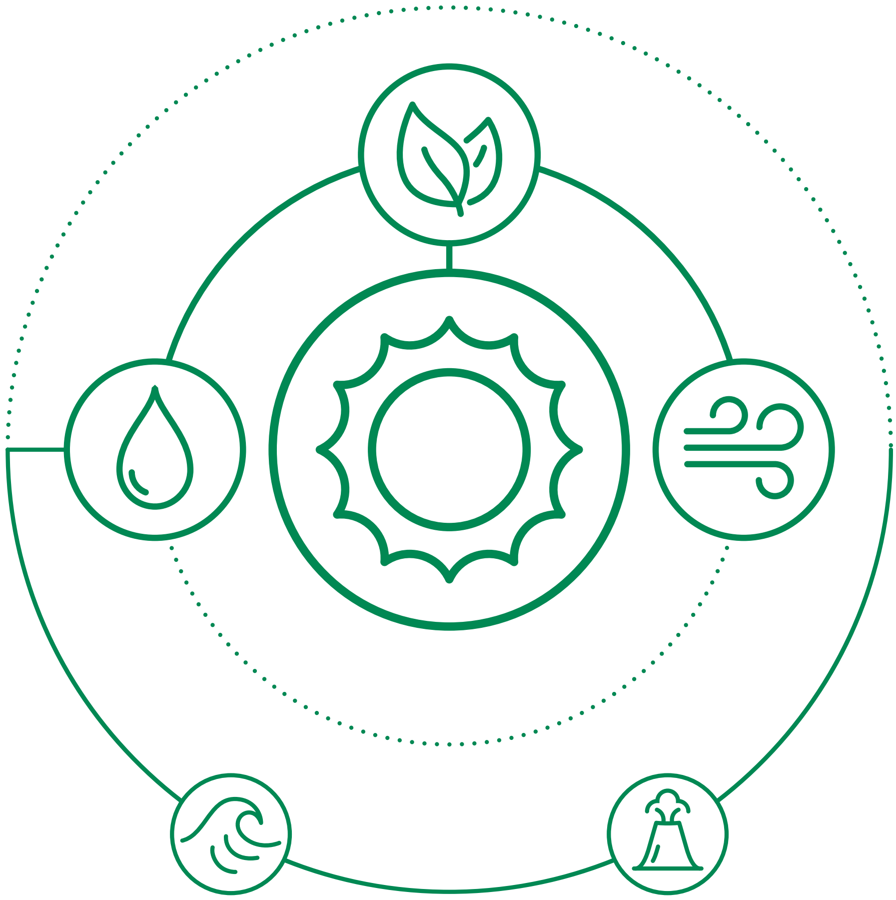
ENERGY COMMISSION OF NIGERIA

IRENA
International Renewable Energy Agency

RENEWABLE ENERGY ROADMAP NIGERIA



IRENA
International Renewable Energy Agency

ISBN 978-92-9260-477-6

Citation: IRENA (2023), *Renewable Energy Roadmap: Nigeria*, International Renewable Energy Agency, Abu Dhabi.

About IRENA

The International Renewable Energy Agency (IRENA) serves as the principal platform for international co- operation; a centre of excellence; a repository of policy, technology, resource and financial knowledge; and a driver of action on the ground to advance the transformation of the global energy system. A global intergovernmental organisation established in 2011, IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy and geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security, and low-carbon economic growth and prosperity. **www.irena.org**

Acknowledgements

This report was prepared by IRENA in close collaboration with the Energy Commission of Nigeria.

This report benefited from the input of various experts, most notably Professor Eli Jidere Bala, Dr Mikaila Zakari and Nafiu Tijjani of the Energy Commission of Nigeria. IRENA colleagues who provided valuable review and support included Ute Collier, Nopenyo Dabla, Imen Gherboudj, Asami Miketa, Mohamed Nababa, Divyam Nagpal and Sebastian Sterl.. This report was developed under the guidance of Dolf Gielen (Director, IRENA Innovation and Technology Centre).

Special thanks are due to the numerous Nigerian stakeholders and experts who took part in the national review workshops (please see full list of stakeholders in Appendix A). Technical review of this report was performed by Paul Komor and it was copy edited by Erin Crum.

Contributing authors: Seán Collins, Ricardo Gorini, Zainab Ajibade (IRENA) and Michael Dioha (Independent Consultant).

For further information or to provide feedback: **publications@irena.org**
This report is available for download: **www.irena.org/publications**

CONTENTS

FIGURES

TABLES

BOXES

ABBREVIATIONS

AUDA	African Union Development Agency
CAGR	compound annual growth rate
CFL	compact fluorescent lamp
CMP	Continental Power Systems Master Plan
CNG	compressed natural gas
CO_2	carbon dioxide
COP26	26th Conference of the Parties
CSP	concentrated solar power
DisCos	distribution companies
DNI	direct normal irradiation
ECN	Energy Commission of Nigeria
EJ	exajoules
ESMAP	Energy Sector Management Assistance Program
EV	electric vehicle
FMP	Federal Ministry of Power
GDP	gross domestic product
GenCos	generation companies
GW	gigawatt
GWh	gigawatt hour
IAEA	International Atomic Energy Agency
IRENA	International Renewable Energy Agency
kt	kilotonne
kWh/m^2	kilowatt hours per square metre
LED	light-emitting diode
LPG	liquefied petroleum gas
m	metre
MESSAGE	Model for Energy Supply System Alternatives and Their General Environmental Impacts
MJ/m^2	megajoules per square metre
Mt	million tonnes
Mtoe	million tonnes of oil equivalent
MW	megawatt
NADDC	National Automotive Design and Development Council
NBS	National Bureau for Statistics
NDC	Nationally Determined Contribution
NEEAP	National Energy Efficiency Action Plan
NEMP	National Energy Master Plan
NEP	National Energy Policy
NEPAD	New Partnership for Africa's Development
NGN	Nigerian naira
NREAP	National Renewable Energy Action Plan
NREEEP	National Renewable Energy and Energy Efficiency Policy
O&M	operation and maintenance
PES	Planned Energy Scenario
PHCN	Power Holding Company of Nigeria
PJ	petajoules
PV	photovoltaic
RE	renewable energy
REmap	Renewable Energy Roadmap
REMP	Renewable Energy Master Plan
RESIP	Rural Electrification Strategy and Implementation Plan
RPO	renewable portfolio mechanism
s	second
SDG7	Sustainable Development Goal 7
SEC	specific energy consumption
SEforALL	Sustainable Energy for All
SMEs	small and medium-sized enterprises
SPLAT	System Planning Test
TCN	Transmission Company of Nigeria
TES	Transforming Energy Scenario
TFEC	total final energy consumption
TIMES	The Integrated MARKAL-EFOM System
TJ	terajoule
TV	television
TWh	terawatt hour
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
VRE	variable renewable energy

FOREWORD

Francesco La Camera

Director-General

International Renewable Energy Agency

The Federal Republic of Nigeria is the most populous country in Africa and the largest economy on the continent. The country is expected to experience rapid economic growth in the coming decades, leading to a significant increase in energy use. Nigeria has therefore reached a vital juncture at which it must decide whether to maintain its reliance on fossil fuels – accepting the inevitable environmental and economic risks that path entails – or capitalise on its ample indigenous renewable energy resources to drive economic development, decrease energy costs and significantly reduce its greenhouse gas emissions.

This renewable energy roadmap for Nigeria was developed in collaboration with the Energy Commission of Nigeria and offers a long-term perspective to 2050 guided by IRENA's *World energy transitions outlook*.

As Nigeria commits to ever more ambitious climate targets, including net-zero commitments, planning must begin now in earnest. Nigeria has a unique opportunity to develop a sustainable energy system based on renewable energy resources that can support socioeconomic recovery and development while addressing climate change mitigation and adaptation strategies, and accomplishing energy security, universalisation and affordability goals.

This report provides a comprehensive renewables-focused energy pathway for the development of a cleaner and more sustainable national energy system. It explores end-use sector electrification, the rapid expansion of renewable generation, energy efficiency solutions, the role of emerging technologies as well the importance of expanding power sector integration. It also presents sector specific technological pathways and investment opportunities that will enrich the regional debate and help accelerate the energy transformation across Nigeria.

Accelerating the energy transition will require far-sighted choices, discipline and wise investments, backed by international co-operation and strong national planning in Nigeria. IRENA stands ready to work with Nigeria and our close national partners to help make the vision presented in this report a reality.

FOREWORD

Senator (Dr) Adeleke Olorunimbe Mamora

Honourable Minister

Federal Ministry of Science, Technology & Innovation

Federal Republic of Nigeria

Sustainable energy is the driver of modern development. Availability of adequate, reliable, sustainable and cost-effective energy is important for the socio-economic development of any nation. Given Nigeria's progress in this regard, it is necessary to continue identifying options for scaling-up sustainable energy supply to achieve Sustainable Development Goals (SDGs) in the country. The International Renewable Energy Agency (IRENA) has developed this Renewable Energy Roadmap (REMap) for Nigeria through the Energy Commission of Nigeria and in collaboration with energy professionals and relevant Ministries, Departments and Agencies in the country. By providing this thorough assessment, it is hoped that individuals, firms and governments can be encouraged to embrace renewable energy to benefit the national economy and the lives of the Nigerian people.

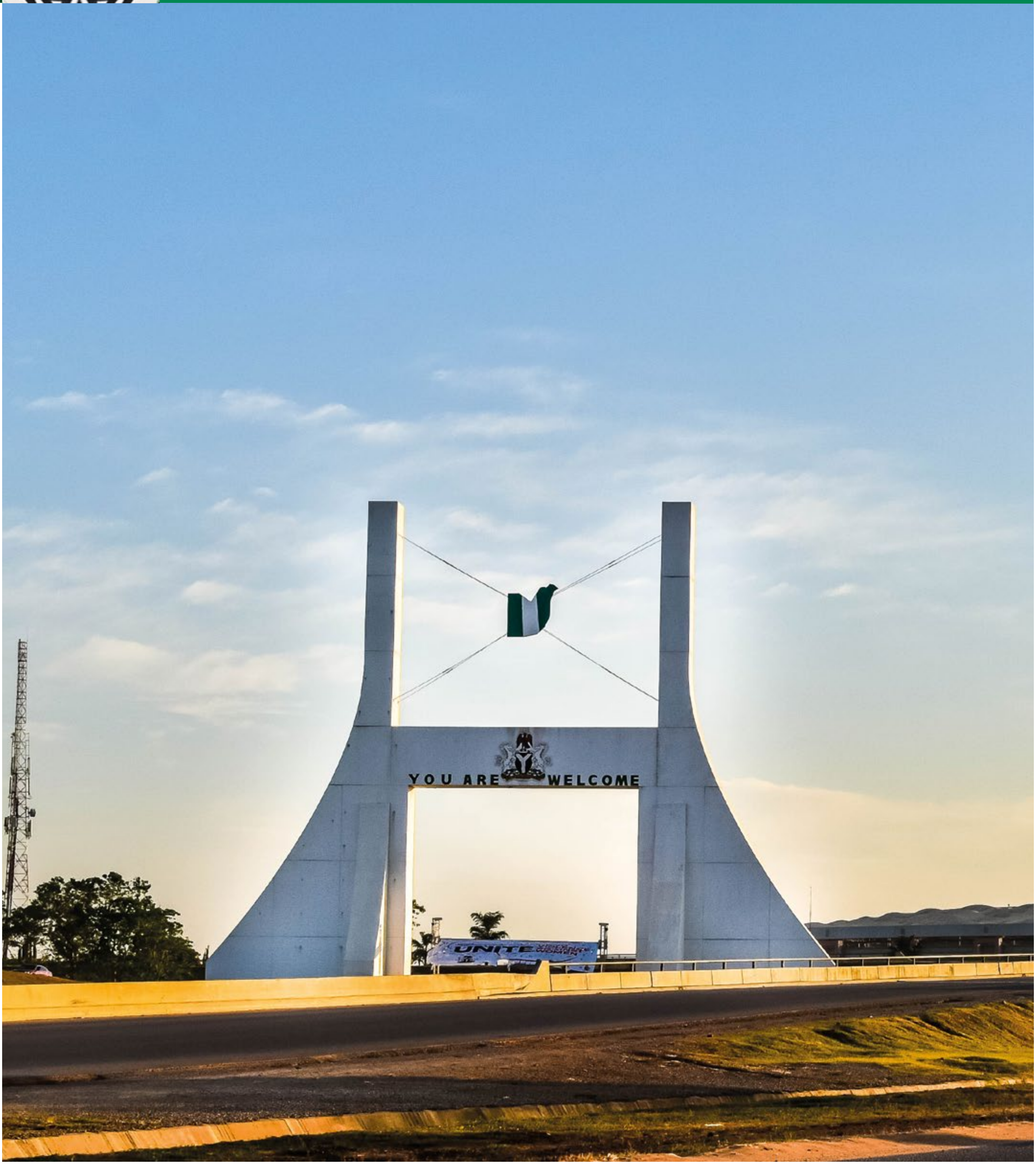
Nigeria is endowed with abundant renewable energy resources - namely solar, wind, hydro and biomass - that can be harnessed to scale up its energy supply and achieve universal energy access, energy security and the reduction of greenhouse gas emissions for climate change mitigation. Energy consumption in the country is expected to continue to increase due to a rising population and improvements in the socio-economic life of the people.

This report demonstrates how the renewable energy resources of Nigeria can be integrated and scaled-up to achieve a sustainable energy mix - both on- and off-grid - while meeting growing energy needs to support the country's development. It provides analysis of the energy types and quantities currently utilised in all sectors of the economy, namely residential, commercial, industry, agriculture and transport. It also predicts how energy types and quantities may evolve in two scenarios up to 2050.

This assessment is timely, given the Government of Nigeria's commitment to reducing its greenhouse gases by 20% unconditionally and 47% conditionally by 2030, as well as to reach net-zero emissions by 2060, as expressed by at COP26 in Glasgow in 2021.

This contribution to Nigeria's efforts to increase the share of renewable energy in its energy mix is highly appreciated, and will be useful in reviewing the national energy policy and strategic energy plans, as well for academics, consultants and investors interested in improving access to clean energy sources for various applications in Nigeria.

KEY FINDINGS AND MESSAGES



Key findings and messages

Nigeria is at a key juncture in time; with a growing population and a range of socio-economic challenges, it requires sustainable energy sources to meet the growing needs for all the sectors of its economy and achieve universal access to modern energy services. This report demonstrates how renewable energy technologies will be key in achieving a sustainable energy mix and meeting the growing needs of the country.

Universal provision of energy services for cooking and power are key objectives of national energy policies, in addition to priorities of energy affordability, energy security, and reduced air pollution and carbon dioxide (CO_2) emissions. Renewable energy sources can be a driving force in achieving all these goals because they are some of the lowest-cost energy sources today and are domestically abundant and less polluting than conventional or traditional sources of energy.

This study shows how, under current plans and polices, Nigeria will experience substantial increases in primary energy requirements and CO_2 emissions. However, the analysis also shows that various economic growth rates over time imply the need for structural changes in the economy as well as for induced shifts in the patterns of end-use demands. The study presents how an increased renewable uptake scenario, named the Transforming Energy Scenario (TES), sees future capacity expansion of Nigeria's electricity supply system provided largely by renewables, which reduces primary energy requirements (because most of the renewables deployed are more efficiently converted to useful energy than fossil fuels) and greenhouse gas emissions in tandem with increased electrification compared with the Planned Energy Scenario (PES), which represents what would occur under current and planned policies. Key results and actions needed to reach the ambition are presented in Table 1.

In the TES, **the share of primary energy requirements met with renewable energy reaches 47% by 2030 and 57% by 2050**. In terms of **final energy consumption** this corresponds to a renewable share of **52%** by 2030 and **59%** by 2050. Electrification plays a significant role in achieving this renewable energy share with the share of electricity in final energy use nearly doubling by 2050 to **27% from 2015 levels, in addition to other modern energy forms.**

Investment in renewables is more cost-effective than the conventional pathway. The TES **has lower investment costs** than the PES, USD **1.22 trillion (2010)** compared with USD **1.24 trillion (2010)**, while delivering the same energy service. In terms of average annual investment values, this corresponds to USD **35 billion USD (2010) per year** compared with USD **36 billion USD (2010) per year**. This shows that investment in renewables is cost-effective – it is cheaper than the planned case, regardless of the economic growth rate achieved. Therefore, by using its abundant and largely untapped renewable energy resources, Nigeria could provide sustainable energy for all its citizens in a cost-effective manner. However, the study also shows that under very high economic growth (10% annual gross domestic product [GDP] growth rate), current energy policies would be insufficient to meet the total electricity needs of Nigeria by 2050, with substantial shares of distributed oil-based generation needing to remain in the Nigerian electricity supply mix.

Achieving the TES will require a **shifting of and scaling-up of investments** in Nigeria in the short term to **avoid fossil fuel lock-in infrastructure investment** with long lifetimes such as natural gas pipelines. In the year 2050, in terms of primary energy requirements, the TES uses **over 40% less natural gas** and **65% less oil than** the PES, which has a profound implication for infrastructure investments for these uses of resources. The risk of stranded assets is substantial, especially given the cost, price stability and energy security benefits of renewables in comparison with fossil fuels. Fossil fuels are often touted as bridging fuels in the energy transition, but the end destination of this bridge is often neglected.

Improvement upon existing efforts to promote clean cooking and access to modern forms of energy are needed. **Traditional bioenergy plays a large role** in the energy sector of Nigeria, meeting nearly half of final energy consumption in 2015. Achieving universal energy access by 2030 has the potential to alter the final energy demand composition of Nigeria. In 2015, the base year, the buildings sector accounts for the largest energy consumption. However, its share in total final energy demand gradually diminishes as universal modern energy access is also gradually being realised to 2030. This is pivotal in **reducing the share of traditional bioenergy in final energy consumption to 42% by 2030 and just 15%** by 2050. Cooking is the most energy-intensive activity in the buildings sector today, but as the use of inefficient traditional biomass stops and households transition to efficient cookstoves by 2030 and beyond, the share of the residential sector in total final energy drops substantially. This sees the residential sector overtaken by the transport and industry sectors on account of the magnitude of growth expected in these sectors in the future. Should traditional biomass be considered as renewable energy, then modern energy access has the capacity to reduce the share of renewables in household fuel mix. However, this must be carefully considered in terms of efficiency of the stoves and effects of air pollution. This study shows that to promote renewable energy in the Nigerian residential sector, there is a need to diversify the cooking mix with electricity and modern renewables that are convenient for cooking in a way that is comparable to or even better than liquefied petroleum gas (LPG).

Expansion of existing appliance efficiency and lighting programmes is needed. In the TES, the share of **efficient lighting, refrigerators and air conditioners** rises in both rural and urban households up to **50%** by 2030 and to **100%** by 2050. This scenario in 2050 sees an increase in household income level which need not increase energy demand. This ambitious scenario demonstrates how a shift towards the adoption of energy-efficient technologies can reduce the overall energy requirement of the sector.

An acceleration of electricity capacity additions, especially distributed solar photovoltaic (PV), in the power sector will be key to unlocking Nigeria's renewable energy resources. Regular outages in the centralised power system combined with frequent natural gas and water shortages for generators mean that system peak power capacity is substantially below the rated capacity of the system. This has led to a high reliance on costly distributed oil-based power generation with profound implications for air quality, economic cost of unreliable electricity and expensive backup. The TES shows how this need not be the case and how the benefits of Nigeria's wealth of solar resources can be unlocked.

Total installed power generation capacity needs in the TES reach **62 gigawatts (GW)** in 2030 and **178 GW** in 2050, of which **77%** is renewable in 2030 and **92%** is renewable in 2050. Solar PV capacity is a "no-regrets" investment in this scenario, reaching **32 GW** in 2030 and **115 GW** by 2050 in the central TES. In terms of electricity generation shares, this corresponds to **70%** by 2030 and **84%** by 2050. Fostering innovative **financing mechanisms** for distributed renewables and utility-scale technologies such as blended finance and microfinance will help deliver this, especially in the **substitution of diesel generators by solar home kits and mini-grids,** which have a higher upfront cost but significantly lower operation cost. This will combine favourably with increased electrification of various end uses, further driving down the energy intensity of demand sectors with some of the lowest-cost power available on the market today.

Hydropower will also be key in balancing the centralised power system by offering flexibility to mitigate solar power variability. The TES sees **hydropower reaching 13 GW in 2030 and 15.5 GW** in 2050. Despite having relatively larger installed capacities in the TES, electricity generation under current and planned policies remains larger because renewables, such as solar PV, are constrained by the resources underpinning them. The TES shows that there is further scope to improve energy efficiency beyond the levels envisaged under current and planned policies. This energy efficiency will be key in pivoting the Nigerian economy towards high-innovation sectors using domestic energy renewables and energy-efficient technological options, especially solar PV power driven electrification of end use.

