployed hydropower and fossil-based (natural gas) energy sources. The latter accounts for nearly 90% of the installed capacity since independence, highlighting the nation's rentier characteristics (Pavanelli et al. 2023; Osunmuyiwa, Biermann, and Kalfagianni 2018; Barnea, Hagemann, and Wurster 2022). Such rentier characteristics impede it from adopting alternate energy sources like solar PV and nuclear energy, leading to an installed capacity of 0 GW from these sources by 2030 (Table **4**.**2**). In the second scenario, solar PV is deployed, while nuclear technology fails to be deployed by 2030. Within this scenario, installed solar capacity comes from achieving the target defined in the National Renewable Action Plans (NREAP). As shown in Table **4**.**2**, achieving this target would add 5 GW of solar PV capacity to the Nigerian electricity mix.

Table 4.2: Scenario matrix for the pathways, targets, and capacity within scenarios.

| | | **Solar pathways** | | | |
|---|---|---|---|---|---|
| | | No solar deployed | National Renewable Action Plans (NREAP) | Nationally Determined Contribution (NDC) | Ambitious solar deployment |
| **Nuclear pathways** | No nuclear energy deployed | 0 GW | 5 GW | 6.5 GW | 11.5 GW |
| | Nuclear energy target | 1.2 GW | 6.2 GW | 7.7 GW | 12.7 GW |

Similar to the second scenario, added electric capacity in the third scenario comes from only solar energy, with no contribution from nuclear energy. However, this scenario only attains the 6.5 GW solar PV target of the Nationally Determined Contribution (NDC). The largest solar capacity is deployed in the fourth scenario when both NREAP and NDC targets are met in 2030, adding 11.5 GW to Nigeria's electricity mix. Nuclear power fails to contribute to electricity generation in the fourth scenario but does in the fifth scenario when Nigeria installs one nuclear power plant (NPP) with a capacity of 1.2 GW[45] (Table **4.2**). Nevertheless, the fifth scenario sees no solar uptake to supplement the installed nuclear capacity. Table **4.2** illustrates that added electricity capacities in the sixth and seventh scenarios total 6.2 GW and 7.7 GW, respectively. In these scenarios, Nigeria uptakes nuclear and solar energy technologies in 2030, with the sixth scenario achieving the solar PV NREAP target without the solar PV NDC target and vice versa for the seventh scenario. In the last scenario, the NREAP, NDC, and nuclear targets are all met to deliver 12.7 GW of electric capacity, a figure approximately equalling Nigeria's current installed electric capacity (Pavanelli et al. 2023). Table **4.3** summarizes the eight scenarios and their respective installed capacities.

Table 4.3: Installed capacity across eight scenarios.

| **Scenarios** | **Scenario Description** | **Capacity (GW)** |
|---|---|---|
| 1 | Neither solar nor nuclear energy deployed | 0 |
| 2 | Solar PV capacity of NREAP deployed | 5 |
| 3 | Solar PV capacity of NDC deployed | 6.5 |
| 4 | Solar PV capacity of NREAP and NDC deployed | 11.5 |
| 5 | Nuclear power capacity of one NPP deployed | 1.2 |
| 6 | NREAP solar PV capacity and one nuclear power plant deployed | 6.2 |
| 7 | NDC solar PV capacity and one nuclear power plant deployed | 7.7 |
| 8 | Solar PV capacities (NDC, NREAP) and one nuclear power plant deployed | 12.7 |



[45] One nuclear power plant (NPP) has an average installed capacity of 1.2 GW and given the assumption that one nuclear power plant is deployable by 2030, I adopted this as my nuclear energy target.

### 4.1.2 Required investments across scenarios

#### 4.1.2.1 Solar PV and nuclear technology cost

Afful-Dadzie, Mallett, and Afful-Dadzie (2020) assessed energy transition challenges in Ghana by evaluating the cost of electricity generation from several power generation technologies. The authors provide capital costs for the power generation technologies considered in their study. The capital cost of utility-scale solar PV was estimated to range between \$2,434 to \$2,671 per KW. As shown in Equation 9, I calculated the mean of the provided cost range to derive a singular cost value. From my calculation, I estimated the capital cost per KW of solar PV technology deployed at \$2,553. Therefore, I estimate that to deploy 1 KW of solar PV in Nigeria, a capital investment of \$2,553 is required.

$$Estimated\ solar\ PV\ capital\ cost = \frac{\$(2{,}671\ + 2{,}434)}{2} = \$2{,}553$$

**Equation 9**

Following this step, I ensured that the high-risk perceptions of deploying RE technologies in developing economies were reflected in the derived cost of solar PV, as higher-risk perceptions translate into higher capital costs (*section 2.2.1*). I confirmed that these risks were reflected as a comparison between the estimated cost of solar PV and global average from IRENA (2021) revealed huge disparities. The cost of deploying 1 KW of solar PV energy in Nigeria (\$2,553/KW) was three-fold that of the global average (\$857/KW), illustrating high-risk perceptions for RE deployment in Nigeria. Although other factors could contribute to the higher costs of deploying RE technologies in industrializing economies, risk perceptions represent a highly influential factor.

Nuclear technology cost with light-water reactor configurations was derived from the United States Energy Information Administration (EIA 2022). Section 3.2.1.1 provides information about the rationale for choosing the light-water reactor configuration. The EIA places the cost per KW of electricity produced from nuclear light water reactors at $6,695, which I approximated to $6,700. Table **4.4** summarizes the capital cost of solar PV and nuclear technologies.

Table 4.4: Capital cost of solar PV and nuclear technologies with corresponding sources.

| Technology | Capital cost ($/KW) |
|---|---|
| Solar PV | 2,553 |
| Nuclear energy | 6,700 |

Source: Author's own calculations based on Afful-Dadzie, Mallett, and Afful-Dadzie (2020) and Energy Information Administration (EIA 2022).

#### 4.1.2.2 Investment requirements across scenarios

Results from the scenario matrix highlighted that eight scenarios could occur in Nigeria by 2030 (see Table **4.3** for a summary of the scenarios). In the first scenario (Neither renewable nor nuclear energy deployed), no electric capacity is added to Nigeria's electricity mix. As such, no financial value could be estimated in the scenario, denoting no investments required. In contrast, the remaining seven scenarios all deployed electric capacities. Therefore, required capital investments for the respective capacities across these scenarios could be derived. I converted the capital costs of both technologies under consideration to reflect the capacity unit across scenarios (i.e., \$/KW to \$/GW). Table **4.5** shows the values of the converted capital cost of solar PV and nuclear energy.

Table 4.5: Converted capital cost of solar PV and nuclear technologies

| **Technology** | **Capital cost (\$/KW)** | **Converted capital cost (\$/GW)** |
|---|---|---|
| Solar PV | 2,553 | 2,553,000,000 |
| Nuclear energy | 6,700 | 6,700,000,000 |

With the converted capital cost (\$/GW) of solar PV and nuclear energy, I present the investment requirements across scenarios by classifying them into two groups: single technology and multiple technology scenarios. The former represents scenarios where only one power generation technology type was deployed (solar PV or nuclear), while the latter represents scenarios where both solar PV and nuclear technologies were deployed.