Faster adoption of biofuels and electric vehicles (EVs) when combined with an increased role for public transportation, will help to sustainably meet growing transportation demand. Nigeria has a biofuel policy but lacks a dedicated EV policy and will need substantial expansion of the power sector and its reliability to facilitate a reliable shift to EVs. The share of electric private cars could reach **10%** by 2030 and **35%** by 2050 in the TES, while biofuel-based private cars could account for **20%** in 2030 and **25%** in 2050. A major challenge to the implementation of alternative fuels in

Nigeria's transport sector is the lack of availability of the fuels, which thereby reduces the choices available to Nigerian consumers. The penetration of EVs here in this study rely on a reliable power sector with significant reinforcement of the transmission system in tandem with off-grid renewables expansion. The TES also sees significant modal shifts: **20% of private car demand shifts to public transport; 40% of interstate passenger road movement and 40% of freight shift to rail**. This scenario also sees these being enhanced by significant amounts of renewable energy, with **40% of trains and 35% of buses being electric by 2050**. Expansion of the railways could facilitate much of this modal shift; however, this would necessitate large infrastructure and upfront investment costs. This modal shift would best be accompanied by a corresponding increase in renewables-driven transportation sources.

Nigeria would benefit from the promotion of the adoption of solar process heat in large industries where it could deliver a reliable supply of thermal energy and reduce local air pollution. Industrial clusters should be promoted in policy so that multiple small and medium enterprises can derive process heat from a few solar thermal installations. In the TES, these technologies could serve up to **8% of industrial energy demand by 2030 and 29% by 2050**. This would also play a significant part in reducing the role of traditional bioenergy in the sector. Also, electric process heat provided via renewables should be encouraged for industries that lack the capacity to adopt solar thermal systems.

Efficient irrigation pumps and tractors in the agriculture sector should be promoted to improve energy security by reducing the impact of internal fuel price volatility on the sector. Awareness of solar irrigation pumps and their associated benefits needs to be promoted, especially in rural areas. Polices also need to be developed and promoted for the technologies that underpin the TES to deliver higher efficiency and renewable energy use in this sector to encourage their adoption by farmers. Key will be the promotion of solar-based irrigation pumps, which reach penetrations in irrigation of **15%** by 2030 and **50%** by 2050 in this scenario, in addition to the share of biofuel and electric tractors, which combined reach **25%** by 2030 and **60%** by 2050.

Irrespective of the level of GDP growth, CO_2 emissions are on an upward trend. Energy sector CO_2 emissions were about **119 million tonnes (Mt) per year** in 2015 and in the PES rise rapidly to **516 Mt per year** by 2050. In the TES these grow much more slowly to **189 Mt per year** by 2050. Additionally, it is shown in 2030 that the dominant source of CO_2 emissions in the country shifts from the power sector to the transport sector, clearly identifying the sector which should be prioritised for emissions mitigation measures in the future.

Overall, policies for accelerated deployment of renewables are needed, but careful selection of technologies is needed to unlock the benefits achieved in this study. Also, the highly distributed institutional structure of the energy sector in Nigeria means that **co-ordination of policies will be essential to unlocking integrated energy transition planning and ensuring its success**. A cross-cutting agency or body tasked with doing so would be helpful in building consensus and developing a coherent plan which in turn would allow for the scaling-up of renewable energy to meet the needs across the Nigerian energy sector.

Table 1 Key results of the analysis for Planned and Transforming Energy Scenarios and key actions needed to achieve the Transforming Energy pathway

		Where the present plans lead		Where a renewables-driven pathway can go		Actions to achieve this ambition
	2015	**2030 PES**	**2050 PES**	**2030 TES**	**2050 TES**	
Renewable energy share in final energy (includes traditional bioenergy)	48%	43%	40%	52%	59%	· Integrated energy transition planning by a cross-cutting body needs to be developed for coherent planning and achieving a higher share of renewables across the energy sector, especially for the promotion of modern renewables and reduction of traditional bioenergy use (which while on a decreasing trend as a share of energy demand in PES, is outpaced by demand growth that sees higher consumption by 2030 and 2050 unless alternative policies are adopted)
Modern renewable energy share in final energy (excludes traditional bioenergy)	1%	8%	10%	23%	44%	
Electrification share of final energy	16%	19%	18%	22%	27%	
Renewable energy share in power generation	9%	36%	42%	70%	84%	· Attract foreign and domestic direct investments with a targeted focus on renewables and de-risking investments · Develop financing mechanisms for distributed renewables and technologies such as microfinance · Develop partnerships with the Central Bank of Nigeria, Rural Electrification Agency and original equipment manufacturers for increased electrification and research and development · Optimise access to affordable power and clean energy and promote local content participation know-how across the value chain
Variable renewable energy share in power generation	1%	18%	19%	34%	44%	
Total power generation capacity, both utility and off-grid (GW)	33 GW	56 GW	136 GW	62 GW	178 GW	
Solar – Utility (GW)	Negligible	5 GW	25 GW	10 GW	40 GW	
Solar – Off-grid (GW)	0.8 GW	13 GW	29.5 GW	21.2 GW	75 GW	

	2015	Where the present plans lead: 2030 PES	Where the present plans lead: 2050 PES	Where a renewables-driven pathway can go: 2030 TES	Where a renewables-driven pathway can go: 2050 TES	Actions to achieve this ambition
Hydropower (GW)	2 GW	5.9 GW	13 GW	9.2 GW	15.5 GW	· Reinforce the transmission grid with additional loops and expanded wheeling capacity to improve system reliability · Technology and skills capacity building and transfer for development and roll-out of renewable power sector technologies and infrastructure
Battery storage capacity (gigawatt hours [GWh])	0.8 GWh	13 GWh	29.5 GWh	21.2 GWh	75 GWh	
Renewable energy share in transport	0%	2%	7%	16%	39%	· Technology transfer and capacity building for infrastructure development · Financing and investment for infrastructure of all modes of EVs · Create a dedicated EV policy
Number of electric cars	Negligible	Negligible	Negligible	2.8 million	28 million	
Number of efficient modern bioenergy cookstoves	Negligible	6.5 million	11 million	12 million	33 million	· Creation of awareness campaigns across all regions and communities to address the acceptability and scaling-up of all clean cooking technologies · Capacity building and training in terms of anaerobic digestion for home and community-based biogas digesters
Number of electric cookstoves	2.5 million	3 million	11.7 million	7.8 million	35 million	
Renewable energy share in industry (excluding traditional biomass)	1%	2%	2%	14%	36%	· Promote the adoption of solar and electricity-derived process heat in large industries
Number of electricity-powered pumps in agriculture (grid and off-grid)	700	2 100	9 600	4 500	22 100	· De-risk agricultural lending to increase energy access and efficiency in food production for sustainable development

01 INTRODUCTION

Introducction

The Federal Republic of Nigeria is the most populous country and largest economy on the African continent. It is home to one of the fastest-growing populations globally, which has led to a rapidly increasing demand for energy services that will be key to unlocking economic development. This presents a substantial opportunity to develop the rich natural renewable energy resources of the country and unlock low-carbon growth.

Nigeria is a lower-middle-income developing country which has shown its commitment to the global transition to a sustainable energy future and increasing its share of renewables in the energy mix. Nigeria signed and ratified the Paris Agreement, a landmark agreement to reduce global greenhouse gas emissions to limit global temperature increase to below 2°C and has made commitments to develop its energy system in line with these goals. In its recent revision of its Nationally Determined Contribution (NDC) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) as part of the Paris Agreement, Nigeria has pledged an unconditional 20% reduction on emissions in a business-as-usual scenario by 2030, and an upward revision of its conditional reduction pledge from 45% to 47% dependent on sufficient financial assistance, technology transfer and capacity building. In addition, at the 26th Conference of the Parties (COP26), Nigerian President Muhammadu Buhari pledged that Nigeria will cut emissions to net zero by 2060.

The post-COVID-19 recovery will need to balance meeting these goals with the substantial development challenges facing the country in order to achieve sustainable growth and development. Improving access to modern forms of energy and the high levels of unemployment remain key barriers to economic development and are the primary focus areas for the government in its pursuit of a prosperous future for the nation. Thus, the strategies set out in the Nigerian NDC were written with a view to addressing all these challenges while simultaneously mitigating emissions growth. These strategies spanned the whole energy system of the country and included 13 gigawatts of decentralised solar photovoltaic in addition to improvements in the energy efficiency in the power, residential, commercial, industry and transport sectors.

Achieving these goals would lead to considerable changes in the national energy system and would shape the investment decisions over the coming years. Nigeria has large renewable potential and has already made some promising strides towards increasing domestic deployment of renewable energy. Nigeria has the potential to play an important role in the global energy transformation. The International Renewable Energy Agency (IRENA) and the Nigerian Energy Commission collaborated on this Renewable Energy Roadmap project, also referred to as REmap Nigeria, to explore how best to unlock the country's renewable energy potential while also ensuring tremendous sustainable growth.

This study analyses the additional renewable energy deployment potentials out to the year 2050 in close consultation with key stakeholders, with an additional 2030 focus to aid shorter-term policy development, across the Nigerian energy system and as a result provide additional context for energy policy discussions of how increased ambition in terms of renewable energy, beyond the current government policy and targets, can be realised. This analysis expressly does not aim to replace national energy sector planning, but rather seeks to further inform it with an expansive analysis of realistic renewables deployment potential and provide input to further national energy sector ambition.

1.1 The REmap process

IRENA developed the Renewable Energy Roadmap (REmap) programme (IRENA, 2014) in response to requests from members for assessment and determination of strategies and pathways to increase the share of renewable energy in energy systems.

REmap focuses on identifying the long-term realistic potentials of renewable energy to the year 2030 and 2050 in all parts of the energy system. This process quantifies related costs and investment requirements and assesses its contribution and climate objectives. It is a simple and transparent analysis of technology options that quantifies the potential of renewable energy by end-use sector for the countries and regions to which it is applied. This approach is often linked with a variety of dedicated sectoral models to help analyse the pathways developed in terms of different end-use and transformation sectors. The choice of an options approach is deliberate, as REmap is an exploratory study of additional renewable energy potential. Its core strength lies in its consultative and collaborative nature where the renewable energy roadmap is developed in collaboration with and evaluated by energy sector stakeholders in the country or region in question. IRENA has conducted country-level REmap analyses and has prepared country reports for the People's Republic of China, Ethiopia, Germany, Mexico, Poland, South Africa, Ukraine, the United Arab Emirates and the United States, among others.

The country analyses follow the approach of:[1]

---

[1] *All the REmap related material and methodology are available for download at www.irena.org/remap. There is also a detailed overview of REmap methodology, sources and papers available on the website.*

- Building the **Planned Energy Scenario (PES);** this represents the baseline for energy demand and fuel mix out to 2030 based on current policies and strategies at country level, including targets for renewables.

- Determining technology options based on renewable potential (based on theoretical overall resource potentials and both technical and economic factors that constrain deployment) realisable to 2030. These are called **REmap Options** and serve to substitute for conventional technologies that are considered in the PES.

- Assessing **REmap Options** for electricity and heat production, energy end use in industry and buildings (*i.e.* residential, commercial, public), and for the transport sector. The sum of the options results in a new energy mix, which is called the **Transforming Energy Scenario (TES)**.

Throughout this analysis, the renewables share is determined in relation to total final energy consumption (TFEC).[2] End-use sectors comprise the following:

- **Buildings:** include the residential, commercial and public sectors. Renewable energy is used in direct applications for heating, cooling or cooking purposes, or as renewable electricity.

- **Industry:** refers to downstream industrial activities only such as the manufacturing sector, where renewable energy is consumed in direct use applications that comprise mainly process heat, and as electricity from renewable sources.

- **Transportation**: which can make direct use of renewables through the consumption of liquid and gaseous biofuels, or through use of electricity generated from renewable energy technologies.

- **Other sectors**: including agriculture (including fisheries and forestry), mining and construction.

The REmap analysis in the case of this study was strongly guided by local stakeholders including both the IRENA focal points at the Energy Commission of Nigeria, from which there was strong collaboration throughout, and the outcome of stakeholders' consultations held in Abuja in January 2020. The analysis at every stage has been presented and discussed to make sure the resulting analysis fits the national context and realities facing the country. Not only does it help with the suitability of the study but its participatory nature offers genuine local input to the work and meaningfully shapes its results. This is core to the application of the REmap process and was influential throughout the modelling process. Additionally, the REmap approach often involves analysing the impact of differing growth rates on the PES, REmap Options and the subsequently derived TES.

[2] *TFEC is the energy delivered to consumers, whether as electricity, heat or fuels that can be used directly as a source of energy. This consumption is usually subdivided into that used in: transport; industry; residential, commercial and public buildings; and agriculture; it excludes non energy uses of fuels.*

1.2 Scenario definitions for Nigeria

Planned Energy Scenario (PES)

The PES is essentially the primary reference case for this study, providing a perspective on energy system developments based on current national energy plans and other planned targets and policies, including Nigeria's NDC under the Paris Agreement. The PES is based on existing policy and plans, with no other substantial measures. Energy and environmental policies influence future energy demand and supply trends. The Nigerian government has a long history of developing sound policies but has faced challenges in establishing implementation mechanisms. Over the years, several policies and programmes have been developed for the energy sector. Here, it was assumed that the various programmes outlined in the Nigerian energy/climate policies will be realised.

Transforming Energy Scenario (TES)

The TES describes an ambitious, yet realistic, energy transformation pathway based largely on renewable energy sources and steadily improved energy efficiency (though not limited exclusively to these technologies). This could set the energy system on the path needed to keep the rise in global temperatures to well below 2°C and towards 1.5°C during this century. The TES proposed by this study is aimed at expanding the current scope of renewable energy development in the country well beyond the stated capacities outlined in the national energy policy frameworks. While an understanding of current national plans and recent national developments was derived in the PES, an understanding was also gained as to how renewables can play a more significant role than envisaged in these plans, which still feature significant levels of fossil fuel reliance. This scenario serves to maximise the use of renewable energy technologies across the energy system in a transformative and cost-effective manner with many benefits that extend well beyond the energy sector. Furthermore, in the TES, assumptions are made on the end-use technologies in terms of new technologies penetration as well as improvements in the efficiency of the existing stock. The PES and TES are very different scenarios; the TES seeks to provide a realistic assessment of how renewable energy can be increased beyond current plans with many secondary benefits. The TES does not intend to replace the PES; rather, it seeks to provide an alternative development pathway strongly based on renewable energy technologies and can serve as context to further inform existing or planned energy policies.

02 MODELLING METHODOLOGY AND KEY ASSUMPTIONS

Modelling methodology and key assumptions

2.1 Modelling methodology and socio-economic assumptions

Each Renewable Energy Roadmap (REmap) study is a bespoke process using the data and tools best suited to the needs of the study. This is also the case for the REmap Nigeria analysis, where data sources, methods and models were chosen to make the best use of the data available to present a renewable energy pathway that explores the potential for further renewable energy deployment. This section serves to outline the methodology and key assumptions for the study, which are elaborated in more detail in Appendix B.

The overall approach employed in this study was to use an integrated energy system model to analyse how Nigeria's growing energy service demands can be supplied under various scenarios out to 2050. This study largely relies upon energy system analysis using TIMES (The Integrated MARKAL-EFOM System) modelling framework for Nigeria (Loulou, Remme, *et al.*, 2005; Loulou, Remne, *et al.*, 2005). The main output of TIMES are the energy system configurations to meet energy service demands, which are exogenous to the model and further detailed in Appendix B. The model determines values for primary energy supply, final energy consumption, energy flows, greenhouse gas emissions, capacities of technologies and marginal emissions abatement costs based on an assumed set of cost parameters and demand projections.

On the demand side of TIMES-Nigeria model, econometric models were developed based on various macroeconomic drivers that are used to understand the changing patterns of end-use demands. The macroeconomic form of any country serves as the basis of its development trajectory and also plays a key role in determining its future energy demand trajectory and corresponding emissions. Population and gross domestic product (GDP) are the key forces influencing the patterns of growth, production and consumption choices in an economy. The GDP trajectories used in this study were requested at the REmap workshop held in Abuja in January 2020 with key stakeholders spanning the Nigerian energy sector and the Honourable Minister of Science and Technology to help enable a deeper understanding of scenarios developed. The implications of these results were further discussed and validated at the final review workshop held in Abuja in late 2022. The central scenario used for this study is 7% per year annual growth rate (a rate which was decided upon in consultation with stakeholders) with two additional growth rate scenarios also considered with a 5% per year average growth pessimistic case and 10% per year average growth optimistic case. Demand driver analysis is imperative to examine the associated costs and benefits of undertaking alternative choices and understanding the macroeconomic implications on the economy. Accordingly, this study examines how these drivers may influence final energy consumption in the Nigerian economy.

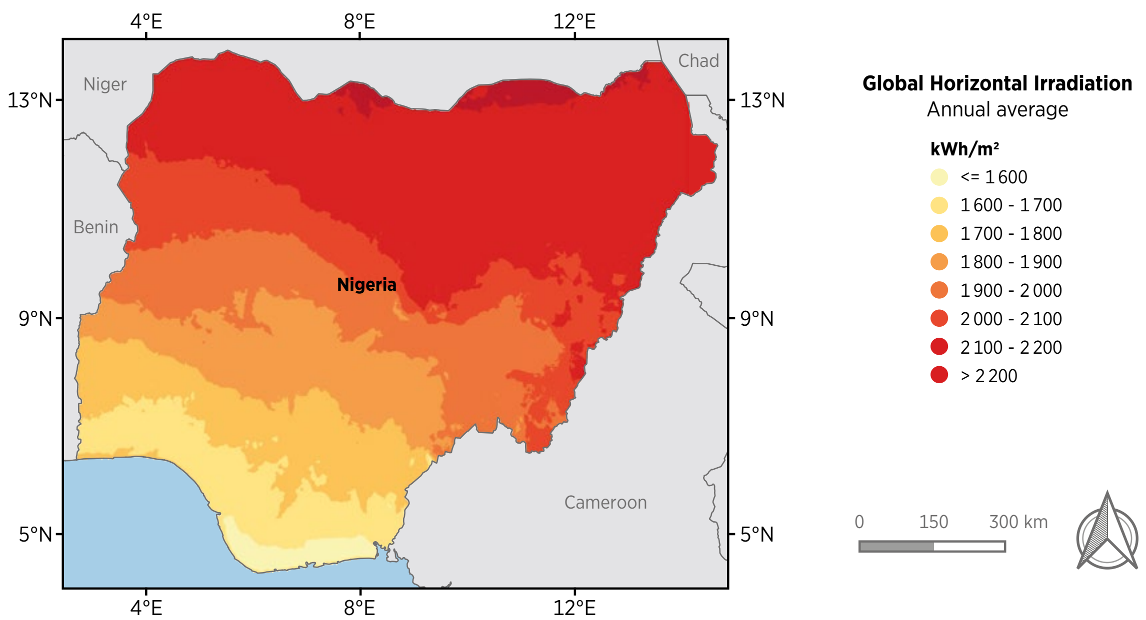
2.2 Nigeria's renewable energy resources

Nigeria has vast natural renewable energy resources which will be essential for sustainable development of the country; however, at present these resources are very much underexploited. In the case of this study the potentials were based on (2014a, 2014b), Sobamowo and Ojolo (2018), (2019), IHA (2021) and the U.S. Department of Trade (2021) are displayed in Table 2. The historic generation capacity and bioenergy use in 2015 as shown in 2015 in Table 2 are based on ECN (2015a), IRENA (2021a) and the U.S Department of Trade (2021) in addition to feedback received by stakeholders at the REmap workshop held in Abuja, Nigeria, in January 2020.

Solar

Nigeria has high solar resource potential characterised by an average annual global horizontal irradiation ranging between 1600 kilowatt hours per square metre (kWh/m^2) and 2200 kWh/m^2

Figure 1 Average annual global horizontal irradiation in Nigeria



Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

Source: Global Solar Atlas (2020).[3] Notes: Base map: UN boundaries.