1. Investment requirements across single technology scenarios (second, third, fourth, and fifth scenarios)

In the second scenario, the NREAP solar PV capacity of 5 GW is deployed by 2030. The investment needed to actualize this scenario was given as:

$$Required\ scenario\ investment = 5\ \times\ 2{,}553{,}000{,}000 = \$12{,}765{,}000{,}000$$

**Equation 10**

From the above results, the investment required to realize the second scenario is $12,765,000,000. I repeated this step for scenarios that deployed a single technology (i.e., the third, fourth, and fifth scenarios), where their capacities were multiplied by their corresponding capital cost (solar PV cost for the third and fourth scenarios and nuclear energy cost for the fifth scenario). Repeating this step for the third, fourth, and fifth scenarios revealed 2030 investment requirements of $16,594,500,000, $29,359,500,000, and $8,040,000,000, respectively.

2. Investment requirements across multiple technology scenarios (sixth, seventh, and eighth scenarios)

The sixth scenario sees the deployment of one nuclear power plant (1.2 GW) and solar PV capacity of the NREAP (5 GW). I made the following calculation to estimate the investment requirements:

$$Required\ scenario\ investment = (1.2 \times 6{,}700{,}000{,}000) + (5 \times 2{,}553{,}000{,}000)$$
$$= 8{,}040{,}000{,}000 + 12{,}765{,}000{,}000 = \$20{,}805{,}000{,}000$$

**Equation 11**



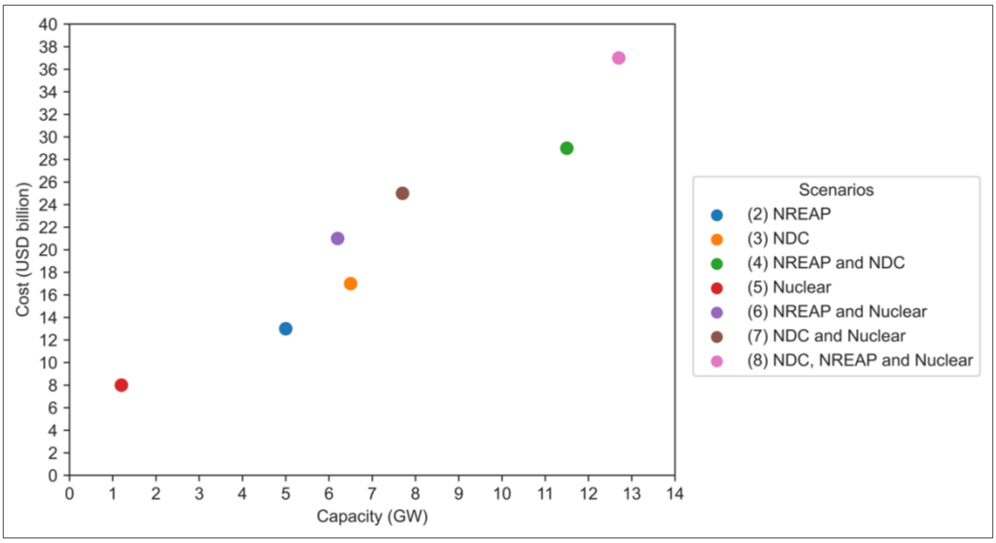
Therefore, the required investments for the sixth scenario stood at $20,805,000,000. I repeated this process for the seventh and eighth scenarios that deployed solar PV and nuclear technologies. My calculations estimated financial values of $24,634,500,000 and $37,399,500,000 in the seventh and eighth scenarios, respectively. Table **4.6** details information about the eight scenarios that includes their description, deployed capacities, and capital costs.

Table 4.6: Derived eight scenarios with corresponding capacities and approximated capital costs.

| Scenarios | Scenario Description | Capacity (GW) | Cost ($ billion) |
|---|---|---|---|
| 1 | Neither solar nor nuclear energy deployed | 0 | 0 |
| 2 | Solar PV capacity of NREAP deployed | 5 | 13 |
| 3 | Solar PV capacity of NDC deployed | 6.5 | 17 |
| 4 | Solar PV capacity of NREAP and NDC deployed | 11.5 | 29 |
| 5 | Nuclear power capacity of one NPP deployed | 1.2 | 8 |
| 6 | NREAP solar PV capacity and one nuclear power plant deployed | 6.2 | 21 |
| 7 | NDC solar PV capacity and one nuclear power plant deployed | 7.7 | 25 |
| 8 | Solar PV capacities (NDC, NREAP) and one nuclear power plant deployed | 12.7 | 37 |

Figure **4.1** depicts the investment requirements as a function of the deployed capacities across scenarios and presents a logical trend. The trend shows that the higher the capacity deployed, the higher the investment requirements. However, one scenario fails to be consistent with this trend. The outlying scenario represents the sixth scenario (*purple circle in Figure* **4.1**), where Nigeria deploys the required capacities of the NREAP solar target and one nuclear power plant by 2030 (Table **4.6**). Although this scenario installs a slightly lower capacity (6.2 GW) than the NDC scenario (6.5 GW), its investment requirements are higher than the NDC scenario (*orange circle in Figure* **4.1**) by $4 billion (Table **4.6**). The wide disparity in required investments between these scenarios is due to the higher cost of deploying nuclear energy. Table **4.5** shows that the capital cost for deploying 1 GW of nuclear capacity ($6.7 billion) is more than double the capital cost for installing 1 GW of solar capacity ($2.6 billion). Thus, given that the sixth scenario (NREAP and nuclear) deploys solar PV and nuclear technologies, while the third scenario (NDC) deploys only solar PV, it is logical that investment requirements are higher in the former than in the latter.

Figure 4.1: Deployed capacities across scenarios and corresponding investments needed.




## 4.2 RQ 2: Identification of reference cases for the target cases

### 4.2.1 Similarity criteria and consideration of agency

For this thesis, I defined the similarity criteria of achieving similar outcomes in similar contexts as investments made at the national level, which were relatively equal to the estimated investments across scenarios (i.e., the target cases). As shown in Table **4.6**, the required investments to deploy the respective electricity capacity across the scenarios by 2030 range from $8 billion to $37 billion. Therefore, historical analogies (past investments) that fell within this range were identified and analysed. Also, given the agency of public and private actors in financing energy transitions in Nigeria (*see section 3.1*), emphasis was placed on identifying and analyzing investments sources where public and private actors play(ed) a huge role in its mobilization. This process yielded a total of five reference cases:

I. Foreign Direct Investment (FDI) flows to Nigeria
II. Official Development Assistance (ODA) flows to Nigeria
III. Just Energy Transition Partnerships (JETP) pledged flows to South Africa, Vietnam, and Indonesia
IV. Loans from Russia to Bangladesh for nuclear power construction
V. Renewable energy investments in Germany

I initially considered investments within Nigeria's oil and gas sector as a potential reference case. However, data on these investments failed to be open access due to restrictions from the Nigerian National Petroleum Corporation (NNPC)[46]. Within the five identified reference cases, public and private actors are influential in mobilizing finance from these sources. In one reference case (ODA), however, investments are primarily made from public sources. My demonstration of causal reasoning – through the similarity criteria – and consideration of agency – through the reference cases from public sources – align with the principles for a robust feasibility assessment identified by Jewell and Cherp (2023) (*see section 2.3.2*). The following sub-section provides information about the five reference cases.



[46] The NNPC is tasked with exploiting Nigeria's fossil-fuel reserves by exploring, producing, and refining fossil resources to ensure sustainable national development (World Economic Forum 2023).

### 4.2.2 Presentation of reference cases

#### 4.2.2.1 Official Development Assistance (ODA)

Official Development Assistance (ODA) is considered "governmental aid that promotes and specifically targets the economic development and welfare of developing countries" (OECD 2021, 1). This aid is provided by the Development Assistance Committee (DAC), which serves as a multinational forum for large aid providers (OECD 2023b). The DAC comprises 32 members, including 31 countries and the European Union (OECD 2023b). ODA flows to developing economies can take two forms: grants or soft loans (OECD 2021). Financial resources provided as grants are interest-free without requiring reimbursement from the receiving nation. Contrarily, soft loans require repayment with interest, although at much lower rates than what commercial banks offer (OECD 2021). Data on ODA flows extended till 2021, with $3.4 billion channelled to Nigeria in 2021.

#### 4.2.2.2 Foreign Direct Investment (FDI)

Foreign direct investment (FDI) represents a category of international investment where an investor, spanning an organization, individual, or national government, invests in a foreign nation's assets or acquires ownership shares within foreign companies (OECD 2023a; European Commission 2023). These investments often manifest through acquiring shares in an existing enterprise or creating a subsidiary to develop the operational capacity of the existing enterprise (European Commission 2023). Beyond serving as a financial source, FDI flows contribute to building or improving bilateral relationships through economic integration and technology transfer between markets (OECD 2023a). The most current FDI flow to Nigeria was retrieved which stood at $3.31 billion in 2021.

#### 4.2.2.3 Just Energy Transition Partnerships (JETP)

During the 2021 UN Climate Change Conference of the Parties (COP26) in Glasgow, the Just Energy Transition Partnerships (JETP) was launched. It represents an incipient collaborative financing tool that seeks to support the decarbonization of coal-dependent emerging economies in a socially equitable manner (Kramer 2022). Finance within the JETP is mobilized by an alliance called the International Partners Group (IPG) that comprises the EU, the UK, the US, Japan, Germany, France, Italy, Canada, Denmark, and Norway (Barnes 2022). Like ODA flows, funding from the JETP will take the shape of grants and low-interest loans (Barnes 2022). Three nations have adopted the JETP, receiving financial pledges from the IPG. These nations include South Africa, Vietnam, and Indonesia, receiving commitments of $8.5 billion, $15.5 billion, and $20 billion, respectively (European Commission 2021; Barnes 2022; European Commission 2022). These financial commitments represent the reference cases.

#### 4.2.2.4 Russian loans for nuclear construction in Bangladesh

Government-to-government financing for nuclear energy development represents a financial model for nuclear financing (*see section 2.2.3*). In this approach, countries with established nuclear experience fund the construction of nuclear power plants (NPPs) in countries lacking the financial capacity for nuclear deployment (Terlikowski et al. 2019; IAEA 2021). In 2015, the Bangladesh Atomic Energy Commission (BAEC) signed a contract with AtomStroyExport – Russia's nuclear power equipment and service exporter – that amounted to $12.65 billion for the construction of two nuclear power plants (NPPs) in Bangladesh (World Nuclear Association 2021). The Russian government agreed to finance 90% of investment requirements for the construction of the NPPs, amounting to $11.38 billion.

#### 4.2.2.5 RE investment in Germany

Energy transitions within Germany represent the country's path to achieving an energy-secure, environmentally sustainable, and economically productive future (BMWK 2022). In actualizing this path, the German government have committed to fundamental shifts in the electricity sector by substituting nuclear and fossil-based energy sources for renewables (BMWK 2022). Furthermore, the nation's ambition is also evident through its revision of its renewable energy targets from 65% to 80% in its electricity mix by 2030 (Amelang and Wehrmann 2020). Investment trends are consistent with the newly adopted targets rising from €14 billion in 2021 to €20 billion in 2022 (BMWK 2023). The 2022 RE investment of €20 billion was adopted as the fifth reference case for this thesis. The conversion of this figure using the exchange rate specified in the methodology yielded \$19 billion. Table **4.7** summarizes the reference cases, their financial value, and duration.

Table 4.7: Reference cases for low-carbon energy investment in Nigeria.

| Reference Cases | Financial value ($ billion) | Duration |
| --- | --- | --- |
| Official Development Assistance to Nigeria (2021) | 3.4 | Per annum over 7 years |
| Foreign Direct Investment to Nigeria (2021) | 3.3 | Per annum over 7 years |
| Just Energy Transition Partnership | 8.5 (South Africa)<br>15.5 (Vietnam)<br>20 (Indonesia) | Over 3 – 5 years |
| Loans (from Russia to Bangladesh) | 11.4 | 8 years |
| German RE investment | 19 | 1 year |

Source: Author's own calculations based on World Bank (2023j), OECD (2023c), Barnes (2022), European Commission (2021), European Commission (2022), World Nuclear Association (2021, 2023b), BMWK (2023).

## 4.3 RQ 3: Benchmarking required scenario investments against reference cases

### 4.3.1 Comparing required scenario investments to reference cases with very similar contexts

Among the five identified reference cases (see Table **4.7**), two reference cases, the ODA and FDI to Nigeria, have very similar contexts to the required investments across the scenarios. These investments were made at the national level and the beneficiary was the Nigerian economy itself. Therefore, the need to account for contextual disparities was unnecessary. With ODA and FDI flows being annual investments, I estimated what these financial sources could provide to Nigeria by 2030 if current values remain constant over the next seven years:

$$Total\ potential\ ODA\ flows\ till\ 2030 = 3{,}400{,}000{,}000\ \times\ 7 = 23{,}800{,}000{,}000$$

**Equation 12**

Therefore, if current ODA flows remain constant, a total of \$23.8 billion could be provided by 2030 (Equation 12). A slightly lower figure of \$23.1 billion from FDI flows could flow to Nigeria if current investments are maintained. Following this estimation, I calculated Nigeria's average population size between 2022 and 2030 (Equation 13Equation 14).

$$Projected\ population\ size\ (2030) = \left(\frac{2.4\ \times\ 7}{100} \times 219{,}000{,}000\right) +\ 219{,}000{,}000$$

$$= 255{,}792{,}000$$

**Equation 13**

$$Average\ population\ size = \frac{(255{,}792{,}000 + 219{,}000{,}000)}{2} = 237{,}000{,}000$$

**Equation 14**

From Equation 14, the average population size in Nigeria between 2022 and 2030 would be approximately 237,000,000. With the estimated average population size, I normalized target (required investments across scenarios) and reference (ODA and FDI flows) cases on per capita investments to make comparisons:

$$Required\ per\ capita\ investments\ for\ second\ scenario = \frac{13{,}000{,}000{,}000}{237{,}000{,}000} = \$55$$

**Equation 15**

From the result of Equation 15, the per capita investments required to realize the second scenario (Solar PV capacity of NREAP deployed) is \$55. I repeated Equation 15 for the remaining scenarios (excluding the first) by replacing the numerator with the corresponding investment requirement. Table **4.8** summarizes required per capita investments across the scenarios.