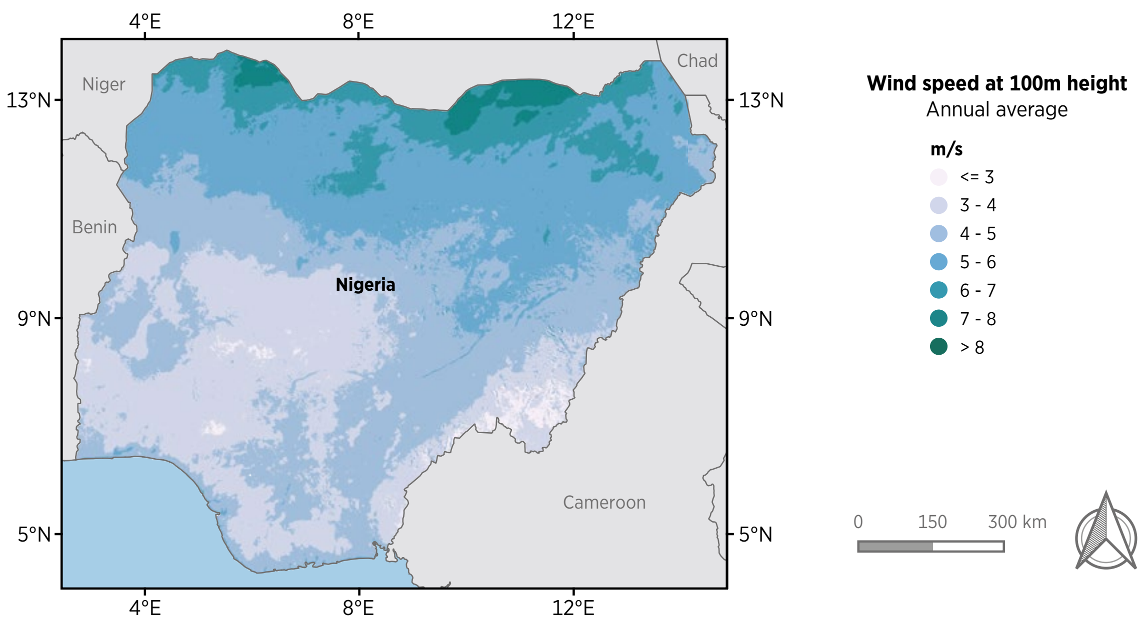
[3] *Global Solar Atlas 2.0, a free, web-based application, is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilising Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info.*

with the highest values (greater than 2 000 kWh/m^2) located in the northern part of the country. IRENA estimates the technical potential for solar photovoltaic (PV) in the country at 210 gigawatts (GW) considering only 1% of the suitable land can be utilised for project development (IRENA and AfDB, 2022). The potential for concentrated solar power (CSP) is also very significant with a potential of approximately 88.7 GW and is mostly located in northern Nigeria, where the direct normal irradiance is highest (Ogunmodimu, 2013).

Wind

The country has moderate wind potential with average wind speeds at 10 metres (m) height ranging between 2.1 m/second (s) and 8 m/s with the highest values (greater than 7 m/s) located in the northern part of the country. IRENA estimates the technical potential for wind at 3.2 GW considering only 1% of the suitable land can be utilised for project development (IRENA and AfDB, 2022). Apart from the coastal and offshore locations, the wind speed in southern Nigeria is relatively low, while higher wind speeds are experienced in the northern region (Emodi and Yusuf, 2015; Idris, Ibrahim and Albani, 2020). Currently, there is no estimate of offshore wind potential in Nigeria. However, the Federal Ministry of Power says that it is conducting an offshore wind mapping. For this study, it is assumed that only onshore wind turbines will be deployed in Nigeria. The target of the National Renewable Energy Action Plan (NREAP) is to achieve 0.17 GW of grid-connected wind capacity by 2020 and 0.8 GW by 2030.

Figure 2 Average annual wind speed in Nigeria



Disclaimer: This map is provided for illustration purposes only. Boundaries shown on this map do not imply any endorsement or acceptance by IRENA.

Source: Badger et al. (2015).[4] Notes: Base map: UN boundaries.

[4] *Global Wind Atlas 3.0 is a free, web-based application developed, owned and operated by the Technical University of Denmark. The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilising data provided by Vortex, using funding provided by ESMAP. For additional information: https://globalwindatlas.info.*

Hydro

Nigeria has a large hydro potential of around 24 GW and a small hydro potential of about 3.5 GW. This potential for the most part is yet to be exploited. In 2015, Nigeria had about 1.9 GW installed capacity of large hydro and about 60 megawatts of small hydro (ECN, 2014b; IHA, 2021; U.S. Department of Trade, 2021).

Biomass

Exploiting the huge potential of biomass resources in the country, especially in the form of agricultural residues for power generation, will go a long way to resolving the current energy crisis in Nigeria (Simonyan and Fasina, 2013). While there exist many biomass options for power generation, this study considers only agricultural residues as feedstock for biomass power plants (ECN, 2015a)

Table 2 Upper bounds on renewable energy resources

Energy resource	Unit	2015	Total	Percentage utilised in 2015
Large hydro	GW	1.9	24	8%
Small hydro	GW	.06	3.5	2%
Wind	GW	0	3.2	0%
Bioenergy	PJ	1 229	29 800	4%
Solar PV	GW	0.017	210	0%
CSP	GW	0	88.7	0%

03 ENERGY CONTEXT AND POTENTIAL

Energy context and potential

This section presents the national energy sector data and current trends in the Nigerian energy system as the baseline for the Renewable Energy Roadmap (REmap) analysis. It presents the current role and uses of renewables in the national energy mix, as well as the drivers for increased renewables deployment and socio-economic and environmental implications from current energy production and use. Table 3 below provides an overview of the key macroeconomic and energy system indicators. The numbers help to describe the population and economy that the Nigerian energy system serves and to explain some of the energy policy choices of the country and are based on a wide range of sources (NBS, 2020; SE4ALL, 2021; World Bank, 2021).

Table 3 Key economic and energy sector indicators for Nigeria

Indicator	2015
Population	181 million
Urban population	48% of total population
Land area (total)	923 000 square kilometres
Gross domestic product (GDP)	NGN 69 trillion (Nigerian naira)/USD 443 billion (2010)
Per capita GDP	NGN 381 215/USD 2 450 (2010) per capita
Access to electricity (% of population)	60% overall (urban: 86%; rural: 41%)
Access to clean cooking technologies (% of population)	18%

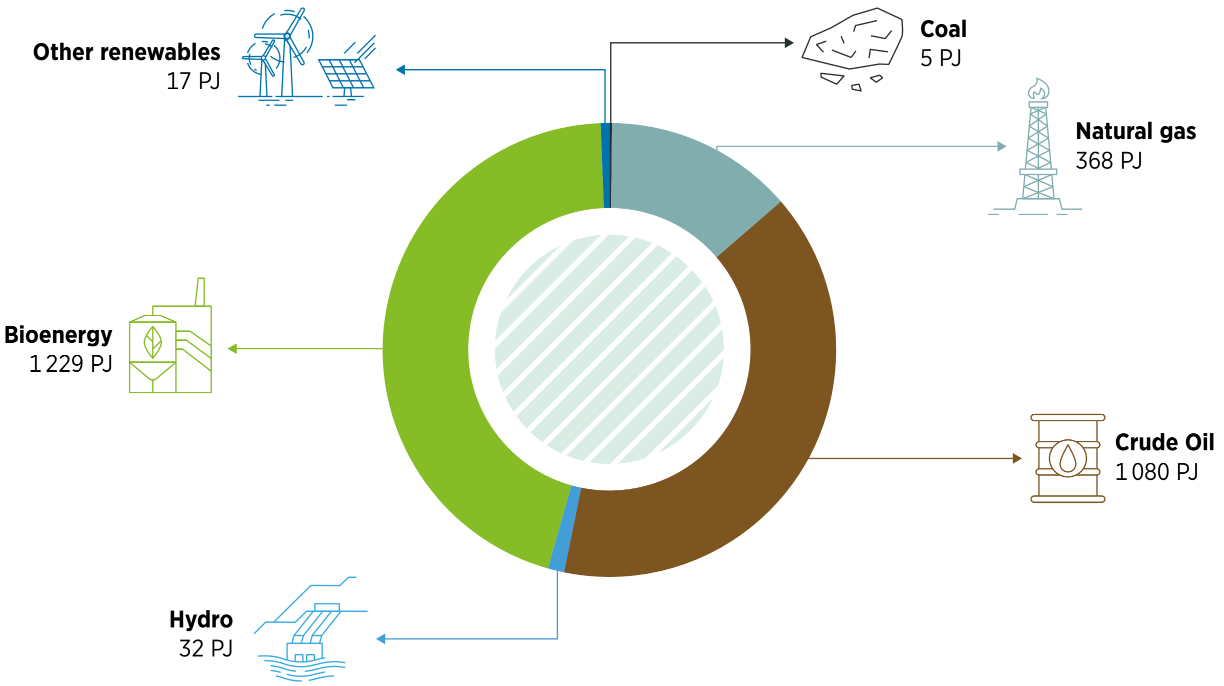
The Federal Republic of Nigeria is the most populous country in Africa with a population of nearly 200 million people and has the largest economy in Africa in terms of GDP (Olawale, 2020). The total final energy consumption (TFEC) in Nigeria amounted to around 2.1 exajoules (EJ) in 2015, which is approximately 9% of the TFEC in Africa. Currently, Nigeria's energy sector is heavily dominated by fossil fuels and traditional biomass (Ley, Gaines and Ghatikar, 2015). Nigeria is the 13th-largest producer and the 8th-largest exporter of crude oil in the world (Africanvault, 2015; Investopedia, 2019).

Table 3 provides a snapshot of the nation as a whole and offers perspective on areas to focus on for the development of this study. In terms of access to electricity and clean cooking, the rural-urban divide is very apparent with rural areas having substantially lower attainment of access to both. These observations merit consideration while evaluating the renewable energy options for Nigeria. The relatively low urbanisation rate combined with low GDP per capita and large population signify large potential for economic expansion in the future, which evidences the opportunity to ensure that it be a sustainable pathway.

Nigeria is a major actor in Africa, and will play a key role in determining the continent's future, as its population is estimated to double to over 400 million by 2050, according to Statista (Statista, 2022). This shows clearly how Nigeria's vast resource potentials for solar energy, hydropower and bioenergy (Brimmo *et al.*, 2017) will be key to unlocking economic growth, expansion of provision of modern energy services and sustainable development not only in Nigeria but Africa as a whole.

The rest of this section explores the energy context of Nigeria in terms of how energy is currently used in each sector of the energy system in addition to recent key national energy policies that are shaping the near-term expansion of the energy sector and serves as context and basis for the energy pathways presented as part of this study. The base year for this analysis was 2015; it was selected because at the time of writing it was the year for which the available dataset was richest. All results presented for this base year are based on a bottom-up, technology-rich assessment of energy use.

Figure 3 Nigerian primary energy supply in 2015 base year (2 730 PJ) based on model results and validated through a range of stakeholder engagement



Note: PJ = petajoules.

3.1 Primary energy

The primary energy supply of Nigeria is highly renewable at a share of approximately 47%. Biomass dominates the energy mix in Nigeria with a share of 43%, as presented in Figure 3. This is due to its extensive use for heating and cooking purposes where substantial progress remains to be made in terms of access to clean cooking fuels, as shown in the later sections. The biomass subsector in Nigeria is highly informal with a lot of uncertainties regarding its usage, especially in rural areas, and issues relating to fuel stacking in the Nigerian buildings sector. It is also unclear to what degree biomass is used in the Nigerian industry sector. Thus, the share of biomass in Nigeria's primary energy supply may be greater than the value from the model due to differences in methodological approaches, energy access levels and efficiency values of the modelled biomass technologies. As per the Nigerian National Bureau of Statistics living standards survey, there was only about 18% access to clean cooking (gas and electric stoves) in Nigeria in 2019 (NBS, 2020). However, international statistics suggest that access to clean cooking in Nigeria was around 13% in the same year (IEA, IRENA, UNSD, World Bank, WHO, 2022, p. 7). The data discrepancies may be attributed to the differences in survey and measurement techniques and what constitutes clean cooking. Most cooking uses traditional biomass, which indicates that air quality can be substantially improved by moving to other technologies and many deaths associated with air pollution avoided.

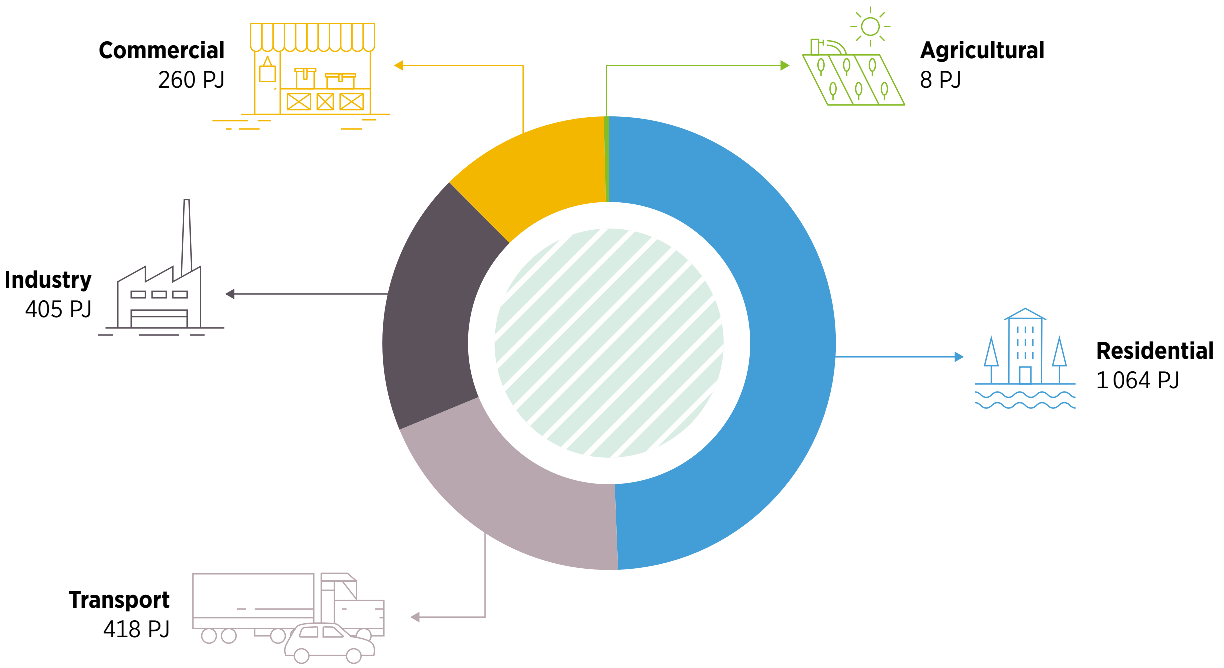
Oil makes up a similar share of primary energy requirement as bioenergy. While Nigeria is trying to get its refineries working at optimum capacity, the existing capacity is insufficient to satisfy the local demand for petroleum products. To meet this requirement, 80% of the refined oil products used in Nigeria are imported from abroad (PWC, 2017). Despite the ongoing construction of a large oil refinery capable of refining up to 650 000 barrels per day (George, Payne and Zhdannikov, 2021), Nigeria has much to gain from pivoting towards domestic renewable energy sources in place of domestic fossil fuels. As shown in Pai *et al.* (2021), global fossil fuel employment may drop by 80% in a 2°C scenario compliant with the Paris Agreement, while renewable-based employment could increase fivefold. Nurturing local development of abundant renewable energy resources would potentially spur local innovative renewable energy champions in such a scenario, which would enable the creation of local jobs and spin-off industries.

Natural gas, other renewables and hydropower make up the remainder of primary energy requirement of Nigeria and are used in the power sector for the most part. The low penetration of variable renewables such as wind and solar shows the opportunity that lies in integrating them in the power sector given the substantial cost reductions of the technologies in recent years and the enormous natural resource that Nigeria has, especially for solar power (IRENA, 2021b). Among the many advantages of these technologies, their modularity makes it easier to operationalise in a decentralised setting and in combination with storage can reliably provide power to a significant extent.

Unlike many other countries, Nigeria has relatively low coal use. At present, there is no coal power generation of note in the country. The current local consumption is mainly from the cement, brick, foundry and bakery industries.

All this shows that while the primary energy supply of Nigeria has a very substantial non-fossil share, its composition has negative externalities that, if changed going forward, could allow for improved air quality, domestic job creation and economic expansion. The proceeding subsections further unpack the composition of this energy use at present in Nigeria and contextualise the scenarios developed as part of the REmap analysis out to 2030 and 2050.

Figure 4 Total final energy consumption by sector in Nigeria 2015 (2 155 PJ) based on model results and validated through a range of stakeholder engagement

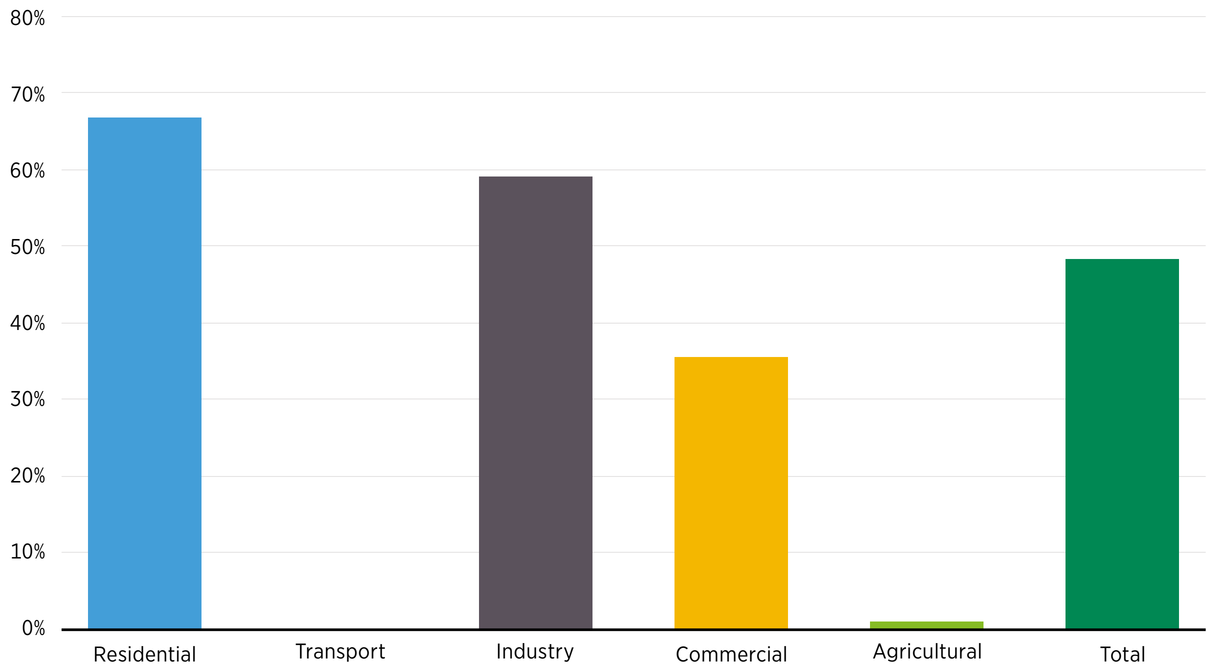


3.2 Total final energy consumption

Nigerian TFEC is dominated by the residential sector, making up nearly 50% of final energy consumption; the industrial and transport sectors each make up a fifth, with the remainder supplying the needs of the commercial and agricultural sectors. Energy demand in the agricultural sector is negligible due to the low mechanisation of the sector. This will change as the Nigerian population and economy expand to meet the needs of the country.

The outcome of this study provides additional context on how best to inform policy decisions by analysing various possible future pathways with a view to advancing the role of renewable energy. This study aims to develop a renewable energy pathway for the Nigerian energy system, but central to this is facilitating sustainable development. As shown in Figure 5, the renewable energy share in most sectors, especially the residential sector is quite high; this is because of the very substantial use of firewood and other sources of traditional biomass. Thus, considering energy use purely based on renewable energy share belies the advancement needed to improve modern energy access and improved air quality which is a key focus of the Transforming Energy Scenario (TES).

Figure 5 Renewable energy share in total final consumption by end-use sector, most of which is from inefficient combustion of traditional biomass derived based on a range of documents and stakeholder engagement



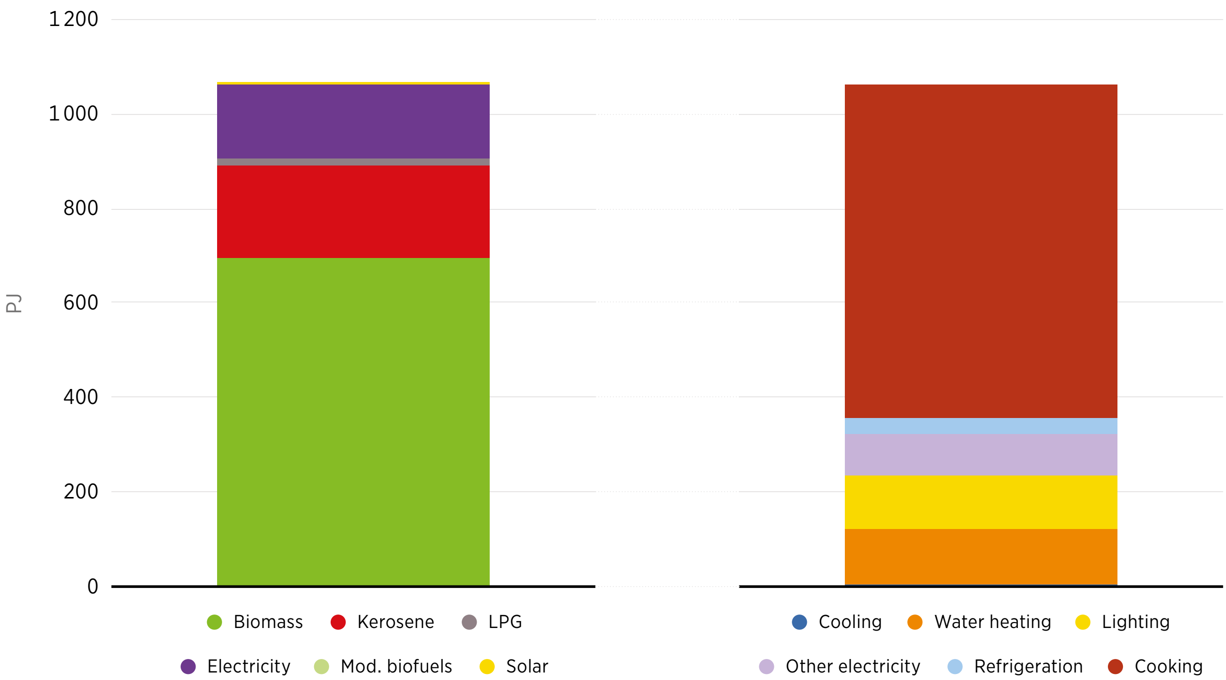
That said, Nigeria has made some promising strides towards sustainable development with an array of policies designed to advance this goal. These policies are accounted for in all scenarios developed as part of this study and are further described in the following sections.

3.3 Buildings sector (residential and commercial)

Nigerian households and commercial enterprises (restaurants, malls, banks, hotels, etc.) use energy for different purposes: cooking, water heating, lighting, air conditioning, refrigeration and for powering other miscellaneous electrical appliances such as fans, computers, washing machines, phones, televisions (TVs) etc. Owing to the increases in GDP, per capita income and urbanisation, improved lifestyle, and the general increase in population, there has been a substantial increase in Nigeria's residential sector energy demand. The final energy demand of the residential sector has varied over the years and has increased at a compound annual growth rate (CAGR) of 2.64%, from 50.92 million tonnes of oil equivalent (Mtoe) in 1990 to around 105.59 Mtoe in 2018 (IEA, 2021). The final energy demand of the commercial sector has increased at a CAGR of 2.04%, from 1.94 Mtoe in 1990 to around 3.41 Mtoe in 2018 (IEA, 2021). The energy basket of the sectors mainly consists of electricity, kerosene, liquefied petroleum gas (LPG) and biomass (fuelwood, animal dung and charcoal) (ECN, 2013).

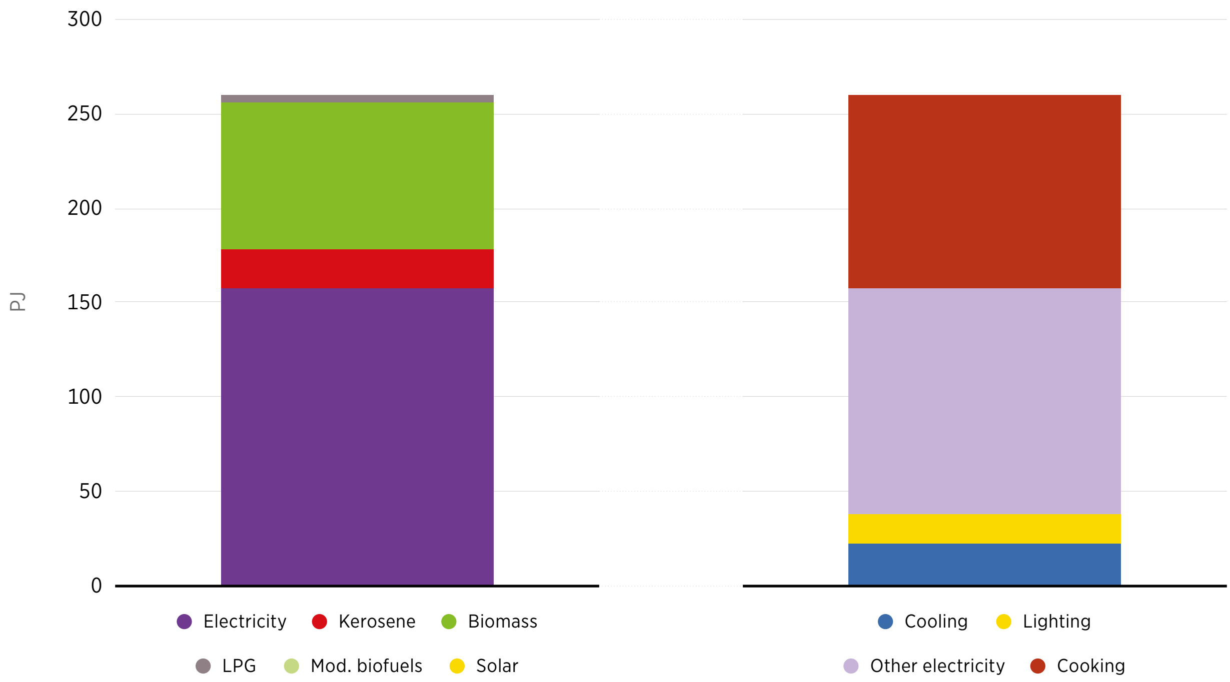
Due to the observed spatial heterogeneity in residential energy use, the energy demand of the Nigerian residential sector may be grouped as demand from rural and urban households (Dioha and Kumar, 2020). With respect to electricity access, in 2019 only 46% of the rural population had access while in the urban areas the value was around 90% (NBS, 2020). However, there is disparity between various statistical sources on this with the Sustainable Development Goal 7 (SDG7) tracker indicating a level of 25% in rural areas and 84% in urban areas in 2020 (IEA, IRENA, UNSD, World Bank, WHO, 2022). With respect to clean cooking, there is also disparity of data. The Nigeria Living Standards Survey of the National Bureau of Statistics suggests that around 18% of Nigerians have access to clean cooking (NBS, 2020) while the SDG7 tracker indicates that only about 15% of Nigerian households had access to clean cooking in 2020 (IEA, IRENA, UNSD, World Bank, WHO, 2022). Depending on the data source, all indicators show that the challenge is more pronounced in rural areas, where only about 6% of the rural population have access to clean cooking (NBS, 2020). The main challenges to modern energy access in Nigeria include lack of access to adequate financing, lack of adequate business models, inadequate planning and poor governance, as well as weak human/institutional capabilities.

Figure 6 Total final energy consumption in residential buildings in 2015 based on model results and validated through a range of stakeholder engagement



The fuels/technologies used for cooking in the Nigerian residential/commercial sector are diverse. Traditional three-stone fire, improved woodstove, LPG, kerosene and electric stoves are used for cooking in the sector. Fuelwood is the predominant fuel for cooking, especially in the rural areas of Nigeria. It is usually collected from the nearby forests in the villages in rural areas. However, in the urban areas, fuelwood is usually purchased from local vendors who sell it at a marginal price compared with other cooking fuels such as LPG. The high reliance on traditional biomass for cooking has led to the depletion of many forests in the country and has also resulted in the destruction of several natural ecosystems (Gujba, Mulugetta and Azapagic, 2015). Furthermore, air pollutant emissions such as carbon monoxide and particulate matter – from the incomplete combustion of biomass in inefficient cookstoves – have severe health implications and contribute to around 64 000 deaths per year in Nigeria (HEI and IHME, 2018).

Figure 7 Total final energy consumption in commercial buildings in 2015 based on model results and validated through a range of stakeholder engagement



As most buildings in Nigeria (especially in the rural areas) are not equipped with water heating facilities, they use cooking devices to making hot water for bathing. Moreover, many households fitted with water heaters mainly use the standard inefficient types. With respect to lighting, Nigerian households depend on electricity, kerosene, dry cell batteries (such as alkaline cells or rechargeable lithium-ion cells), candles, grass, etc., but at the national level, electricity, dry cell batteries and kerosene constitute the main sources of lighting for the vast majority of households. The electric lighting technologies include incandescent bulbs, compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs). Electrical appliances such as refrigerators and air conditioners are mainly localised in urban households. Most of the appliances found in Nigerian buildings are very old and inefficient. Some of them are scraps that are imported from Western countries after they have served their useful life. This scenario indicates that there is a large scope for improved energy efficiency in the sector. With the growing urbanisation and increased demand for a luxurious lifestyle, the use of refrigerators and air conditioners is expected to rise in the future (Dioha and Kumar, 2020).

Various programmes have been initiated to reform the residential and commercial sectors in Nigeria as a solution to the challenges. Recently, there have been a lot of efforts and political discussions to provide all households in Nigeria with modern energy access by 2030. The National Renewable Action Plan (NREAP) and the Sustainable Energy for All (SEforALL) Action Agenda[5] seek to increase electricity access to around 75% (90% in urban areas and 60% in rural) by 2020 and to 90% by 2030.

[5] *The Action Agenda is a strategy-driven and holistic document acting as an umbrella for energy sector development at the national level. It defines the national SEforALL objectives and determines how the three goals of SEforALL can be achieved.*

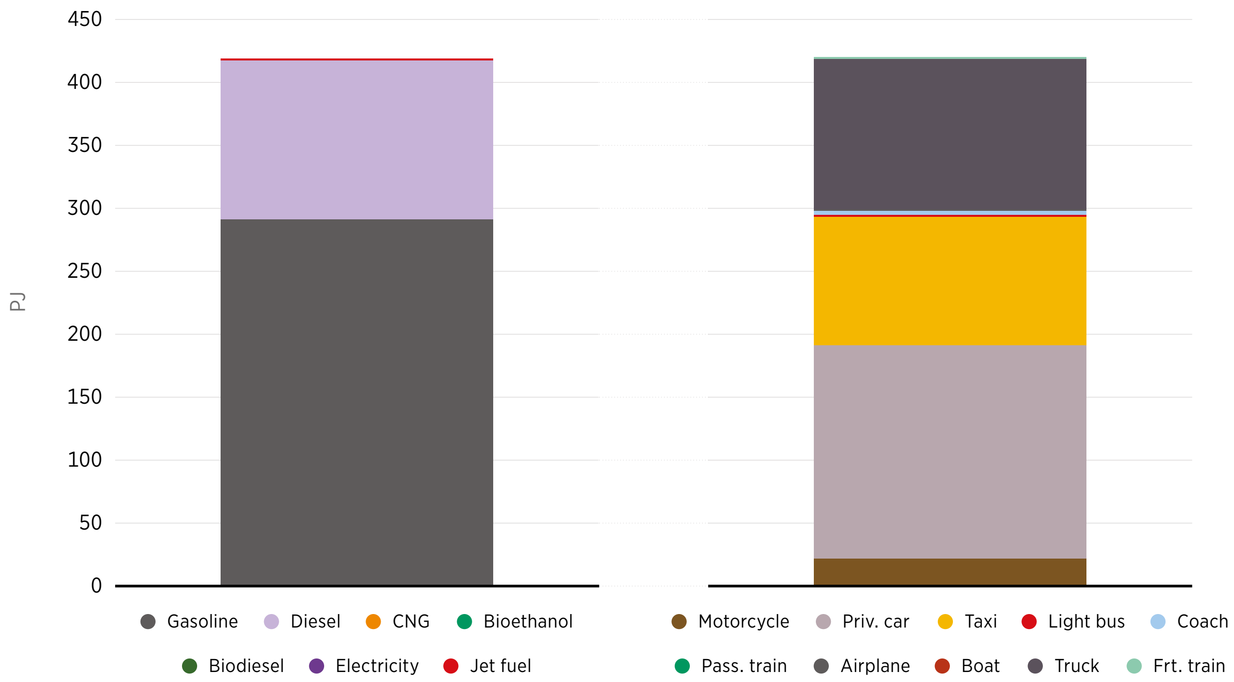
The SEforALL Action Agenda also seeks to replace 50% of traditional firewood consumption for cooking with improved cookstoves by 2020 and 80% by 2030, working together with the private sector to deploy LPG at reasonable cost for Nigerians by 2020 and subsequently up to 2030. The NREAP also seeks to expand efficient lighting to almost 100% of households by 2030. Furthermore, the current COVID-19 pandemic has put severe limitations on investment in modern energy access (including clean cooking systems) in the country, which, in turn, is pushing the country further away from achieving universal access to clean cooking by 2030. Notwithstanding, Nigeria continues to see progress in the diffusion of clean cooking equipment in the country. The Nigerian Alliance for Clean Cookstoves is working to bring in new partners to further strengthen and support the distribution of clean cookstoves (NACC, 2021). The alliance is also supporting many enterprises in Nigeria to access development funds such as Spark and Women's Empowerment Funds and the Catalytic Small Grant to promote the adoption of clean cookstoves (One Earth, 2021). A national testing centre for cookstoves and fuels has also been developed (Clean Cooking Alliance, 2021). A programme to reduce dependency on firewood has been launched in Katsina state in partnership with the European Union; Oxfam; the International Centre for Energy, Environment and Development; and the Nigerian Alliance for Clean Cookstoves (Oxfam, 2021). The joint programme provides support to women-owned enterprises and conducts business development training for local entrepreneurs on the production and marketing of a more consumer-friendly, fuel-efficient stove (Global Alliance for Clean Cookstoves, 2016).

In recent years, the government has made giant strides in phasing out incandescent bulbs through its various agencies and programmes. The Energy Commission of Nigeria (ECN) and the United Nations Development Programme (UNDP) have also worked on joint projects to promote energy efficiency in Nigeria's residential and commercial sectors. The project strategically aims at reducing the energy consumption of key end-use technologies such as light bulbs, air conditioners and refrigerators. Other energy efficiency initiatives in the sector include the enforcement of FDNIS ECOSTAND 071-2:2017EE: Minimum Energy Performance Standards Part 2: Air conditioning products. This standard covers requirements for domestic and commercial air-conditioning products. Other government ministries (*e.g.* Federal Ministry of Environment) and non-governmental organisations are also working towards improving the energy situation of the sectors.

3.4 Transport sector

Against the backdrop of rapid population and GDP growth, the energy demand of the Nigerian transport sector has grown substantially over the years at a CAGR of 6.42%, from 3.97 Mtoe in 1990 to around 22.69 Mtoe in 2018 (IEA, 2021). The rapid growth in the energy consumption of the sector is expected to continue because of the projected increase in population. The fuel mix of the Nigerian transport sector is dominated by gasoline and diesel (Gujba, Mulugetta and Azapagic, 2013). In terms of vehicles per population, Nigeria's car ownership is just around 64 vehicles per 1000 Nigerians. This value is relatively low compared with 569 vehicles cars per 1000 in Europe (European Automobile Manufacturers' Association, 2021). However, the desire for car ownership in the country is extremely high due to the social status it conveys as well as the limited public transportation system.

Figure 8 Total final energy consumption in transport in 2015 (PJ) based on model results and validated through a range of stakeholder engagement



Note: CNG = compx-ressed natural gas.

The modes of transport in Nigeria include road, air, rail and water. Road is the major mode of motorised transport in Nigeria with private cars contributing over 40% of the final consumption as shown in Figure 8 above. It accounts for over 90% of both passenger and freight movements in terms of kilometre(s) travelled. The major means of road transportation include motorcycles, private cars, taxis, light buses, coaches and heavy-duty vehicles based on the World Bank's vehicle survey in Nigeria (Cervigni, 2013). Motorcycles are mainly used for commercial purpose but are also privately owned. They are mainly the two-stroke-engine type and powered by gasoline. The private cars consist of the sport utility vehicle (SUV), sedan, wagon, pickups and jeeps which are solely used for private purposes. Around 98% of private vehicles run on gasoline. The taxis, light buses and coaches provide the majority of public transport. The heavy goods vehicles (trucks) are mainly powered by diesel. The adoption of flex-fuel, biofuels and electric vehicles is still at the infant stage of development in the country. The air transport subsector in Nigeria accounts for the second-highest share of modal contribution to transport output (Daramola and Fagbemi, 2019). However, the air transport subsector has accounted for just 6-7% of transport GDP in the last couple of years. Nevertheless, the air transport subsector has much more potential for contributing to the local economy, particularly through increased capacity for earning and conservation of foreign exchange (Daramola and Fagbemi, 2019). The Nigerian rail system is underdeveloped with only few locomotives on track and will require major overhaul to become a significant mode of transportation in the country. Nigerian trains are for the most part served by diesel, though currently progress is being made to revamp the Nigerian railway system (Onokala and Olajide, 2020; GCC, 2021). In addition, water travel is also underdeveloped in the country (Obeta, 2014; Onokala and Olajide, 2020).

The growing population will need more public and private transport. Worsening congestion and ever-increasing demand for movement in the large cities such as Lagos, Port Harcourt and Abuja implies that ever-greater numbers of vehicles are required to serve the public. For freight vehicle activity, the anticipated economic growth will drive a greater demand for the movement of freight and goods. Moreover, the existing vehicle fleet is made up of ageing and high-polluting vehicles, the majority imported from Western countries only when they approach the end of their economic life (Ayetor *et al.*, 2021). Poor routine maintenance and the harsh environment in Nigeria mean that the condition of these vehicles deteriorates quickly. Nigeria is also not exempt from the negative impacts of fossil fuel-driven transport. Many Nigerians, in particular those living in traffic-congested towns and cities, such as Lagos and Port Harcourt, are exposed to air pollution, which contributes to cardiovascular and respiratory diseases, and this exacerbates poverty in the country.

In recent years, the federal government of Nigeria has shown its commitment to implement policies and strategies to advance a safe, secure, affordable and sustainable transport system in the country. The Nigerian Biofuel Policy and Incentives came into effect on 24 July 2007 (IEA and IRENA, 2021). The aim is to gradually reduce the nation's dependence on imported gasoline and reduce environmental pollution while at the same time creating a commercially viable industry that can generate sustainable domestic jobs. The NREAP further outlines the intention of the federal government of Nigeria to incorporate biofuels into the transport fuel mix. Currently, there is a ban on the import of two-stroke motorcycles, and the use of motorcycles for commercial purposes has also been banned in certain parts of major cities such as Abuja and Lagos. There are also regulations guiding vehicle emissions standards for all new and imported vehicles (Opara, 2011; George, 2020). The launch of the National Automotive Industry Development Plan in 2014 attracted the interest of leading international carmakers and led to the resumption of small-scale vehicle assembly in the country. According to the National Automotive Design and Development Council (NADDC), there are 31 licensed producers of cars, trucks and buses currently operating in Nigeria with a combined installed capacity of 205 000 vehicles a year, though far fewer numbers are produced due to huge funding, infrastructure and capacity gaps. In early 2019, the NADDC stated that only nine of the assemblers were active. Consequently, in March 2020, as a mark of relative success, the government commissioned USD 1 billion worth of locally assembled vehicles which were made by 17 companies (U.S. Department of Trade, 2021). In all, it appears the high import tariff regime aimed at discouraging imports and spurring local assembly has not yet achieved its goal.

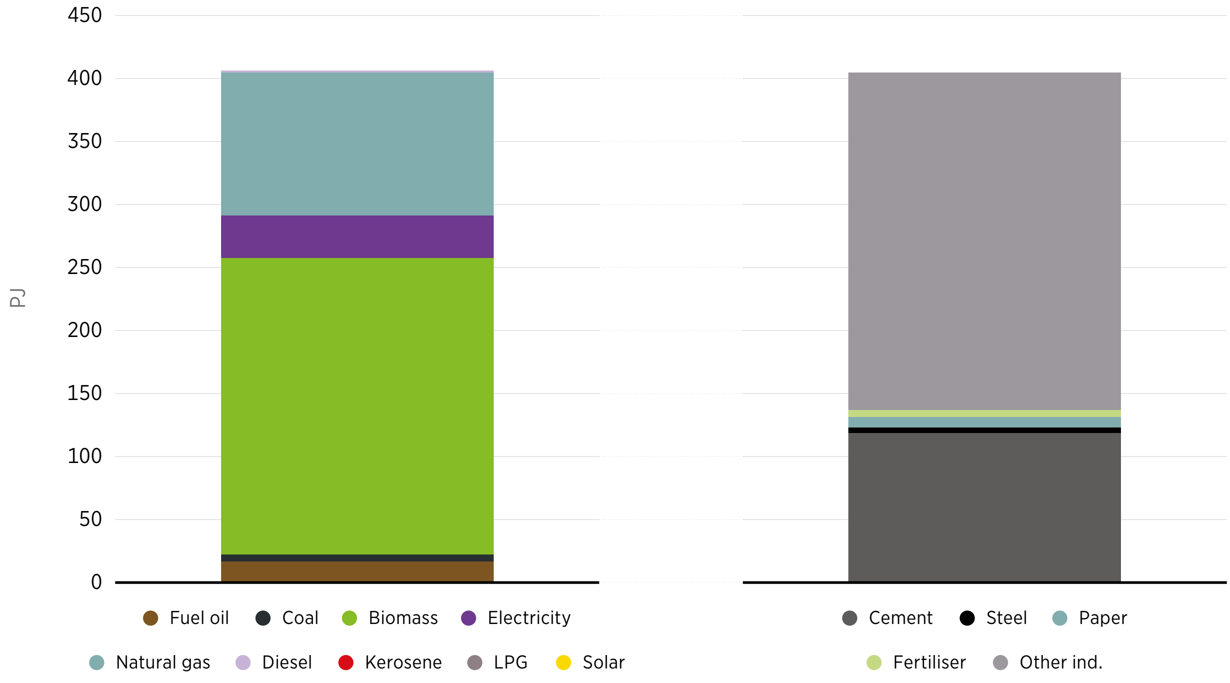
After several attempts to reform Nigeria's downstream oil sector, the Buhari administration has taken steps to reduce fossil fuel subsidies and move to a market-based pricing regime for gasoline in the wake of the oil price crash (Gupte, 2020). The subsidy removal may impact the fuel mix of Nigeria's transport sector. The proportion of private vehicles that run on diesel is negligible, with commercial vehicle owners also opting to run petrol vehicles wherever possible. Hence, it is expected that if alternative vehicle fuels become cheaper than gasoline, many car owners may consider a switch to the less expensive fuel. To make this scenario possible, on 1 December 2020, the Nigerian government launched its National Gas Expansion Programme aimed at distributing LPG across gas stations in order to promote the wider use of gas in vehicles (Reed, 2020).