Table 4.8: Required per capita investments across scenarios.

| Scenarios | Scenario Description | Cost ($ billion) | Required per capita investment ($) |
|---|---|---|---|
| 1 | Neither solar nor nuclear energy deployed | 0 | 0 |
| 2 | Solar PV capacity of NREAP deployed | 13 | 55 |
| 3 | Solar PV capacity of NDC deployed | 17 | 72 |

| Scenarios | Scenario Description | Cost ($ billion) | Required per capita investment ($) |
|---|---|---|---|
| 4 | Solar PV capacity of NREAP and NDC deployed | 29 | 122 |
| 5 | Nuclear power capacity of one NPP deployed | 8 | 34 |
| 6 | NREAP solar PV capacity and one nuclear power plant deployed | 21 | 89 |
| 7 | NDC solar PV capacity and one nuclear power plant deployed | 25 | 106 |
| 8 | Solar PV capacities (NDC, NREAP) and one nuclear power plant deployed | 37 | 156 |

$$Potential\ ODA\ per\ capita\ investments = \frac{23{,}800{,}000{,}000}{237{,}000{,}000} = \ \$100$$

**Equation 16**

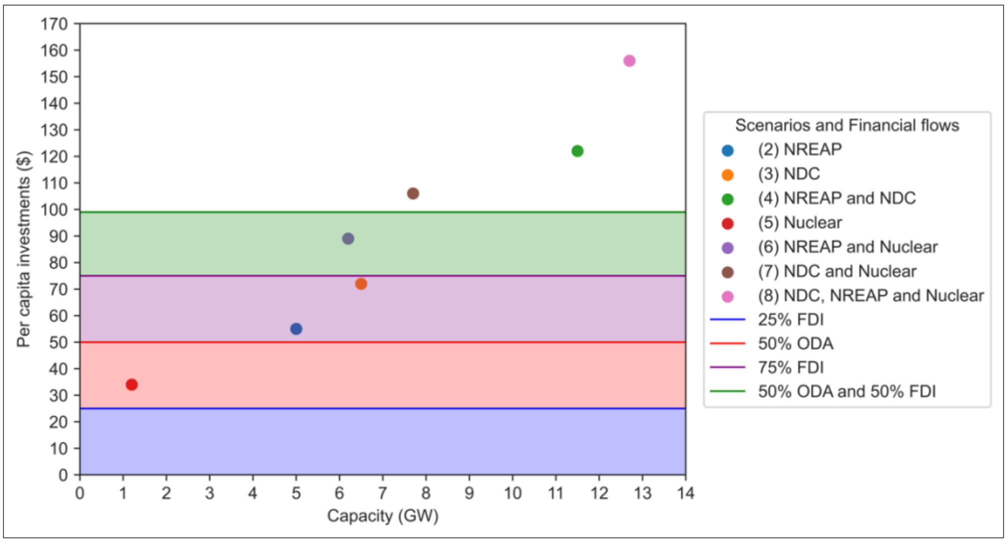
$$Potential\ FDI\ per\ capita\ investments = \frac{23{,}100{,}000{,}000}{237{,}000{,}000} = \ \$98$$

**Equation 17**

Equation 16Equation 17 reveal that potential per capita investments from ODA and FDI flows are relatively similar, with $100 and $98, respectively. Therefore, over the next seven years, ODA and FDI flows – if channelled to energy transitions within Nigeria – could provide per capita investments of $100 and $98, respectively. Given that feasibility zones enable the separation of more feasible from less feasible climate options (*see section 2.3.5*), I constructed feasibility zones to assess the feasibility of scenarios. Considering the close values of per capita

ODA and FDI investments, a mix of potential shares defined the feasibility zones[47]. Figure **4.2** presents the feasibility zones with scenarios depicted in coloured circles and the feasibility zones defined by the coloured zones (*blue, red, purple, green, and white zones*). If a quarter of per capita FDI investments ($25) are channelled to Nigeria's energy transition plan (*blue zone in Figure* **4.2**), none of the scenarios would be implementable as they require higher per capita investments. However, half of ODA per capita investments ($50) is adequate to deploy the 1.2 GW nuclear capacity in the fifth scenario (*red zone in Figure* **4.2**).

Figure 4.2: Feasibility zones defined by ODA and FDI flows.




The second (NREAP) and third (NDC) scenarios have per capita investment requirements of $55 and $72, respectively (Table **4.8**). Increasing per capita FDI investment shares from 25% to 75% would make both scenarios feasible, with the scenarios deploying 5 GW (NREAP) or



[47] The close per capita investments between ODA and FDI sources (i.e., $100 for ODA and $98 for FDI) translates into similar outcomes when compared against scenarios. For instance, a quarter of per capita ODA and FDI investments are $25 and $24.5, respectively. Therefore, the defined feasibility zones in Figure **4.2** would follow a similar pattern irrespective of what financial source defines the zones.

6.5 GW (NDC) of solar PV capacity by 2030 (*purple zone in Figure* **4.2**). Assuming half of ODA and FDI flows go into electricity generation, the sixth scenario (NREAP and nuclear) with per capita investment requirements of $89 becomes feasible (*green zone in Figure* **4.2**). For three scenarios, however, neither ODA nor FDI flows are sufficient for needed per capita investment, making these scenarios infeasible (*white zone in Figure* **4.2**). In the fourth (NREAP and NDC) and seventh (NDC and nuclear) scenarios, per capita ODA investments fall short by $22 and $6, respectively (Table **4.8**). The widest deficit occurs in the eighth scenario, where all solar and nuclear targets are met. This scenario requires per capita investments of $156, which is higher than what ODA ($100) or FDI ($98) per capita investments could provide (Table **4.8** and Figure **4.2**).

### 4.3.2 Comparing required scenario investments to reference cases with broadly similar contexts (Just Energy transition Partnerships, Loans, and German RE investment)

The previous section highlighted that two (out of five) reference cases had very similar contexts to the target cases (national-level investments within Nigeria). In this section, I benchmark the target cases against the other three reference cases with broader context similarities (national-level investments). Unlike FDI and ODA investments made into the Nigerian economy, the JETP, loans, and RE investments occurred in different economies (Table **4.7**). I made comparisons between these three reference cases and the target cases based on GDP shares. I calculated the required GDP shares to deploy the scenarios using Nigeria's 2022 GDP (World Bank 2023d) as follows:

$$Required\ GDP\ share\ for\ second\ scenario = \frac{13{,}000{,}000{,}000}{477{,}000{,}000{,}000} \times \frac{100}{1} = 3\%$$

**Equation 18**

Equation 18 reveals that a 3% share of Nigeria's GDP is required to implement the second scenario. I repeated this procedure for the remaining scenarios to derive the required GDP shares. Table **4.9** presents the required GDP shares across the scenarios.

Table 4.9: Required GDP shares to implement corresponding scenarios

| **Scenarios** | **Scenario Description** | **Cost ($ billion)** | **Required GDP share (%)** |
|---|---|---|---|
| 1 | Neither solar nor nuclear energy deployed | 0 | 0 |
| 2 | Solar PV capacity of NREAP deployed | 13 | 3 |
| 3 | Solar PV capacity of NDC deployed | 17 | 4 |
| 4 | Solar PV capacity of NREAP and NDC deployed | 29 | 6 |
| 5 | Nuclear power capacity of one NPP deployed | 8 | 2 |
| 6 | NREAP solar PV capacity and one nuclear power plant deployed | 21 | 4 |
| 7 | NDC solar PV capacity and one nuclear power plant deployed | 25 | 5 |
| 8 | Solar PV capacities (NDC, NREAP) and one nuclear power plant deployed | 37 | 8 |

Similar to the preceding step, I estimated what share of GDP the three reference cases (JETP, Russia's loans to Bangladesh, and German RE investment) accounted for in their respective countries. For example, for the JETP (South Africa) reference case, the financial value of this investment was divided by South Africa's GDP:

$$JETP\ investment\ share\ of\ South\ Africa's\ GDP = \frac{8{,}500{,}000{,}000}{406{,}000{,}000{,}000} \times \frac{100}{1} = 2\%$$

**Equation 19**

Given the above result of Equation 19, JETP investment in South Africa accounts for 2% of its GDP. I reiterated this step and derived GDP shares for the remaining reference cases by dividing their financial value by the GDP of the corresponding nation. Table **4.10** presents the results. The financial values of reference cases accounted for GDP shares ranging from 0.5% in Germany to 4% in Vietnam.