With the renewed interest of the government in revamping the rail system, and its railway modernisation initiative seeking to replace the existing narrow-gauge system with the wider standard-gauge system – while allowing high-speed train operations on the railway network, it is expected that a substantial amount of road travel demand will shift to rail in the future (AfricaNews, 2020; Clowes, 2021).

3.5 Industry sector

The Nigerian industry sector can be split into several subsectors such as food, beverages and tobacco; basic metal (iron and steel); chemicals and pharmaceuticals; non-metallic mineral products; electrical and electronics; paper and pulp; textiles and leather; domestic and industrial plastic and rubber; motor vehicle and miscellaneous assembly; and wood and wood products. The energy demand of Nigerian industry sector has grown substantially over the years at a CAGR of 4.61%, from 2.13 Mtoe in 1990 to around 7.51 Mtoe in 2018 (IEA, 2021). Figure 9 shows the industry sector's fuel mix, which includes natural gas, fuel oil, coal, electricity and other derived products, with biomass being the most consumed fuel in the sector. Regarding renewable energy systems beyond biomass, the use of solar for industrial thermal applications is nearly absent in the country.

Figure 9 Total final energy consumption in industry in 2015 (PJ) based on model results and validated through a range of stakeholder engagement



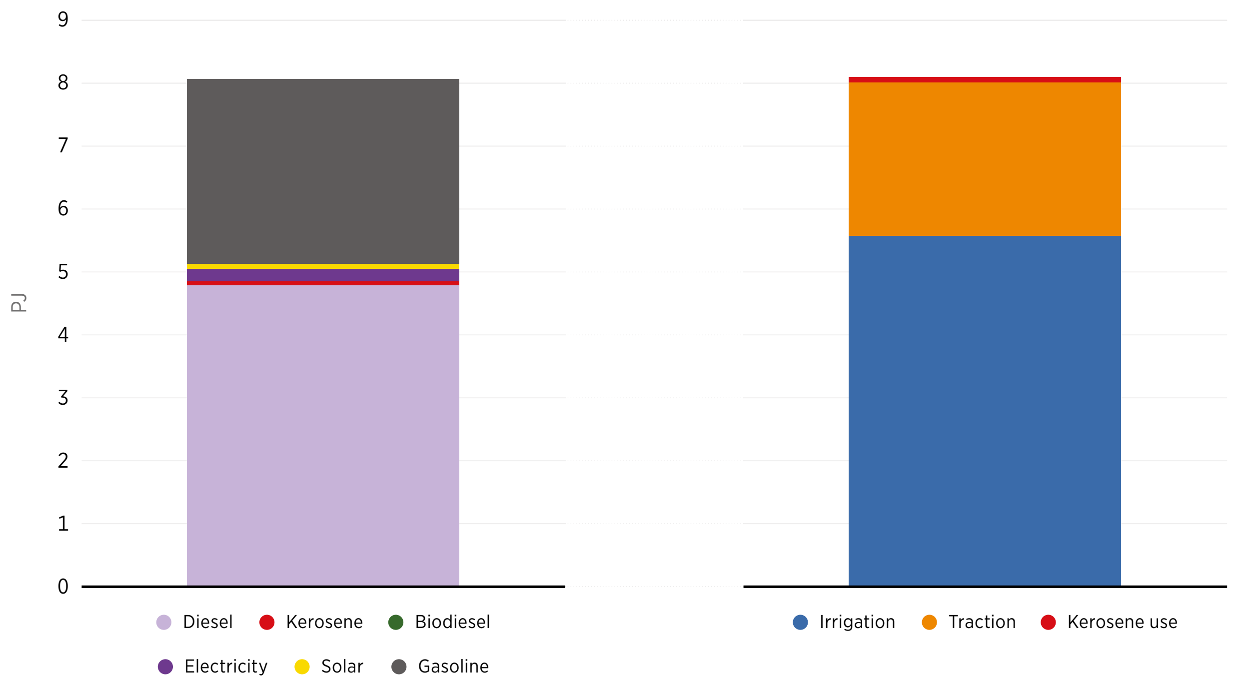
The Nigerian industry sector remains one of the major challenges facing the country. The sector has failed to implement the crucial structural reform necessary for it to play a leading role in economic growth and development. The sector is structurally weak and basic industries such as iron, steel and petrochemicals are not fully developed. Many manufacturers depend entirely on imports for machinery, equipment and spare parts. These factors have led previous development plans to describe the Nigerian manufacturing sector as one of "mere assembly plants". In addition, the skilled workforce necessary to guarantee competitiveness in the modern-day dynamic and globalised world is lacking. Consequently, the sector is unable to attract the necessary investment for economic growth and remains an insubstantial player in the economy.

With respect to technologies, Nigeria's industrial sector is characterised by inefficient technologies and processes (Oyedepo *et al.*, 2015). For instance, the wet process for cement production, which consumes relatively more energy, still exists in Nigeria (Ohunakin *et al.*, 2013). The National Energy Efficiency Action Plan (NEEAP) target for high-energy-consuming sectors (*e.g.* industry) is that energy efficiency will increase by at least 50% compared with baseline.

3.6 Agriculture sector

Although relatively small in energy terms, the agricultural sector plays an important role in the Nigerian economy as it provides livelihood for around 70% of rural dwellers. Primary agriculture accounts for just around 1% of total final energy demand. The energy demand of the Nigerian agriculture sector has remain relatively sTable over the years at around 4 kilotonnes of oil equivalent (IEA, 2021). The fuel mix of the Nigerian agriculture sector mainly consists of diesel, gasoline and kerosene.

Figure 10 Total final energy consumption in agriculture in 2015 (PJ) based on model results and validated through a range of stakeholder engagement



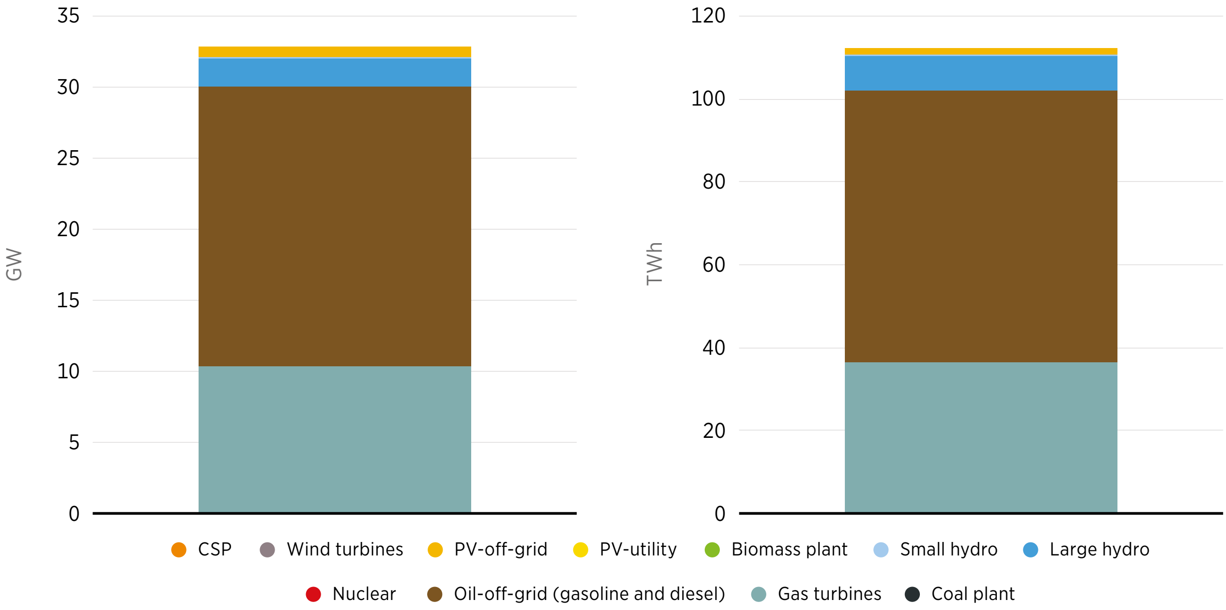
Diesel is the most important energy source in the agricultural sector and accounts for more than half of the energy consumed, and it is primarily used to power irrigation pumps and fuel vehicles, such as tractors and combine harvesters. Diesel is used to run diesel irrigation pumps. A small amount of electricity is used to power grid-based irrigation pumps. Renewable energy technology application is still at a nascent stage of deployment in the sector with just a few solar water irrigation pumps installed in the country. In terms of technological options, Nigeria's agriculture is still underdeveloped and mainly depends on manual labour. With the anticipated future mechanisation, growth in population and corresponding food demand, energy consumption of the sector is expected to increase substantially. While the federal government of Nigeria has developed several policies for the country's agriculture sector, such as the Agricultural Promotion Policy, many energy-related developments in the sector have been at state levels. For instance, in 2018, the Sokoto state government awarded a contract for the construction of 250 solar-powered water schemes, which will be developed in rural areas across the state's 23 local government areas (Solar Business Hub, 2018). However, the impact of some of these schemes remains to be seen.

3.7 Power sector

Nigeria's electricity supply system can be grouped into two: centralised (grid-connected) and decentralised (off-grid) systems. The centralised system consists of the large-scale generation of electricity at centralised facilities such as large hydro and thermal plants. The decentralised electricity supply system consists of a few kilowatts to megawatt capacities such as captive diesel and gasoline generator sets as well as renewable energy technologies (such as solar home systems, streetlights and mini-grids).

Figure 11 presents total on-grid and off-grid installed capacity. The total installed capacity of grid-based systems is around 13 GW. However, today's available on-grid peak generation varies and hovers around 4.5 GW. Nigeria's on-grid generation is dominated by natural gas power stations (86%) and large hydropower plants (14%). However, unavailability of gas, machine breakdowns, seasonal water shortages and limited grid capacity have severely limited the operational performance of these power plants (Yetano Roche *et al.*, 2020). This situation has led to led to acute shortages of electricity supply across the country with blackouts lasting for several hours in a day. The situation has also made many households and business units result to self-generation of off-grid electricity using diesel and gasoline generator sets as back-up. In terms of installed capacity, there is considerable uncertainty about the total capacity of fossil fuel-based self-generation. However, in accordance with the number of generators imported annually into the country, it is assumed that around 15 GW of diesel and petrol-based generation capacity were available in the country as of 2015 (Solar Plaza, 2017), while another study suggests around 30.5 GW (Tambari, Dioha and Failler, 2020).

Figure 11 Power capacity and generation (including off-grid systems) in Nigeria, 2015



Note: CSP = concentrated solar power; TWh = terawatt hours.

Today, around 84% of urban households use back-up power supply systems such as fossil diesel/gasoline generators and/or solar-based systems, while about 86% of the companies in Nigeria own or share a generator (Ley, Gaines and Ghatikar, 2015; Elinwa, Ogbeba and Agboola, 2021). Given the several million captive generators imported into the country, Nigeria leads Africa as the highest importer of generators and is also one of the largest importers worldwide. Nigeria's erratic power supply systems and the relatively expensive captive generation negatively impacts the economy from the residential to the industry sector. Owing to the high costs of captive generation, households and small and medium-sized enterprises spend between two and three times more on kerosene, diesel and petrol than they do on electricity from the grid (All On, 2016). In industry, government figures suggest that the cost of self-generating power makes Nigerian products approximately one-third more expensive than imports (FMITI, 2014). For these reasons Nigeria needs to improve the provision of electricity in the country in terms of both access and reliability in order to reduce the use of captive diesel and gasoline generators.

The transformation of Nigeria's electricity supply system is plagued with several challenges, some of which are common to both the centralised and decentralised systems. The main challenges facing the entire power sector include inadequate financing, relatively high investment risks and policy uncertainty (Latham & Watkins, 2016). The setbacks facing the centralised system are insufficient generation capacity, weak transmission and distribution infrastructures, gas supply constraints, seasonality of water levels, and governance (Latham & Watkins, 2016; Wijeratne *et al.*, 2016). Recent policy developments such as those that were intended to meet the goals of the National Policy on Renewable Energy and Energy Efficiency aimed to address aforementioned challenges include the feed-in tariffs for renewable energy, new metering regulations and guidelines allowing large consumers to purchase power directly from generating companies.

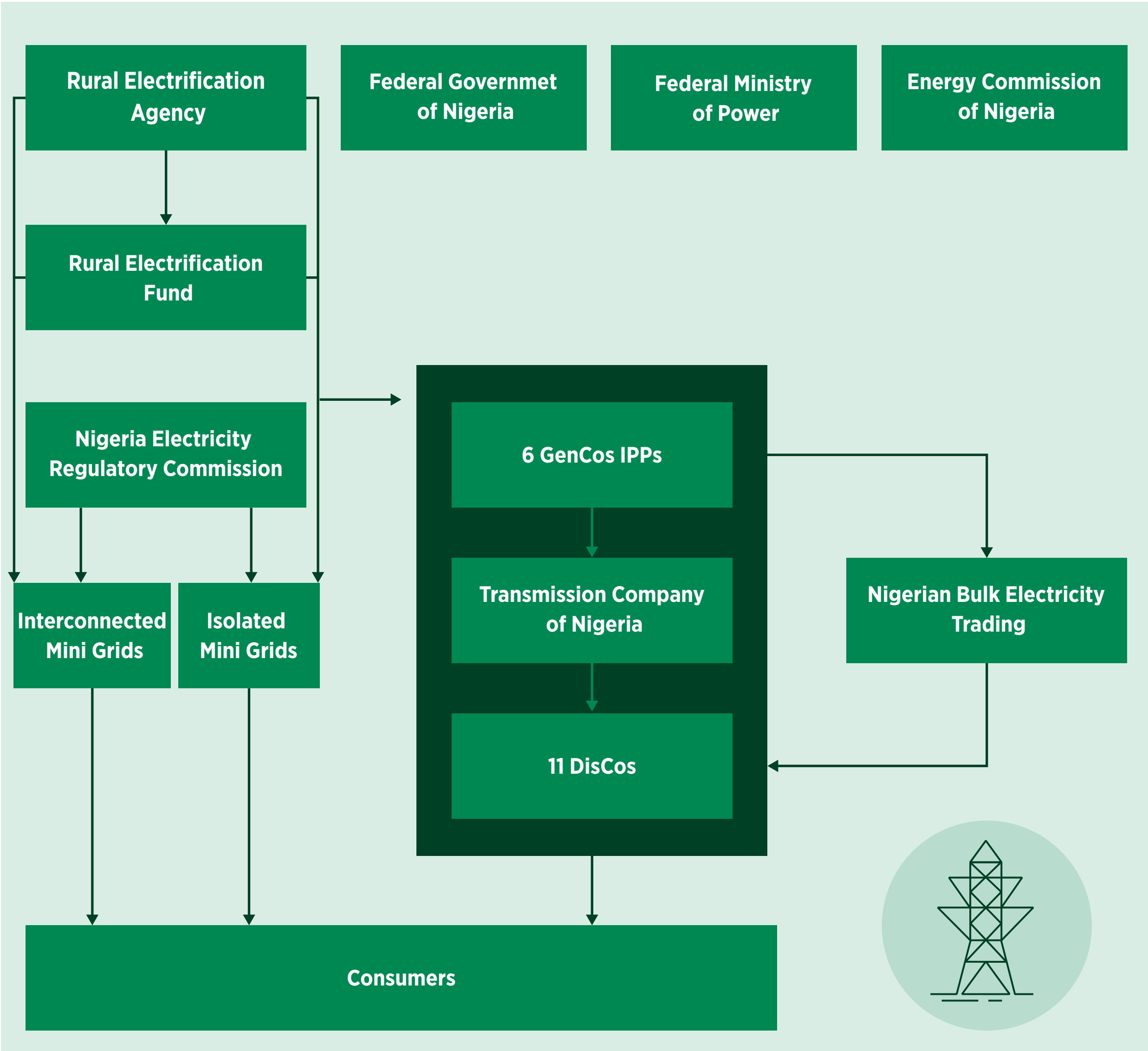
Nigeria has a huge potential off-grid market whether based on solar photovoltaic (PV) mini-grids or through solar home systems. Currently, based on life-cycle assessment, stand-alone solar PV systems are already cost-competitive compared with conventional diesel and gasoline generators used in the country as back-up (Esan *et al.*, 2019). However, solar PV systems have higher initial capital outlay, which makes them unattractive for the poor consumers. Some of the key barriers for investments in the Nigerian decentralised renewables space include poor consumer affordability and poor enabling environment (Latham & Watkins, 2016). Recent policies and programmes, such as the 2016 mini-grid regulation introduced by the Nigerian Electricity Regulatory Commission and government removal of import duties on some solar components, aim to ameliorate the aforementioned challenges (NERC, 2016; Department for International Development, 2019).

While the Nigerian power sector continues to struggle, poor financing remains the key bottleneck to lack of progress. The Nigerian power sector will require substantially more investment to achieve constant power supply. In terms of improving electricity access, around USD 34.5 billion in total investment will be required to provide electricity access to all households by 2030 (Ohiare, 2015). The Transmission Company of Nigeria (TCN) suggests that rehabilitation and expansion of the grid will require an annual investment of USD 1 billion for the next ten years (TCN and PMU, 2017). Currently, the World Bank is financing a USD 486 million International Development Association credit for the Nigerian Electricity Transmission Access Project, to support the development of Nigeria's transmission system (World Bank, 2018). The African Development Bank, which is already working with the country on a USD 410 million transmission project, has pledged to invest an additional USD 200 million through the Rural Electrification Agency, in order to expand electricity access in the country (AfDB, 2020). Recently, the Nigerian federal government signed a six-year deal with Germany's Siemens AG for a three-phase electrification project aimed at increasing Nigeria's power to 25 000 megawatts (MW) that amounts to NGN 1.15 trillion (around USD 3.8 billion [2020]) (U.S. Department of Trade, 2021).

Around USD 34.5 billion in total investment will be required to provide electricity access to all households by 2030.

The institutional structure of the Nigerian electricity sector is presented in Figure 12 as featured in Adeyanju *et al.* (2020) and is composed of a range of different institutions.

Figure 12 Electricity sector structure of Nigeria



Note: GenCos = generation companies; IPPs = independent power producers; DisCos = distribution companies.

Source: Adeyanju et al. (2020)

With respect to transmission, the TCN manages the electricity transmission network in Nigeria. TCN is one of 18 companies that were unbundled from the Power Holding Company of Nigeria (PHCN) in April 2004 and is a product of a merger of the system and transmission operations parts of PHCN. It was incorporated in November 2005 and issued a transmission licence on 1 July 2006. TCN's licensed activities include electricity transmission, system operation and electricity trading. It is responsible for evacuating electric power generated by the electricity GenCos and wheeling it to DisCos. It provides the important transmission infrastructure between the GenCos and the DisCos' feeder substations across the country.

Nigeria's transmission network consists of high-voltage substations with a total (theoretical) transmission wheeling capacity of 7.5 GW and over 20 000 kilometres of transmission lines (NERC, 2021). Currently, transmission wheeling capacity (5.3 GW) is far below the total installed generation capacity of around 13 GW. The entire infrastructure is essentially radial without redundancies, thus creating inherent reliability issues. The grid is characterised by the poor voltage profile in the network (especially in the north due to its radial nature). Overloaded transmission lines and high technical and non-technical losses are a regular feature. The average transmission losses are around 7.4%, which is relatively high compared with emerging countries' benchmarks of 2-6% (NERC, 2021). The transmission system also experiences a number of system collapses during the year. This shows that there exists critical infrastructure and operational challenges in the transmission subsector of the industry. IRENA's West Africa Planning report focused primarily on the regional expansion of the centralised power sector in the region and demonstrated the benefits of co-operation in power system expansion to Nigeria and the wider region out to 2030 (IRENA, 2018a). International transmission with other countries is limited to two lines with Benin (686 MW) and Niger (186 MW) (IRENA, 2018a). A new 650 MW line is also planned as part of the Nigeria-Benin-Niger-Burkina-Faso Power Interconnection Project (also known as the North Backbone Project) which is expected to be commissioned in 2022 (AfDB, 2021). Moving forward, deeper system integration within the Western Africa Power Pool will enable a more reliable power supply regionally and offer Nigeria the chance to export power to the wider region.

04 RENEWABLE ENERGY OUTLOOK

Renewable energy outlook

The previous sections have outlined the energy context in Nigeria and some of the opportunities and challenges that lie ahead. However, Nigeria's energy system is highly dynamic, and the government would benefit from periodically re-evaluating longer-term energy goals to reflect changing market dynamics and priorities for the country. This section presents the International Renewable Energy Agency (IRENA) Renewable Energy Roadmap (REmap) analysis and provides an outlook on the medium-term potential of renewable energy in the country.

The macroeconomic factors that apply to any country serve as the basis of its development trajectory and also play a key role in determining its future energy demand trajectory and corresponding emissions. Table 4 displays these factors as has been assumed in this study for Nigeria, for both the Planned Energy Scenario (PES) and the Transforming Energy Scenario (TES). A further more detailed description of these assumptions can be seen in Appendix B.

Table 4 Key macroeconomic factors underpinning the analysis

Year		2015	2030	2050
	Total population (million)	181	263	401
	Urbanisation level (%)	48	59	70
Gross domestic product (GDP) (billion USD 2010)	Agriculture	102	183	609
	Industry	105	340	1 352
	Services	236	349	1 420
	Total	**443**	**872**	**3 381**
	GDP per capita (USD 2010)	2 450	3 320	8 430

4.1 Planned Energy Scenario to 2050

The PES is based on existing policy with no other substantial measures. As shown in Table 5, several policies and programmes have been developed for the Nigerian energy sector, which is not without ambitions despite the current challenges it faces.

Table 5 Summary of key national policies and action plans on renewable energy and energy efficiency

Policy/Action plan	Year	Short description	Responsible agency
National Energy Efficiency Action Plan (NEEAP)	2016	The NEEAP was developed by the FMP. It sets targets for energy savings and proposes actions for meeting the set targets. The NEEAP targeted 40% efficient lighting in households by 2020 and 100% by 2030; efficient energy increase by 20% by 2020 and 50% by 2030 in the transport, power and industrial sectors; the reduction of distribution losses by 15-20% by 2020 and less than 10% by 2030; and the achievement of 10% biofuel blend by 2020.	Federal Ministry of Power (FMP)
National Renewable Energy Action Plan (NREAP)	2015	The NREAP was developed by the FMP and reiterates the target to attain 30 gigawatts (GW) of power generation capacity by 2030, with a renewables share of 30%.	Federal Ministry of Power
Nigeria Nationally Determined Contribution (NDC)	2015 (revised 2021)	In September 2012, the Federal Executive Council approved the Nigeria Climate Change Policy Response and Strategy and in 2015 the Nigeria NDC was approved. The NDC set conditional and unconditional objectives as 20% and 45% respectively. In its recent revision of its NDC its unconditional pledge is unchanged while its conditional reduction pledge raised from 45% to 47%, which can be conditionally achieved dependent on sufficient financial assistance, technology transfer and capacity building.	Federal Ministry for the Environment
Sustainable Energy for All (SEforALL) Action Agenda	2015	The SEforALL Action Agenda was developed by the FMP. The document provides useful information on energy access and energy efficiency as well as the renewable energy potential and market in Nigeria and relevant policies and barriers to be overcome. Targets include 30 GW of electricity by 2030, with a renewable energy share of 30%.	Federal Ministry of Power
National Renewable Energy and Energy Efficiency Policy (NREEEP)	2014	The NREEEP was developed in 2014 by the FMP to outline measures for promoting energy efficiency and renewable energy in Nigeria.	Federal Ministry of Power
National nuclear programme strategic plan (SP-2015)	2009 (revised 2015)	The SP-2015 was developed by the National Atomic Energy Commission. The goal of the Plan is the deployment of 1 000 megawatts (MW) of nuclear power in Nigeria by 2025 and 4 800 MW by 2035.	National Atomic Energy Commission

Policy/Action plan	Year	Short description	Responsible agency
National Biofuel Policy and Incentives	2007	This policy is aimed at creating a viable biofuels industry, reducing the nation's dependency on gasoline and reducing pollution of the environment. It targets 10% for fuel ethanol and 20% for biodiesel blending ratio by 2020.	Federal government of Nigeria
National Energy Master Plan (NEMP)	2007 (revised 2014)	The NEMP of 2007 defines the execution framework for the National Energy Policy. It covers all energy sources, energy consumption, capacity development, energy financing, energy database and the project cycle (planning, implementation, and monitoring and evaluation). The NEMP sets targets for the share of renewable energy (excluding large hydro) in the national energy sector to increase from 0.7% in the short term (2006-09), to 3.3% in the medium term (2010-15) and 10.6% in the long term (2016-30).	Energy Commission of Nigeria (ECN)
Rural Electrification Strategy and Implementation Plan (RESIP)	2006 (revised 2014)	The RESIP was initially prepared by the Power Sector Reform in 2006 and redrafted by a national power sector committee in 2014. Its aim is to expand electricity access in a cost-effective way, for both off-grid and on-grid electricity supply. The goal of RESIP is to achieve the electricity access target of 75% by 2025 and 90% by 2030 with at least 10% renewable energy sources *e.g.* hydro, wind, solar, etc. by 2025.	Rural Electrification Agency
National Renewable Energy Master Plan (REMP)	2005 (revised 2012)	The REMP was developed in 2005 by the ECN in collaboration with the United Nations Development Programme (UNDP) and was later revised in 2012. The REMP sets out Nigeria's roadmap for increasing the national deployment of renewable energy and promoting sustainable development. The renewable energy capacity targets for the national power sector are 4 628 MW (10%) for 2015, 15 966 MW (18%) for 2020 and 63 032 MW (20%) for 2030.	Energy Commission of Nigeria
National Energy Policy (NEP)	2003 (revised 2006, 2013 and 2018)	The NEP initially published in 2003 and later revised in 2006, 2013 and 2018. It was developed and implemented by the ECN. It covers all aspects of the energy sector, including renewable energy, energy efficiency and rural electrification. It defines, among others, a national target for 75% electrification rate by 2020 and a reduction of electricity generation, transmission and distribution losses from 15-40% in 2013 to less than 10% by 2020.	Energy Commission of Nigeria

For the PES, it was assumed that the various programmes outlined in the Nigerian energy/climate policies would be realised. The main policy documents that served as the base for the PES scenario are:

- NEP
- NREAP
- NEEAP
- NDC
- Nigeria SEforALL Action Agenda
- RESIP

The stakeholder review workshop held in Abuja in January 2020 was instrumental in harmonising these various plans and policies with the latest developments in the country that have occurred since these documents were published. The final workshop held in Abuja in December 2022 was also essential in confirming the final study results were nationally representative. However, the other policy programmes shown in Table 5 which are not explicitly stated in these aforementioned documents have supported the development of the scenarios in terms of targets and structure overall. Further information in this regard for each sector and key technologies are available in Appendix B.

In addition, it is assumed that diffusion of efficient and new technological options will continue based on previous and likely future trends without any substantial extra policy interventions. Where there was doubt on the feasibility of policy targets/frameworks, stakeholders' opinions were taken accordingly. There were also additional scenarios to explore the impacts of differing growth trajectories as discussed in section 2 to help provide a deeper understanding of sensitivity of the pathways developed to these assumptions.

The proceeding sections present the development of the Nigerian energy system out to 2050 based on these aforementioned assumptions and methodology in terms of demand projection (as presented in Appendix B) and how these demands are met in accordance with current policies and plans using The Integrated MARKAL-EFOM System (TIMES) modelling framework (as presented in Appendix B).

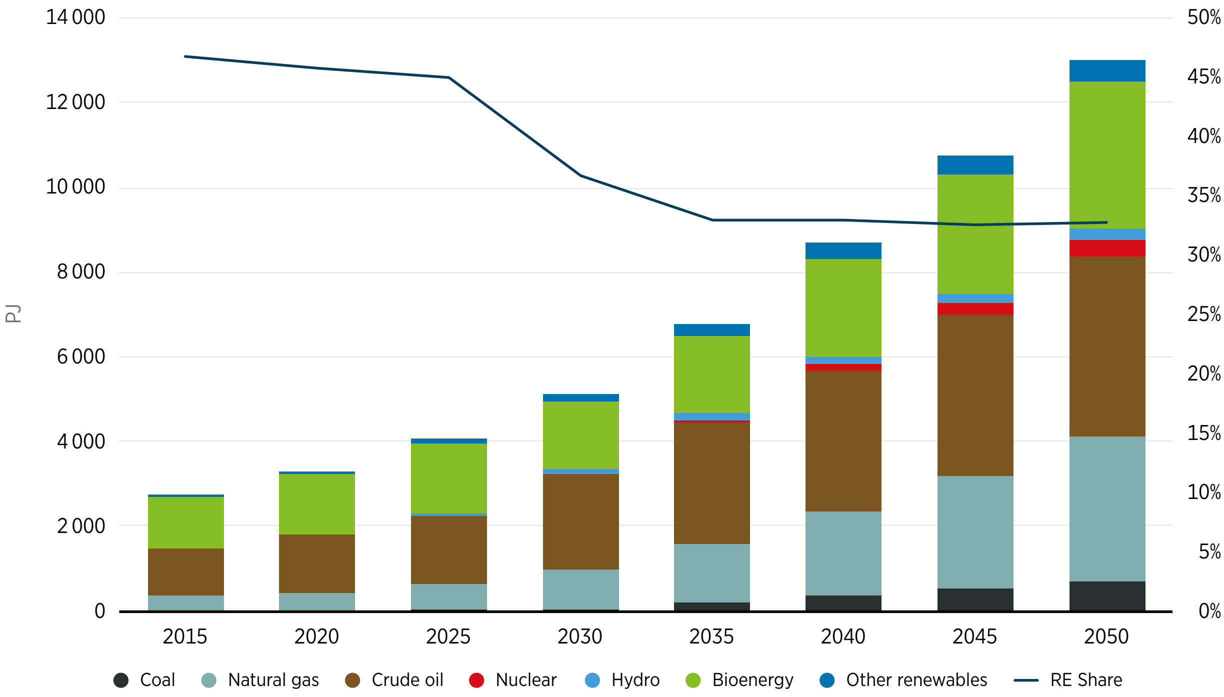
Primary energy requirement

Figure 13 shows the primary energy supply for the PES which represents a view on energy supply based on current and planned policies under a 7% GDP growth rate. Here, the total primary energy supply reaches 5 138 petajoules (PJ) by 2030 and 13 044 PJ by 2050. This indicates a rise by about five times in 35 years largely attributed to the substantial expansion of the economy and population.

Bioenergy is the dominant energy source in 2015 but its share declines from 43% in 2015 to 33% by 2030 and 27% by 2050, while supply rises from 1 129 PJ in 2015 to 1 622 PJ by 2030 and 3 478 PJ by 2050. Although the magnitude of supply of crude oil increases over the modelling time frame, its share in total primary energy mix is set to decline after 2030. The share of crude oil in the supply mix rises from 41% in 2015 to 45% by 2030 and then declines to 33% by 2050.

The 2050 decline in the share of crude oil in primary energy supply mix is on account of the expansion of the utilisation of other energy sources such as natural gas as well as renewables. For the modelling time frame, upward growth is observed in natural gas. Figure 13 shows that the share of natural gas rose from 18% in 2015 to around 24% by 2030 and 2050. Despite the magnitude of coal rising in the supply mix from 5 PJ in 2015 to 39 PJ (2030) and 696 PJ (2050), its share remains around 1% by 2030 and 6% by 2050. This can be attributed to the low domestic utilisation of coal in the country. Analysis shows that "other renewables" will increase from 17 PJ in 2015 to around 161 PJ by 2030 and 512 PJ by 2050. The share of "other renewables" in primary energy mix will grow modestly from less than 1% in 2015 to around 3.5% in 2030 and 4.3% by 2050. Thus, by 2030 and 2050 in the PES, renewables (hydro, bioenergy and "other renewables") will account for

Figure 13 Primary energy requirement under current plans and policies

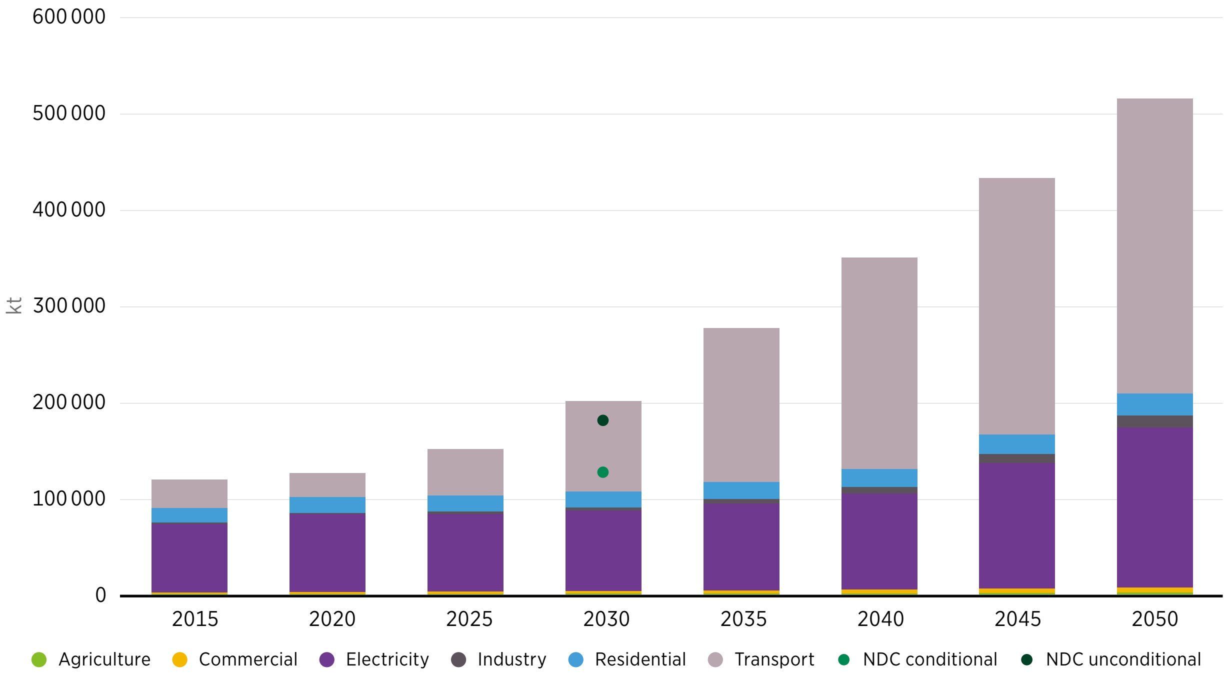


around 37% (2030) and 33% (2050) of the primary energy supply mix.

Carbon emissions

The total carbon dioxide (CO_2) emissions from the energy sector increase from 119 million tonnes (Mt) in 2015 to 201 Mt in 2030 and 516 Mt in 2050 Figure 14, which corresponds to an increase of over threefold in 35 years. In the PES, the unconditional NDC CO_2 emissions target for 2030 is met but that the conditional NDC requirement would not be. In 2015, electricity generation is the largest source of CO_2 emissions in the energy sector. However, by 2030, the transport sector becomes the largest source of CO_2 emissions in the energy sector and maintains this position up to 2050, owing to the huge growth of the fossil-powered transport system. In 2030, within the energy sector, transport emissions account for 47% and increase to 59% by 2050. The decline in the share of the power sector in total CO_2 emissions from the energy sector can be attributed to the rapid growth of renewable energy technologies deployment in the power sector, which are cost-effective to install at scale even without additional incentives.

Figure 14 CO_2 emissions by sector based on current plans and policies



Note: kt = kilotonnes.

Final energy demand

The total final energy demand under current and planned policies grows from 2 155 PJ in 2015 to 3 765 PJ in 2030 and 10 351 PJ in 2050, increasing over four times in 35 years. The total final energy demand of the transport sector grows at the fastest pace, with a compound annual growth rate of 6.8%.

Figure 15 shows that the percentage share of the residential sector in final energy demand is largest in 2030, accounting for around 35% of the total. However, by 2050, the transport sector overtakes it and contributes the most to final energy demand with a share of about 45%. The share of the residential sector is seen to fall over time since the size of its energy consumption grows slowly, while that of the commercial and agriculture sectors grows more slowly across study horizon. The renewable energy share of total final energy consumption (TFEC) is also anticipated to decrease along the study horizon from just below 50% in 2015 to about 40% in 2050. The substantial growth in renewable energy use in industry, as shown in Table 6, does not mitigate the rapid expansion of the transport sector, where the renewable energy share is only 7% by 2050. The growth in demand in the residential sector is not that significant compared with other sectors; in proportional shares of TFEC it goes from 49% in 2015 to just 18% in 2050. This owes to demand growth in other sectors but is also due to significant efficiency gains over the period achieved through the roll-out of clean cooking technologies. The composition of final energy demand trajectories for each sector are further elaborated in the proceeding subheadings of this section.

Figure 15 Total final energy consumption by sector under current plans and policies

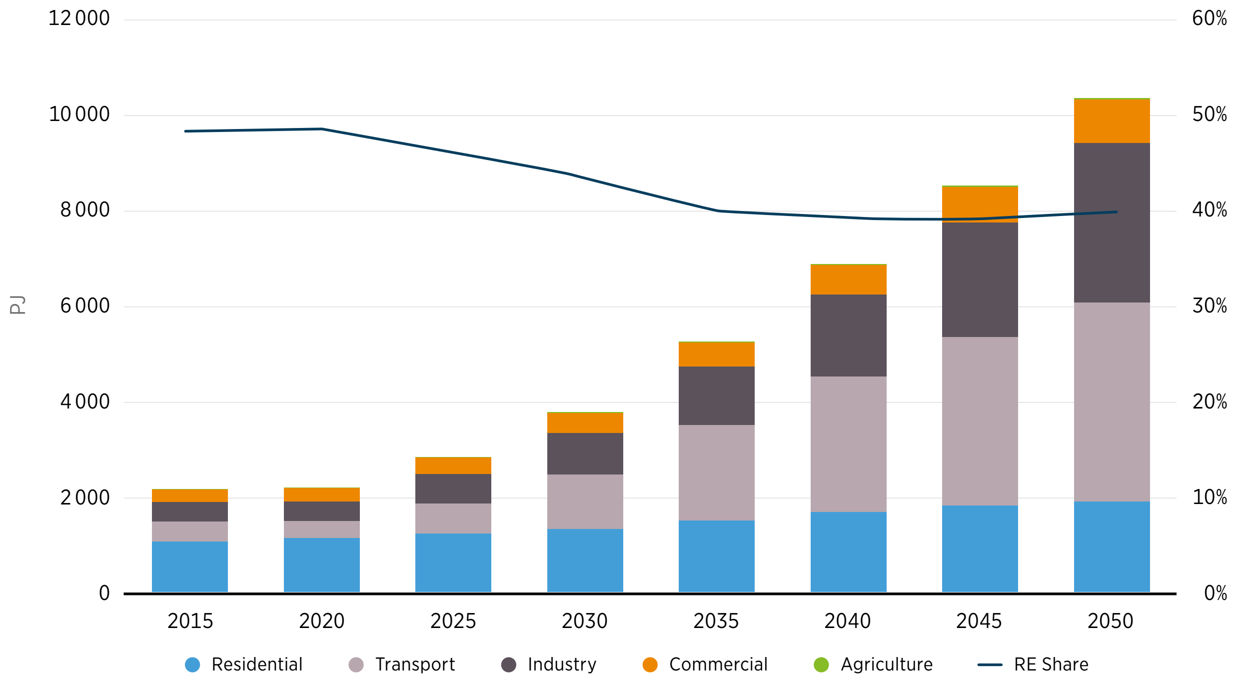
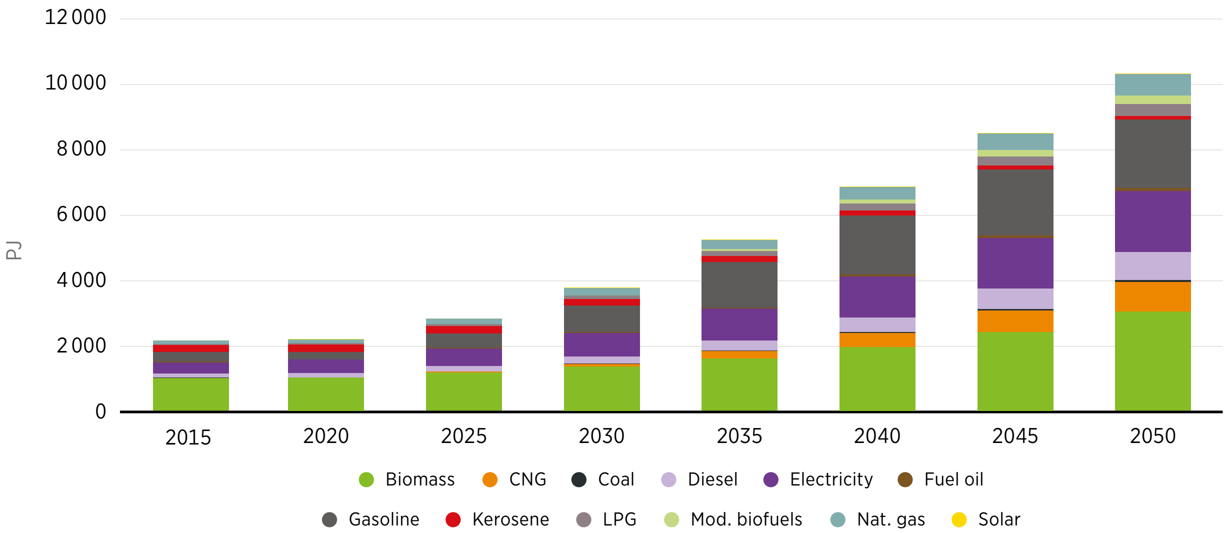


Table 6 Renewable energy by sector under current and planned policies (PJ)

	2015	2020	2030	2040	2050
Residential	710	721	826	1 018	949
Transport	0	0	18	123	277
Industry	239	239	580	1 208	2 417
Commercial	92	102	210	354	480
Agriculture	0	0	0	1	2

Figure 16 further elaborates on the final energy consumption as projected in Figure 15 with the most notable expansion in energy use coming from gasoline, diesel and natural gas, whose use expands very substantially as a result of its increased use in the transport sector. Meanwhile, the use of biomass substantially increases out to 2050, expanding threefold in energy terms as a result of increased use in industrial applications while its use in the residential and commercial sectors reduces due to increased electrification of these end uses.