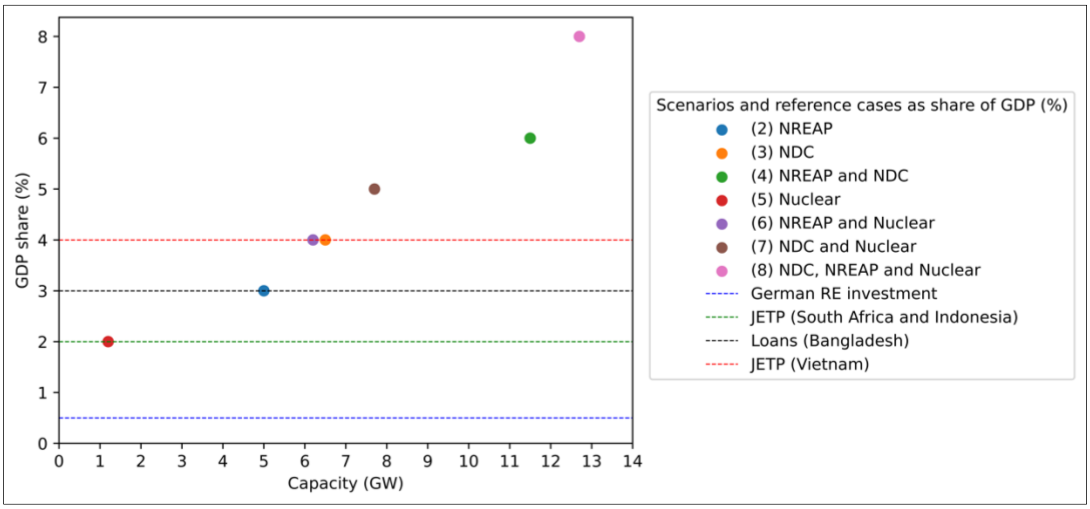
Table 4.10: Share of GDP across reference cases

| Reference Cases | Financial value ($ billion) | GDP ($) | GDP share (%) |
|---|---|---|---|
| JETP (South Africa) | 8.5 | 406 billion | 2 |
| JETP (Vietnam) | 15.5 | 409 billion | 4 |
| JETP (Indonesia) | 20 | 1.3 trillion | 2 |
| Loans (Bangladesh) | 11.4 | 460 billion | 3 |
| RE investment (Germany) | 19 | 4.1 trillion | 0.5 |

Source: Author's own calculations based on World Bank (2023e, 2023f, 2023g, 2023h, 2023i)

Figure **4.3** displays the derived GDP shares of target and reference cases. Required GDP shares of target cases (scenarios) are presented in coloured circles, while GDP shares of reference cases are represented with coloured dashed lines (Figure **4.3**). Across all GDP shares of reference cases, German RE investment accounted for the least with 0.5% (*blue dashed line*). Contrarily for target cases, the fifth scenario (nuclear) requires the lowest GDP share. To implement this scenario, the Federal Government of Nigeria (FGN) must allocate GDP shares of 2%, equalling the GDP rates of JETP investments in South Africa and Indonesia (*green* *dashed line*). GDP shares of this scenario would be four times larger than German RE investment shares. If an additional percentage by the FGN could be earmarked for energy transitions to a total of 3% for the second scenario, it would match the GDP percentage of loans to Bangladesh (*black dashed line*). Investments pledged by the International Partners Group (IPG) to Vietnam account for the largest GDP share among all reference cases at 4% (*red dashed line*). If the third (NDC) and sixth (NREAP and nuclear) scenarios, requiring the highest GDP shares in Nigeria, match the GDP share of JETP investment in Vietnam, these scenarios would be implementable.

Figure 4.3: Required investment in scenarios and reference cases as share of GDP.




The fourth, seventh, and eighth scenarios require much higher GDP shares than the observable rates of the reference cases (Figure **4.3**). For example, the seventh scenario (5%) requires ten times the GDP share of German RE investments (0.5%). Likewise, to implement the fourth (NREAP and NDC) and eighth (NDC, NREAP, and nuclear) scenarios, they must double the GDP rates of loans to Bangladesh and JETP (Vietnam), respectively.

# 5 Discussion

The previous chapter presented the results of benchmarking the target cases (required investments across scenarios) against identified reference cases. In this chapter, I discuss the efficacy of these comparisons by systematically assessing the similarities and differences between the target and reference cases to evaluate the relevance of benchmarking (section 5.1). The reference cases are analysed following the order of their presentation in section 4.2.2. In section 5.2, I construct and discuss a plausible scenario of investment flows into Nigeria's energy transition plan from the reference cases while accounting for identified limitations in section 5.1.

## 5.1 Similarities and differences between target and reference cases

### 5.1.1 Official Development Assistance (ODA)

ODA investments seek to address the development needs of developing economies. Among the development concerns of the Federal Government of Nigeria (FGN), energy security for socioeconomic development remains a priority (NREEEP 2015; National Energy Mater Plan 2022). According to the National Development Plan, the FGN seek to "unlock the country's potential in all sectors of the economy for a sustainable, holistic, and inclusive national development" (National Development Plan 2021, 3). The FGN recognize that a stable and sufficient electricity supply is essential to unlocking this potential (National Energy Mater Plan 2022). Given these considerations, the target cases (required investment to deploy electricity capacities across scenarios) represent a development need of Nigeria, which the ODA investments (reference case) seek to address.

Nevertheless, ODA investments are primarily motivated by humanitarian rather than economic development needs. This motivation reflects in the distribution of ODA investment shares across the sectors of its recipients, with higher investment shares made into human-related development needs. In Nigeria, for instance, over half of ODA investments in 2021 went into humanitarian needs (OECD 2023c). The two sectors with the highest investment shares were health and population, accounting for a third of investments, and humanitarian aid, receiving 27% of investment shares (OECD 2023c). Contrarily, economic development received about 20% of ODA investments (OECD 2023c). The economic infrastructure and services sector, presumably accounting for investments in the energy sector, comprised only 9% of ODA investments in 2021 (OECD 2023c). In section 4.3.1, I revealed that half of ODA flows between 2023 and 2030 could implement the fifth scenario. Yet, channelling half of the financial resources from ODA to energy transitions within Nigeria for seven years is unlikely, given the prioritization of humanitarian needs and disparities around sectoral shares.

### 5.1.2 Foreign Direct Investment (FDI)

Similar to ODA investments, FDI flows target the economic sectors of the receiving nation. Within Nigeria, different sectors receive FDI investments, prominently agriculture, energy, telecommunications, manufacturing, and real estate (Lloyds Bank 2023). However, among these sectors, the energy sector attracts the largest share of FDI investments (Lloyds Bank 2023). The literature review highlighted Nigeria as a rentier state, and given this characteristic, it has built relationships with multinational oil corporations like Shell, ExxonMobil, Sunlink, and TotalEnergies, its oil and gas sector is often the recipient of foreign investments (IRENA 2023b). These foreign investments within the nation's oil and gas sector serve upstream activities: exploration, drilling, and extraction of hydrocarbons. For example, between 2020 and 2022, about $1.3 billion was invested in oil and gas exploration by Shell, ExxonMobil, Sunlink, and TotalEnergies (IRENA 2023b). Given that large shares of FDI flows are invested in Nigeria's energy sector, it is broadly similar to the target cases as they represent required investments within Nigeria's electricity sector.