Figure 16 Final energy consumption by fuel under current and planned policies



Note: CNG = compressed natural gas; LPG = liquefied petroleum gas.

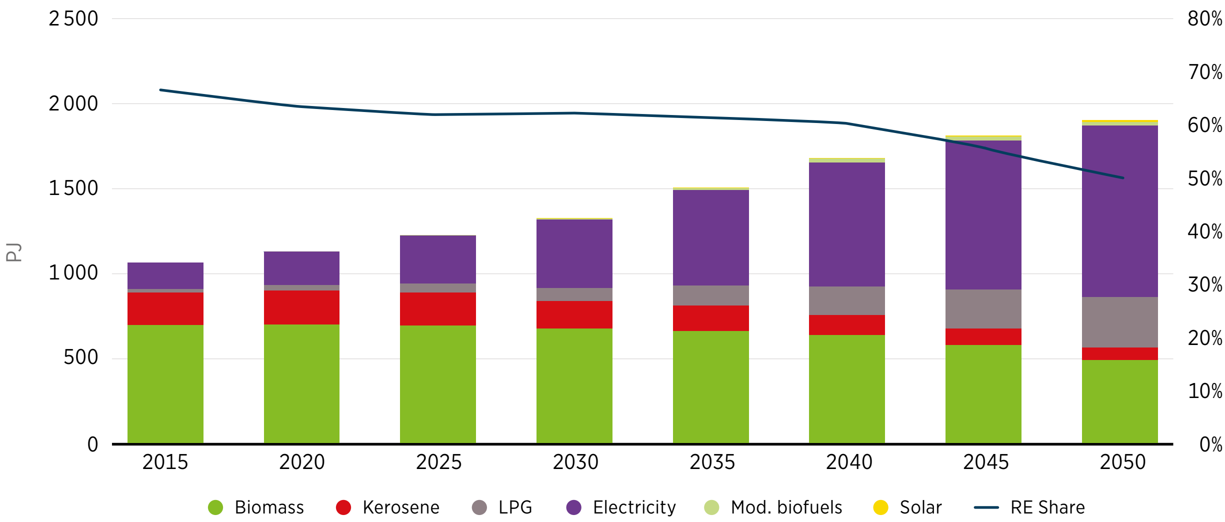
End-use sectors

Buildings

- **Residential**

Figure 17 illustrates the final energy demand of the residential sector by fuel for the PES. The final energy demand of the residential sector in PES grows from 1064 PJ in 2015 to 1327 PJ in 2030 all the way to 1906 PJ in 2050, which corresponds to a near doubling across the 35-year modelling time frame.

Figure 17 Final energy consumption for the residential sector under current and planned policies



Note: RE = renewable energy.

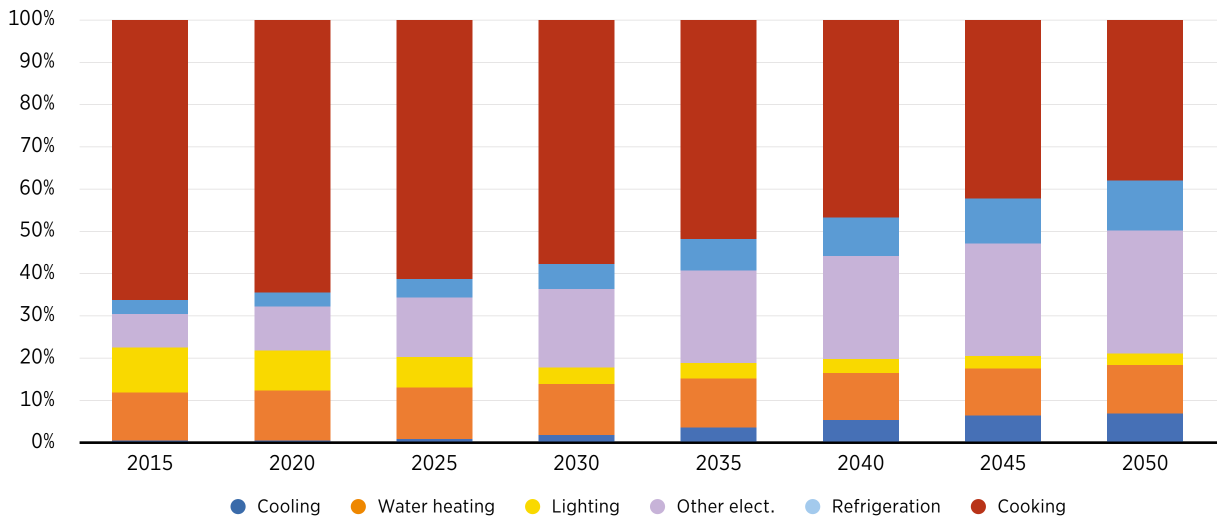
Biomass continues to be an important source of energy, especially in rural areas, as it is used for cooking and water heating. This analysis shows that biomass will remain the dominant energy source by 2030 with a share of around 51%. However, with the penetration of more efficient cookstoves, as well as the growth of other energy services, the share of biomass in 2050 declines to 26%.

In the residential sector, several factors have formed part of the PES in terms of the level of energy access and penetration of efficient and advanced appliances. In terms of electricity, 100% access to electricity is achieved by 2030 in the urban areas but achieved only by 2035 in the rural areas. In the PES, 100% access to clean cooking devices is not achieved in either rural or urban areas.

Owing to greater appliance penetration and the rate of electrification, the electricity demand of the sector increases over five times from 156 PJ in 2015 to 1 012 PJ in 2050 – making electricity the largest contributor to the final energy demand of residential sector in 2050 (53%). With respect to the share of modern renewable energy in the PES, they reach 11% in 2030 and 24% in 2050, inclusive of the renewable share of electricity and exclusive of traditional biomass. This is, however, mitigated by the greater penetration of efficient refrigerators and air conditioners, which are assumed to rise in both rural and urban households from 20% in 2015 to about 40% in 2030 and 70% in 2050. Given that 100% electrification is anticipated to be realised after 2035 (in rural areas), the use of kerosene lanterns for lighting stops after this. Efficient lighting technologies such as compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs) also penetrate into the rural households at a faster rate while incandescent bulbs are phased out completely by 2030.

These changes in demand and efficiency in supply of energy service demands, as shown in Figure 18, have a profound effect on the shares of energy demand of different energy services, with the strongest being in terms of the reduced share of cooking and increased share other electrical appliances.

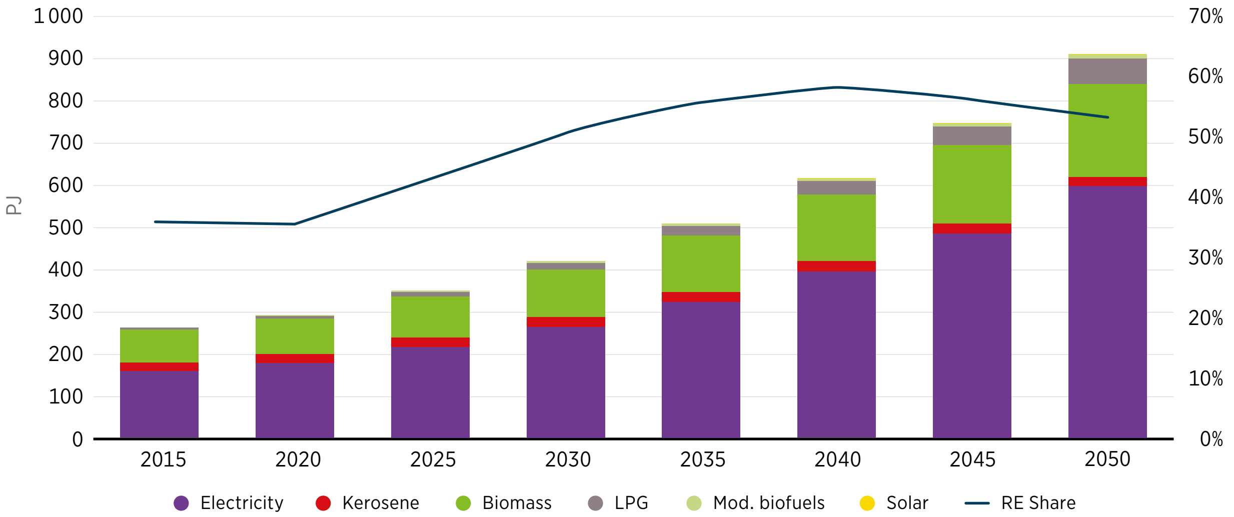
Figure 18 Percentage contribution to residential energy demand under current and planned policies



- **Commercial**

Figure 19 illustrates the final energy demand of the commercial sector by fuel for the planned energy scenario. The final energy demand in the commercial sector grows from 260 PJ in 2015 to 417 PJ in 2030 and 907 PJ by 2050. The two primary fuel sources for the rising energy demand in this industry are electricity and biomass. In comparison to the base year value from 2015, electricity consumption in the sector thus rises by approximately 66% in 2030 and by 277% in 2050.

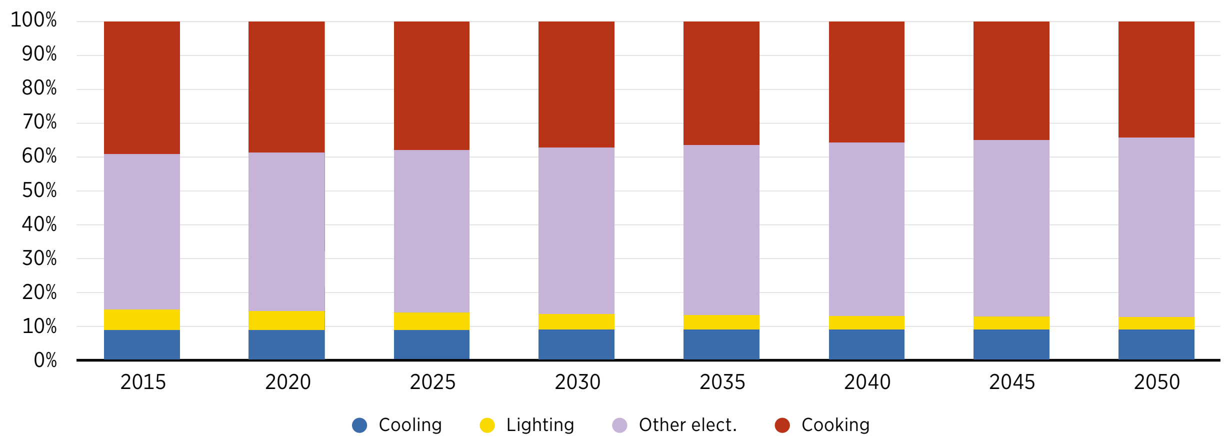
Figure 19 Final energy consumption for the commercial sector under current and planned policies



This stems from the energy service demands of the commercial sector for lighting, air conditioning, cooking and other electrical appliances being met with more efficient appliances over time due to the push for energy efficiency improvements in the NEEAP and NREAP. With respect to the renewable energy share, the commercial sector reaches a share of about 50% in 2030 and 55% in 2050. However, as shown in Figure 19, despite the changes in efficiencies of appliances, the composition is only expected to shift modestly with cooking decreasing and other electrical appliances increasing due to efficiency improvements and demand growth with the expansion of the economy driving a greater breadth of energy service demands.

The total final energy demand overall under current and planned policies increases over four times in 35 years.

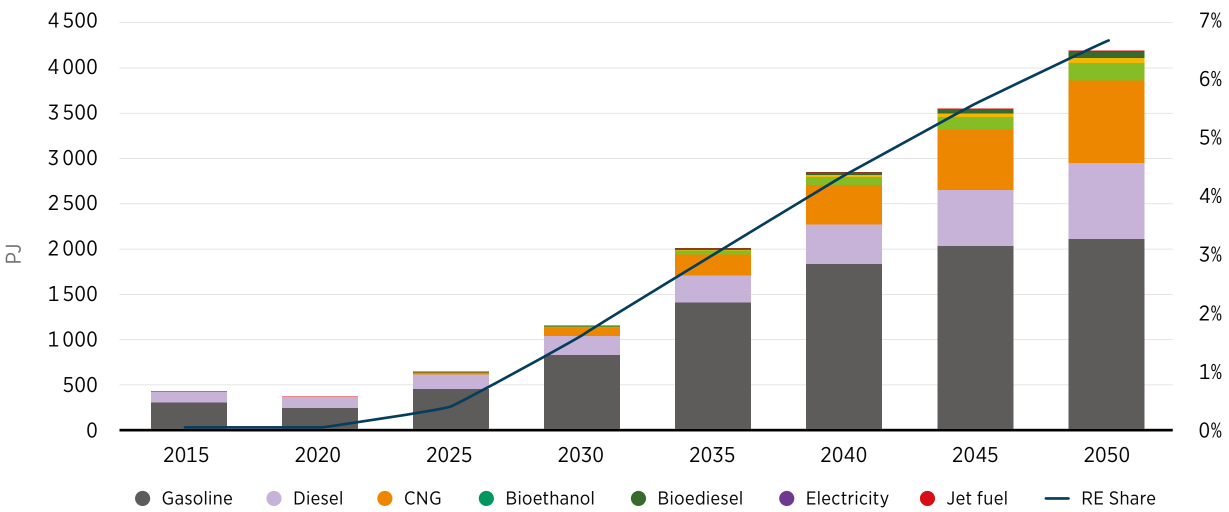
Figure 20 Percentage contribution to commercial energy demand under current and planned policies



Transport

Nigeria's transport sector is dominated (over 98%) by fossil gasoline and diesel, and Figure 21 reflects this in the final energy demand of the transport sector by fuel under planned and current policies. The final energy demand of the transport sector grows from 418 PJ in the base year to 1137 PJ by 2030 and 4172 PJ by 2050. This sizeable increase in demand by the transport sector can be ascribed to the immense growth in use of private cars – a more energy-intensive mode of transport for passenger movement. As income levels grow, the purchase of private vehicles increases and this leads to higher growth of transport energy demand. In 2015, gasoline and diesel were used to meet around 99% of the sector's energy demand. The Nigerian government launched its National Gas Expansion Programme in late 2020; this programme promoted the distribution of CNG across gas stations operated by state energy company Nigerian National Petroleum Corporation (Central Bank of Nigeria, 2020). Thus, in line with this the share of diesel and gasoline in the transport sector is anticipated to reduce to 90% in 2030 and 70% in 2050 on account of the gradual adoption of CNG, biofuels and electric vehicles (EVs) in the PES.

Figure 21 Final energy consumption for the transport sector under current and planned policies



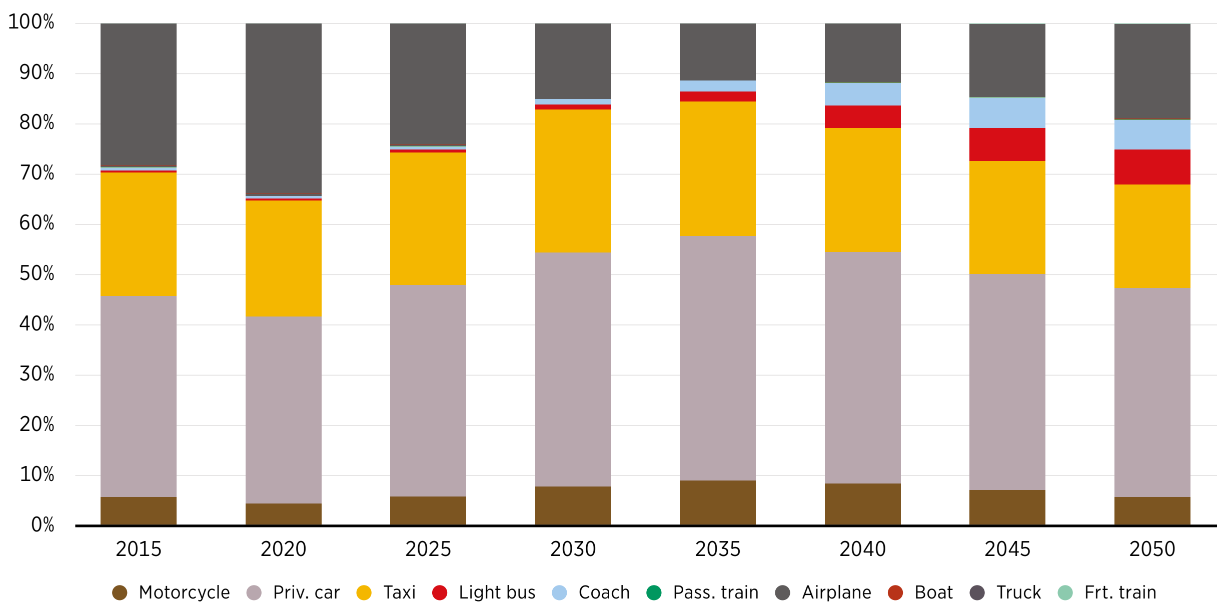
The National Biofuel Policy (NNPC, 2007) and the NREAP both push for the expansion of biofuels usage in the transport sector. Using first-generation biofuels, the target of the NREAP is to achieve 57% ethanol as share of gasoline consumption by 2030 and 17% biodiesel as share of diesel and fuel oil consumption by 2030. However, these are not assumed to be met in the PES with only very modest fractions achieved by 2050 as a conservative assumption based on workshop consultations.

The NDC and the SEforALL Action Agenda envisage the use of domestic gas resources for cars; for this reason the PES assumes a modest increase in the shares of CNG- and biofuels-fuelled vehicles. It is also anticipated that the penetration of biofuels vehicles will be favoured more in comparison with EVs due to the presence of national biofuel policies and a lack of a framework for EV deployment.

The main shifts that occur in the PES in terms of the share of demand are shown in Figure 22 with a key feature being that passenger car transport demand increases strongly out to 2030 and far outpaces growth in public transport, which then picks up at the latter end of the study horizon. It is notable that despite the substantial growth, the share that it represents of transport demand remains the same in 2050 as in 2015, but the absolute growth in demand is an eightfold increase. Energy use in freight is also quite pronounced; though it decreases in proportion by a third of overall transport demand, its growth in absolute energy terms equates to approximately a fivefold increase. This scenario does not favour the penetration of EVs in Nigeria's transport system due to the lack of a dedicated EV policy in the country.

The PES shows rising energy service demands to meet the growing needs of a more affluent and expanding Nigerian population. By relying on internal combustion engines fuelled by fossil fuels in the most part, this has profound implications on the national primary energy requirement, import requirements and local air pollution; alternatives to this will be considered in the TES that positively affect these factors while meeting the growing needs of the Nigerian economy.

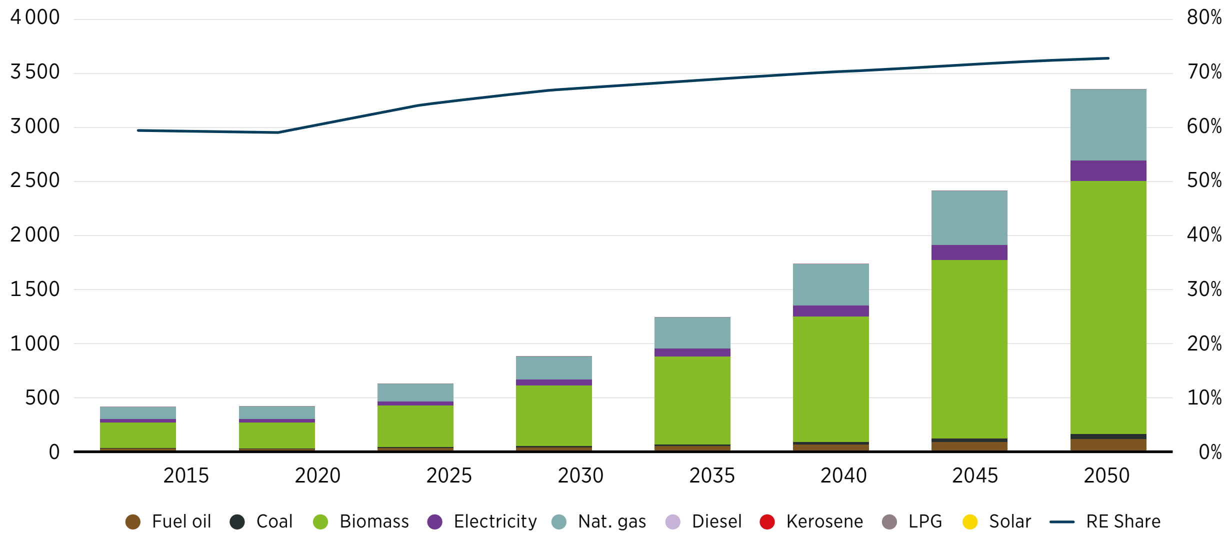
Figure 22 Percentage contribution to transport energy demand under current and planned policies



Industry

The final energy demand of the industrial sector by fuel under current and planned policies grows from 405 PJ in 2015 to 872 PJ by 2030 and 3 336 PJ by 2050, as Figure 23 Illustrates. The NEEAP target for high-energy-consuming sectors (*e.g.* industrial sectors) is that efficient energy will increase by at least 50% compared with baseline. However, the NEEAP does not provide baseline values and it does not have specific targets for key appliances/processes in the various subsectors of industry. Hence, in the PES, efficiency improvement is considered as per the historical trend and in line with the conventional technological options in the Nigerian manufacturing sector.