Despite FDI flows being broadly similar to target cases (energy sector investments going to the national economy), these investments are channelled to fossil-based energy sources rather than low-carbon technologies. This contrast in energy technology investments raises a particular issue about the FDI's function as a reference case. Section 2.2.1 of the literature review established that private investors possess high-risk perceptions of deploying low-carbon technologies like renewables in developing countries. Given these considerations, if foreign investors decide to invest in RE technologies within Nigeria, the financial values of such investments could be considerably lower than fossil-based energy investments due to risk perceptions and bankability. Therefore, FDI flows in low-carbon energy technologies may fail to be as high as investments in fossil-based energy sources.

Data on sectoral shares of FDI investments within Nigeria was scarce. To estimate the potential share of current oil and gas sector FDI investments, I derived the most recent (2017) greenfield oil and gas FDI inflows to Nigeria from Ari (2021). The share of this financial value of the 2017 FDI investment stood at 50%. Therefore, I assumed the oil and gas sector accounts for 50% of estimated FDI flows between 2023 and 2030. As ODA flows, channelling half of FDI flows to Nigeria's energy transition is unlikely. Investors like multinational oil corporations must switch from investing in oil and gas to low-carbon energy immediately to implement the fifth scenario (Figure **4.2**) [48]. Redirecting investments by these oil corporations to low-carbon energy is improbable, which I attribute to two factors. Firstly, it conflicts with their core imperative of energy provision, primarily through fossil fuels. Secondly, oil corporations like TotalEnergies and Shell aim to scale up their production portfolio of oil in Africa, with ongoing exploration across fifteen nations, including Nigeria (Ganswindt et al. 2022; Bousso 2023). As such, the interest of oil corporations remains in fossils rather than low-carbon energy. Similarly, investors across other sectors spanning agriculture, telecommunications, and manufacturing, must likewise make this switch to implement the second and third scenarios as they require 75% of FDI flows to be feasible (Figure **4.2**).

### 5.1.3 Just Energy Transition Partnerships (JETP)

The JETP, as a reference case, possesses a few similarities to the required investments across scenarios (target cases). To begin with, the JETP is principally an energy sector investment, unlike other reference cases like ODA and FDI, where investment flows into different sectors. This characteristic of the JETP being an energy sector investment closely links it to the target cases. Furthermore, the structure of JETP investments follows a North-to-South approach, given that the International Partners Group (IPG) are countries from the Global North and recipients of JETP investments are all countries within the Global South (Indonesia, South Africa, and Vietnam). Considering the target cases are required investments for energy



[48] It should be noted that Figure **4.2** displays the 50% share of ODA rather than FDI flows. However, given their close values in per capita investment ($100 for ODA and $98 for FDI), their feasibility zones are relatively the same.

transitions in Nigeria, a country in the Global South, it draws similarities with JETP recipients. Finally, JETP investments seek to address climate and development needs by replacing fossil-based energy with cleaner energy sources to ensure development follows a clean pathway within JETP beneficiaries. A similar rationale underpins the target cases as scenarios like the second, third, and fourth constitute the NDC and NREAP goals that seek to address Nigeria's climate and development priorities (*see section 4.1.1.1*).

The main divergence between the JETP and target cases is the former's focus on just transitions. Just transitions aim to protect actors within carbon-intensive energy sectors, like coal, from the impact of clean energy transitions (McCauley and Heffron 2018). These impacts often manifest through job losses for coal workers or income losses for coal companies and coal-dependent regions. Therefore, the JETP is motivated by the need to reduce coal dependence in developing economies in a socially acceptable manner (Kramer 2022). Given this motivation, the JETP is tailored to countries that rely on coal for electricity production. For instance, coal constitutes 86%, 62%, and 38% of the electricity mix in South Africa, Indonesia, and Vietnam, respectively (Our World in Data 2023a). Contrary to these nations, Nigeria's coal share in its electricity mix is less than 2% (Our World in Data 2023b). The nation's low share of coal in its electricity mix places it at odds with the imperative for JETP investment. Also, JETP investments serve as an emission-reduction mechanism in recipient countries; however, required investments across scenarios do not function to displace fossil fuels in Nigeria. These investments would deploy additional electric capacity to Nigeria's current installed capacity to meet rising energy demand. Thus, required investments across scenarios would contribute to energy additions rather than low-carbon substitution.

### 5.1.4 Russian loans for nuclear construction in Bangladesh

The beneficiary of this reference case (Russian loans) was Bangladesh which represents a developing country like Nigeria. Beyond being broadly classified as developing economies, both nations have similar financial capacities and energy security motivations. Table 4.10 shows that the GDP of Bangladesh stood at $460 billion in 2022, which was relatively close to Nigeria's 2022 GDP ($477 billion). Also, given that Russian loans were provided to Bangladesh for developing two nuclear power plants (NPPs), it further draws similarity to target cases. Across the eight scenarios, four scenarios (fifth, sixth, seventh, and eighth) deploy nuclear energy, emphasizing its similarity to this reference case.

However, financing Nigeria's energy transition through Russian loans could be difficult under current circumstances. Following Russia's invasion of Ukraine in February 2022, economic sanctions were imposed on the nation, restricting the nation's foreign and trade activities. The effects of these sanctions have also extended beyond Russia's borders to Bangladesh, the receiving nation of the loans. Due to these sanctions, Russia found it challenging to disburse loans guaranteed to Bangladesh, causing delays in the construction of the NPPs (Mahmud 2023). Nevertheless, (Szulecki and Overland 2023) find that sanctions on the nation have mainly affected its fossil industry, while its nuclear energy program has been insulated from sanctions. As such, if established relationships (*see section 2.2.3*) evolve despite current circumstances, the possibility of Russia funding nuclear energy development in Nigeria could increase.

Another consideration is whether such loans can be provided by governments other than Russia. However, there fail to be similar precedents of government-to-government nuclear financing, where Russia, through Rosatom, fails to be the exporting nation. While other nuclear cores like France and South Korea possess state-owned nuclear utilities like Russia's Rosatom, these organizations follow different financing models. Although China represents an outlier given its deployment of NPPs in Pakistan and more recent $4.8 billion agreement with the country, it remains unclear if it can play a similar role due to its nascency in using this approach compared with Russia. Moreover, the financial structure of this agreement is yet to be finalized and could potentially deviate from Russia's approach if the host nation (Pakistan) bears high shares of the cost. Given the lack of similar precedents to Russia's financing approach, Russia holds a unique position, which has been enabled by Rosatom's vertically integrated structure[49] in nuclear energy development (Szulecki and Overland 2023). Thus, given the lack of precedents similar to Russia's approach, governmental loans for nuclear financing may only be available through Russia.

### 5.1.5 RE investment in Germany

The German RE investment reference case caters specifically to the target cases, given that nearly all scenarios, excluding the first (no solar or nuclear energy deployed) and the fifth (one NPP deployed), deploy renewable energy (Table **4.3**). As such, this reference case enabled comparisons between investments made precisely in the renewable energy sector. Also, among the range of RE technologies that received investments from the German government in 2022,



[49] Rosatom can provide all services across the nuclear value chain, including training, construction, finance, non-proliferation regime requirement, and handling of nuclear waste (Szulecki and Overland 2023).

solar PV constituted the highest, accounting for almost 40% ($7 billion). Given that solar PV represents the only RE technology deployed across scenarios, the high share of German RE investments in solar PV increases its suitability as an analogy to required investment across scenarios.

Although the target cases have close similarities to this reference case through investments in the renewable energy sector, the economies in which these investments occur are inherently different. Reference case investments were made in an industrialized economy with high national income, political stability, and institutional capacity. In comparison, target case investments occur in a developing economy with lower income levels and institutional capacity, and political instability. These are factors that influence the investment that the renewable energy sector receives. As revealed in section 2.2.1 of the literature review, macroeconomic conditions within a country influence the risk perceptions of private investors in deploying renewables. The favourable macroeconomic conditions in Germany attract private sector investments in the renewable sector. However, the sub-optimal conditions within Nigeria disincentivize private sector investments in renewables. Also, Germany being a high-income country means it possesses sufficient state funds to supplement private sector investments. On the other hand, the financial capacity of the Nigerian government is far lower than the German government. Thus, it is difficult for Nigeria to deploy financial resources at levels equal to Germany.

## 5.2 Plausible scenario of investments for energy transitions in Nigeria

In constructing a plausible scenario of investments, I make assumptions about the share of investments reference cases could provide, given their identified constraints in section 5.1. For ODA investments, I assume a share of 25% of its potential financial value by 2030 (Equation 12) flows into Nigeria's energy transition plan. Although ODA investments prioritize humanitarian over economic development needs, I explore the plausibility of the Development Assistance Committee (DAC) showing an increased interest in economic priorities. Also, I assume 25% of FDI investments are made into energy transitions through the oil and gas sector rerouting half its investments into renewables rather than fossil-based energy sources.

Given that Nigeria fails to be aligned with the core imperative of the JETP (coal-use reduction in developing economies), no investments flow from the JETP in the plausible scenario. In section 2.2.3, I highlighted Nigeria's established relationship with Rosatom through the Nigeria Atomic Energy Commission (NAEC). In the plausible scenario, this relationship evolves with Rosatom providing loans equalling half of the guaranteed loans to Bangladesh. With the German government committing 0.5% of its GDP to RE investments (Table **4.10**), I assume the Nigerian government follow a similar route in the plausible scenario. Therefore, the FGN allocates 0.5% of its GDP to enable the nation's energy transition[50]. Table 5.1 presents the assumed shares across reference cases and their equivalent financial value in the plausible scenario.



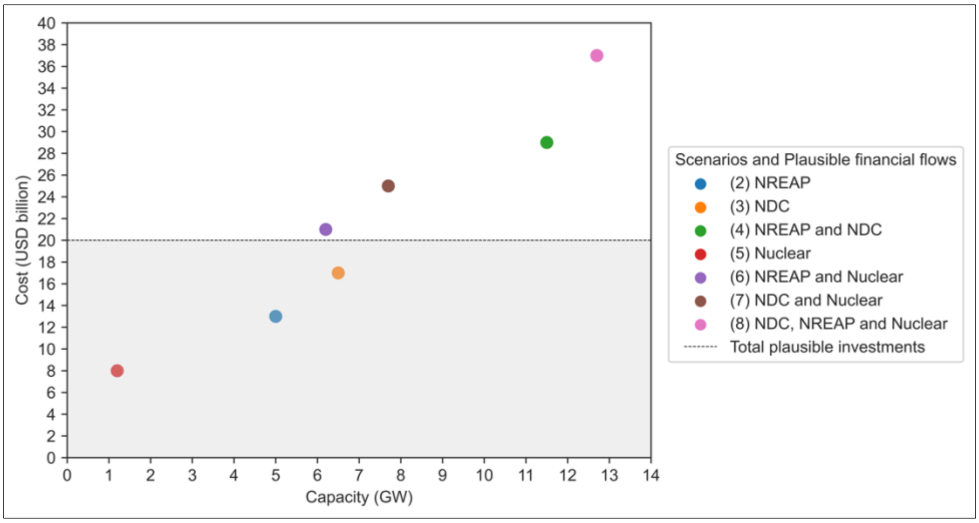
[50] It should be noted that I assessed Nigeria's financial contribution to the plausible scenario if it allocates 0.5% of its GDP for only one year over the seven-year timeframe (2023 – 2030). Also, I estimate the potential contribution using Nigeria's current GDP.

Table 5.1: Potential investment contribution of reference cases under plausible scenario.

| **Reference Cases** | **Assumed share (%)** | **Financial value/GDP ($ billion)** | **Financial value of assumed share ($ billion)** |
|---|---|---|---|
| Official Development Assistance | 25 | 23.8 | 6 |
| Foreign Direct Investment | 25 | 23.1 | 5.8 |
| Just Energy Transition Partnership (Total) | 0 | 44 | 0 |
| Russian loans | 50 | 11.4 | 5.7 |
| Nigerian RE investment (influenced by German RE investment) | 0.5 | 477 | 2.4 |
| **TOTAL** | – | – | **19.9** |

Table **5.1** provides information on the total financial value within the plausible investment scenario as ~$20 billion. With this financial value, I assessed what scenarios could be implemented by 2030. Figure **5.1** maps the target cases (required investment across scenarios) onto plausible investment from reference cases. In Figure **5.1**, scenarios are presented in coloured circles, while the total plausible investment from reference cases represents the black dashed line. Scenarios that fall below this line (*grey zone in Figure* **5.1**) represent feasible scenarios, while those above are infeasible (*white zone in Figure* **5.1**). Three scenarios would be feasible if the assumed shares across reference cases flowed into energy transitions within Nigeria. These scenarios include the second (NREAP), third (NDC), and fifth (nuclear) scenarios. Among the three feasible scenarios, none deploy both solar PV and nuclear technology due to the higher cost of deploying both technologies. These scenarios also only achieve single targets associated with solar or nuclear energy.

Figure 5.1: Feasibility zone defined by plausible investments from reference cases.




The four infeasible scenarios either comprise two targets or deploy solar PV and nuclear energy (Figure **5.1**). The fourth scenario achieves solar targets of the NREAP and NDC, while the other three (sixth, seventh, and eighth) scenarios deploy varied combinations of solar and nuclear energy capacities. The cost of the sixth scenario is slightly higher than the plausible investments by $1 billion (Table **4.6** and Figure **5.1**). The remaining scenarios, however, have a wider gap in cost than the plausible investment of ~$20 billion, ranging from $25 billion in the seventh scenario to $37 billion in the eighth scenario (Table **4.6** and Figure **5.1**). It is essential to note that the feasibility zone defined in Figure **5.1** is speculative rather than binary. For instance, the sixth scenario (NREAP and nuclear targets) is infeasible because of $1 billion. If $20 billion can be invested into Nigeria's energy transition, a slightly higher figure of $21 billion to implement the sixth scenario should also be possible given the relative similarity in financial value. Therefore, the feasibility zone should be considered speculative as opposed to being cast in stone.

# 6 Conclusions and recommendations

## 6.1 Summary

Decarbonizing the global energy system is essential to achieve global climate targets. In decarbonizing this system, countries are taking steps by transitioning from fossil-based energy sources to renewable or low-carbon technologies. Although these efforts are evident in targets and commitments across countries, achieving these targets requires significant investments. Nigeria represents a nation that has adopted energy transition targets to fulfil both climate and development priorities. However, implementing these targets would be challenging given the nation's financial constraints and lack of a robust financial structure for financing energy transitions.

This thesis thus assesses the financial feasibility of energy transition targets within Nigeria. It explores the range of possible targets that could be achieved by 2030 through scenario analysis and quantifies the investment cost required to implement each scenario. In assessing the financial feasibility of each scenario, this thesis employs the feasibility space tool: an analytical tool for assessing the feasibility of an action by its attributes, context, or implementation levels.

This thesis finds that eight possible scenarios could occur by 2030 based on Nigeria's energy transition targets associated with solar PV and nuclear energy technologies. Across these scenarios, the electric capacity that could be added to Nigeria's electricity system ranges from 0 GW to 12.7 GW. The first scenario sees no electric capacity addition to the nation's electricity system, representing a Business-as-Usual (BAU) scenario. In this scenario, the nation's rentier characteristics prevent it from deploying additional capacity from renewable and low-carbon energy sources. Contrarily, in the eighth scenario, Nigeria achieves all three targets of solar PV and nuclear technology by 2030, installing the largest electric capacity across scenarios (12.7 GW). Across the remaining scenarios (second to sixth scenarios), either one or two targets are achieved by 2030.

This thesis also reveals that investment requirements across scenarios (target cases) ranged from \$8 – \$37 billion. Beyond the sixth scenario, all scenarios showed a logical trend where a higher capacity translated into higher capital costs. Through the principles for a robust feasibility assessment coupled with estimated investment requirements across scenarios, reference cases were identified to serve as benchmarks. These reference cases included Foreign Direct Investment, Official Development Assistance, Just Energy Transition Partnership, Russian loans, and German RE investments. Comparisons between the target cases and ODA/FDI sources revealed four scenarios to be feasible but requiring half or more per capita investments flow into energy transitions within Nigeria. However, channelling high shares from these sources would be challenging given the prioritization of specific sectors. The second and fifth scenarios require similar GDP shares of Russian loans to Bangladesh and JETP investments in Indonesia and South Africa, respectively. Likewise, the third and sixth scenarios would be implementable if these scenarios equal the GDP share of JETP investments in Vietnam. Across all comparisons made, the fourth, seventh and eighth scenarios remained infeasible.

These findings enable insights into understanding potential pathways of energy transitions in Nigeria, the required costs to actualize these pathways and how feasible such costs are.

Nevertheless, the limitations of this study must be considered before drawing overarching conclusions. The feasibility assessment approach of this study draws close similarities to the outside view approach, as it employs historical precedents to create benchmarks for comparison with target cases. The limitation of applying this view is that it can be too broad-brushed, failing to identify concrete solutions or approaches to solving a challenge. For instance, in the plausible scenario of investments, theoretical assumptions could be impractical given the constraints or motivations underpinning reference case investments. The outside view is more robust for demonstrating the scale of a challenge, reflected in this thesis through the required significant shift in investment patterns of reference cases to implement scenarios.

Also, disruptions in the geopolitical conditions of Nigeria can significantly influence investment requirements across scenarios. For example, a scale-up in the Islamist insurgency in the northern region of Nigeria, which possesses the highest potential for solar energy, will undoubtedly result in higher capital costs. With private actors also holding agency in providing finance for energy transitions in Nigeria, higher risk premiums will be placed on capital costs to account for these geopolitical risks. Finally, this thesis addresses feasibility from a purely economic perspective and does not consider other dimensions of feasibility i.e., political, socio-cultural, and technical dimensions. These dimensions also influence the feasibility of scenarios as policies, social acceptance, and technological constraints may impede or enable the implementation of scenarios.

In summary, achieving energy transition within Nigeria is theoretically feasible for targets with the lowest capital costs ranging from \$8 – \$17 billion (second, third, and fifth scenarios).

However, implementing these targets requires significant effort by the Federal Government of Nigeria (FGN). Although the three scenarios with the lowest capital cost were deemed feasible in the plausible investment scenario, it is essential to note that the FGN hold little agency over ODA/FDI flows. Furthermore, Rosatom and the Nigeria Atomic Energy Commission (NAEC) have had an established relationship for over a decade; however, nuclear energy financing in the form of loans or otherwise has never been achieved. Therefore, the assumptions for the plausible scenario are optimistic. Despite these optimistic assumptions, only three out of seven scenarios are feasible, demonstrating how financing low-carbon transitions within Nigeria can be challenging. In a regional context, these difficulties would also be present across other SSA countries, given similar financial constraints. Moreover, Nigeria's economy is one of the largest within SSA, yet low-carbon transitions demand substantial effort to be implemented. Thus, achieving such transitions across other SSA nations with smaller economies would likewise demand significant effort.

## 6.2 Recommendations

This thesis makes recommendations for future research and policy. Future research can build on this study by assessing the feasibility of the three scenarios that demand the least capital cost through other feasibility lenses i.e., political, socio-cultural, and technical. Applying these feasibility dimensions to these scenarios will account for further limitations and constrain the bounds of the feasibility space to separate less feasible from more feasible low capital cost scenarios. Also, this thesis recommends more research into successful cases of attracting public and private investments for clean energy transitions in developing economies. Specifically, there is a need to identify mechanisms enabling such investments to replicate similar outcomes in Nigeria or bridge current investment gaps to clean energy transitions.

From a policy dimension, the FGN, through NAEC, could consider advancing its relationship with Rosatom. Accessing the required capital in the order of magnitude for the least-cost scenario where nuclear is achieved (fifth scenario) would be difficult from public or private sources due to social opposition (particularly within nuclear cores of the West) and risk perceptions from private investors. Furthermore, investments from private sources require financial guarantees or bankability, neither of which the FGN can assure due to financial constraints and the underperformance of its electricity supply industry. Given these considerations, Russia currently represents the most viable investment source and is more likely to finance nuclear energy rather than RE, given Rosatom's expertise. At the same time, given the current internal instability and the increasing international isolation, including through sanctions, of Russia, resulting from its war in Ukraine, this strategy is also risky.

Moreover, if the FGN is to advance its relationship with Rosatom, it must be wary of potential energy weaponization by Russia, evident through gas supply cuts across Europe after it invaded Ukraine. The weaponization of nuclear energy is particularly important given that the FGN's preference for a Build-Own-Operate (BOO) structure with Rosatom increases the nation's dependence on Russia. Therefore, if the FGN decides to develop its relationship with Rosatom for nuclear financing, a switch in preference to a Build-Operate-Transfer (BOT) structure is essential to avoid overreliance on Russia.

For the least-cost solar scenarios (second and third), this thesis recommends the development of Public Private Partnerships (PPPs), as neither public nor private investment sources would be sufficient for RE deployment. The role of the public sector would serve to de-risk and incentivize investments from private sources. Given the financial constraints within Nigeria, public actors could extend beyond the FGN to include MDBs like the World Bank. However, implementing such an initiative requires policy stringency, as evidenced in Brazil and Vietnam. These countries have created successful PPPs for RE deployment through their commitment to RE policies. Also, access to sufficient financial guarantees from MDBs like the World Bank would depend on the FGN's commitment to RE policies. Developing a PPP enables sharing of financial burdens for deploying renewables like solar while also building the relationship between public and private actors.

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