Figure 23 Final energy consumption for the industry sector under current and planned policies

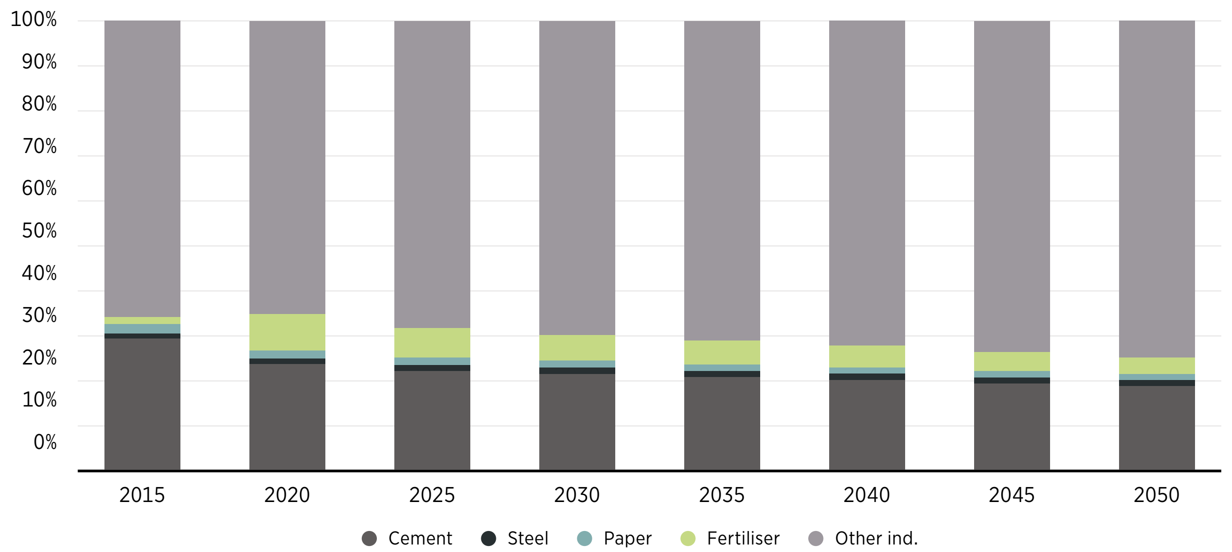


Biomass is used to serve over half of the sector's energy requirements with an accompanying energy consumption which rises by nearly seven times across 35 years. This immense growth in industrial energy consumption is largely due to the growth of manufacturing of energy-intensive products (such as cement, steel, fertiliser, etc.) for infrastructural requirements and the growth in the demand for food, among others. Natural gas and petroleum products are the next most-consumed fuels by the sector. The renewable energy share in the current and planned policies reaches 67% in 2030 and 72% in 2050.

The continuous liberalisation of the Nigerian market is predicted to lead to energy-intensive industries, such as those of cement and fertiliser, improving their energy efficiency levels by adopting state-of-the-art and advanced technologies. The increased competition in such industries will help make energy savings and efficiency through their impact on costs and profitability, though this impact will vary depending on the sectors and corresponding technologies. In the cement sector, the use of wet process is minimised and phased out by 2050 and the use of dry processes with 4-6 stage preheater + precalciner is expanded to account for 100% of cement production processes by 2050. Generally, it is assumed as per the NEEAP that the specific energy consumption (SEC) of these large-scale industrial subsectors will improve, but it has been implemented in this study by the adoption of new and advanced technologies (which have better SEC) over the study time frame.

The “other industries” sector mainly consists of small and medium-sized enterprises, mostly consisting of informal industries. Moreover, their fragmented nature remains a barrier to their swift adoption of energy-efficient technologies and sees them increase as a proportion of industrial energy demand out to 2050, as shown in Figure 24

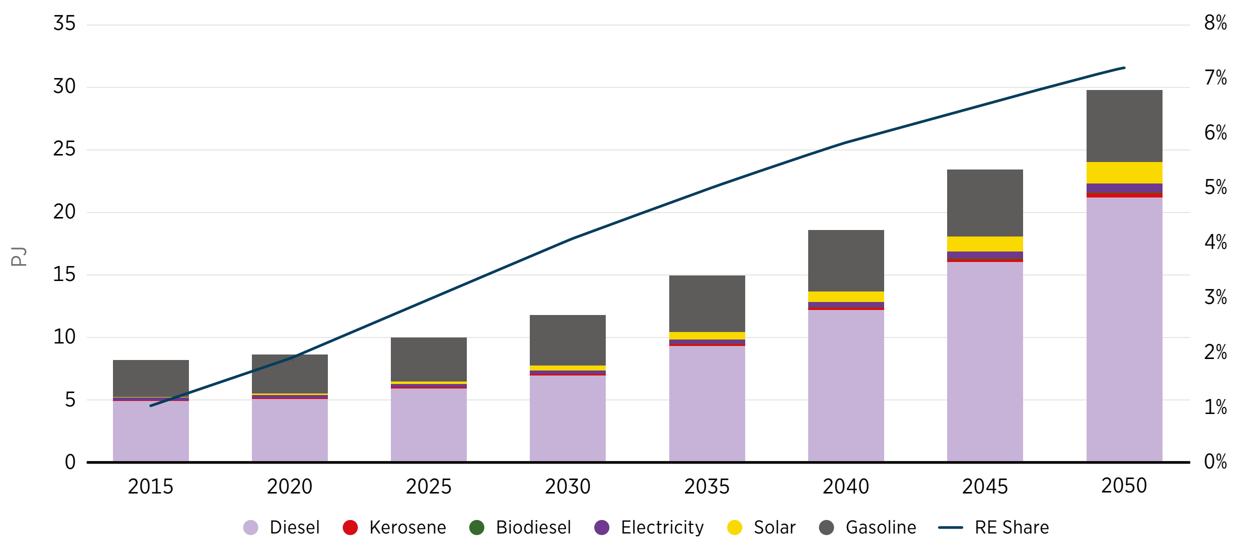
Figure 24 Percentage contribution to industrial energy demand under current and planned policies



Agriculture

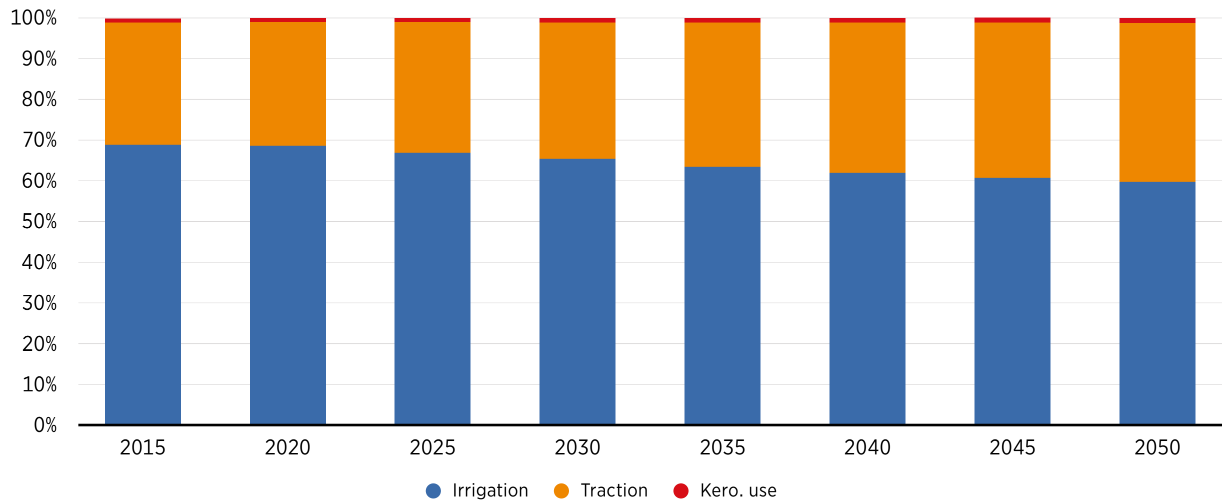
Energy in the agriculture sector is primarily needed for irrigation and land preparation. In Figure 25 the final energy demand under current and planned policies for the agriculture sector by fuel is shown to rise from 8 PJ in 2015 to 12 PJ in 2030 and 30 PJ in 2050. Diesel is the main fuel used in the sector and it is mainly applied in irrigation water pumping as well as in tractors.

Figure 25 Final energy consumption for the agriculture sector under current and planned policies



In 2015, gasoline was assessed as having a share of 55%,, diesel 45% and grid-based irrigation pumps 5%, with the share of solar-based pumps serving demand being negligible. Over the horizon of the study it is expected that the share of solar-based irrigation pumps reaches 5% by 2030 and 10% by 2050 while the share of advanced electric grid-powered pumpsets in irrigation is assumed to gradually increase to 8% by 2030 and 25% by 2050. In addition, the share of biofuel-powered tractors increases from 0% in 2015 to 5% by 2030 and 15% by 2050. Furthermore, the share of efficient diesel-based tractors in the sector is assumed to gradually improve. Thus, the renewable energy share in the agricultural sector is expected to remain low under planned and current policy, going from a share of about 1% today to 4% in 2030 and 7% in 2050.

Figure 26 Percentage contribution to agricultural energy demand under current and planned policies



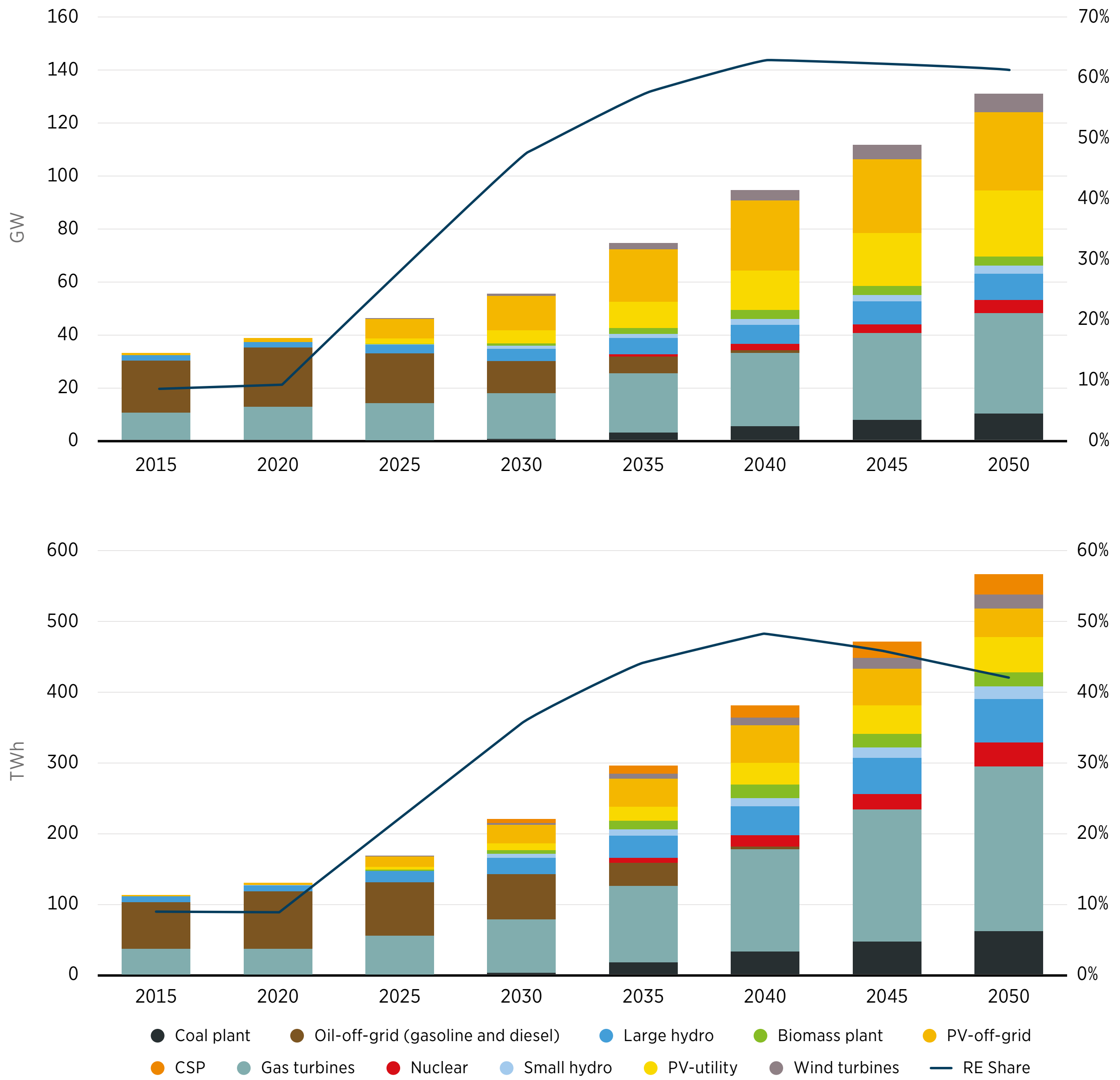
Power sector

Total installed capacity, off-grid included, grows from 33 GW in 2015 to around 56 GW by 2030 and 136 GW by 2050, reaching a renewable share of 60% in 2050, driven primarily by the cost reductions of renewable energy technologies which make them essential considerations in the expansion of capacity. This corresponds to an increase of over three times in overall generation capacity compared with the base year (2015). The analysis shows that captive generation (oil) will decline to 12.1 GW by 2030 and then will be totally flushed out of Nigeria's installed power capacity mix by 2050. However, this understanding is based on the assumption that the PES is fully implemented. Despite the expansion of renewable energy capacity in this scenario, fossil generation (gas, oil and coal) are set to dominate the total installed capacity by 2030 with a share of around 53%. However, by 2050, the share of fossil generation declines to 35.4% on account of the expansion of renewable energy capacity in the system as well as the development of nuclear power. The share of renewables (including large hydro) in total capacity by 2030 is 47% and by 2050 is 61%. Off-grid photovoltaic (PV) systems continue to account for the maximum share of the total installed capacity of renewable energy technologies. Off-grid systems currently supply the majority of capacity at a share of 62%, which drops to 45% by 2030 and 22% by 2050, indicating a more robust centralised power system serving the majority of capacity needs in Nigeria by the end of the decade.

In terms of power generation, the evolution over time corresponds to the expansion of generation capacity, which shows that total electricity production increases from 112 terawatt hours (TWh) in 2015 to 220 TWh in 2030 and 566 TWh in 2050. The share of renewable energy in total power generation rises from 9.2% in 2015 to 35.5% in 2030 and 42% in 2050. off-grid PV systems account for the largest source of renewable energy power generation by 2030. However, by 2050, large hydro becomes the largest source of renewable power generation, followed by utility-scale PV and then off-grid PV. In reality, this may not be the case as the choice of technologies is not always based on least-cost solutions.

Figure 27 shows the installed capacities and electricity generation for each electricity supply technology in the central PES and this is further unpacked for each technology considered.

Figure 27 Centralised and decentralised power generation capacity and generation under current plans and policies



Box 1

IRENA and IAEA to help African Union develop continental power master plan

IRENA and the International Atomic Energy Agency (IAEA) have been selected as modelling partners for the development of the African Continental Power Systems Master Plan (CMP). The initiative is led by the African Union Development Agency (AUDA) with the technical and financial support of the European Union, and is aimed at establishing a long-term continent-wide planning process. The two agencies' modelling tools will be the official planning models utilised in this initiative and both agencies will lead the development of an electricity master plan that promotes access to affordable, reliable and sustainable electricity supplies across the continent.

A unified transmission network in Africa will enable inter-country trade between African countries as well as cross-continental trade with Europe and Asia, via existing links in North Africa, allowing African countries to source electricity from a wide range of competitive, clean energy sources. It will also create beneficial socio-economic opportunities by increasing interregional access to affordable African renewable energy resources within the continent, fostering investment opportunities and job growth and ultimately contributing to the region's sustainable development.

The urgency of this task is underlined by the prospect of carbon lock-in. Existing plans in eastern and southern African countries include more than 100 GW of new coal-fired power plants by 2040 – the development of which would triple CO_2 emissions to 1200 Mt per year. Under the CMP, power generation options will be reviewed and reconsidered to maximise socio-economic benefits while simultaneously minimising emissions.

IRENA and the IAEA, as modelling partners, will support African stakeholders with the development of the CMP identifying surplus and deficit regions/countries in Africa in terms of electricity generation and demand. This will help identify the most cost-effective ways of expanding clean electricity generation and transmission infrastructure across the African continent.

IRENA and IAEA will also train AUDA-NEPAD (New Partnership for Africa's Development) staff and Power Pool experts on the use of the modelling tools, including IRENA's System Planning Test (SPLAT) models using the IAEA's Model for Energy Supply System Alternatives and Their General Environmental Impacts (MESSAGE) tool, and support the team in the development of the CMP, ensuring knowledge transfer and capacity building.

The MESSAGE-SPLAT capacity expansion models are a key component and product of IRENA's support to African countries. Built using the MESSAGE software, the agency has developed SPLAT models covering 47 African countries across the five African power pools. They have been used in IRENA's capacity-building programmes on energy planning across the continent.

The IAEA and IRENA co-operate on energy planning with a view to enhancing the effectiveness and impact of capacity-building efforts by joining the complementary competencies of the two organisations. This process could be helpful for Nigeria, in particular with respect to the TES, as it would show how the Nigeria power sector would operate within a broader regional power system which in turn would allow an understanding be gained of the key benefits of regional integration of renewable power and how it could be achieved.

4.2 Transforming Energy Scenario to 2050

This section discusses the TES, which is an assessment of the accelerated potential of renewable energy in Nigeria. The key findings relate to the REmap Options, which are renewable energy technologies and sources that have additional potential to be utilised or deployed on top of developments in the PES. This section's main aim, therefore, is to outline where the additional potential of renewable energy lies in Nigeria, both in meeting the aims of existing energy policies/plans and also increasing renewables even further. Further information in this regard for each sector and key technology is available in Appendix B. The REmap Options explore the potential to increase renewables across all sectors of Nigeria's energy system – it uses a mixed approach aimed at maximising renewable energy deployment and looks at options in power, buildings (both residential and commercial), transport, industry and agriculture applications. It also evaluates these renewable options in terms of their costs, benefits and investment needs. The TES is not intended to replace the PES; rather, it seeks to provide another development pathway strongly based on renewable energy technologies and can serve as a complement to the existing energy policies and plans.

Drivers for renewable energy

The REmap Options identify areas across Nigeria's entire energy system where additional potential for using renewable energy lies. The criteria for selecting these options are not based solely on cost, but also on additional motivating factors that incline governments to support increased deployment of renewable energy technologies. These factors can include efforts to improve energy security, develop the domestic value chain and the resulting job creation, and to reduce adverse health effects, environmental damage and mitigation of climate change.

The REmap Options do show that renewables are in many cases the least-cost option for energy supply in Nigeria, especially in areas not connected to the grid. The cost case is even more appealing when considering benefits that arise from reduced air pollution and CO_2 emissions. As the costing section shows, the grouping of technologies identified in REmap not only reduce energy system costs as a whole – meaning lower overall energy costs for consumers – but also result in at least twice as much savings from reduced externality costs due to lower levels of air pollution and environmental damage.

Fossil fuels carry price volatility risk, particularly where they are imported. Valuing this risk is difficult, but should be considered when evaluating energy system investments. The renewables identified in this section either have no fuel price volatility (such as for solar, wind or hydro resources), or in the case of bioenergy are based largely on the local agro-economic conditions, which generally affords government more control over the market and certainty on how costs will develop over time.

The sections that follow go into more depth on what additional potential is available, in which technologies and sectors. They also quantify those technologies and sources in terms of their costs, benefits and investment needs. Below is a short summary of the key findings:

Box 2

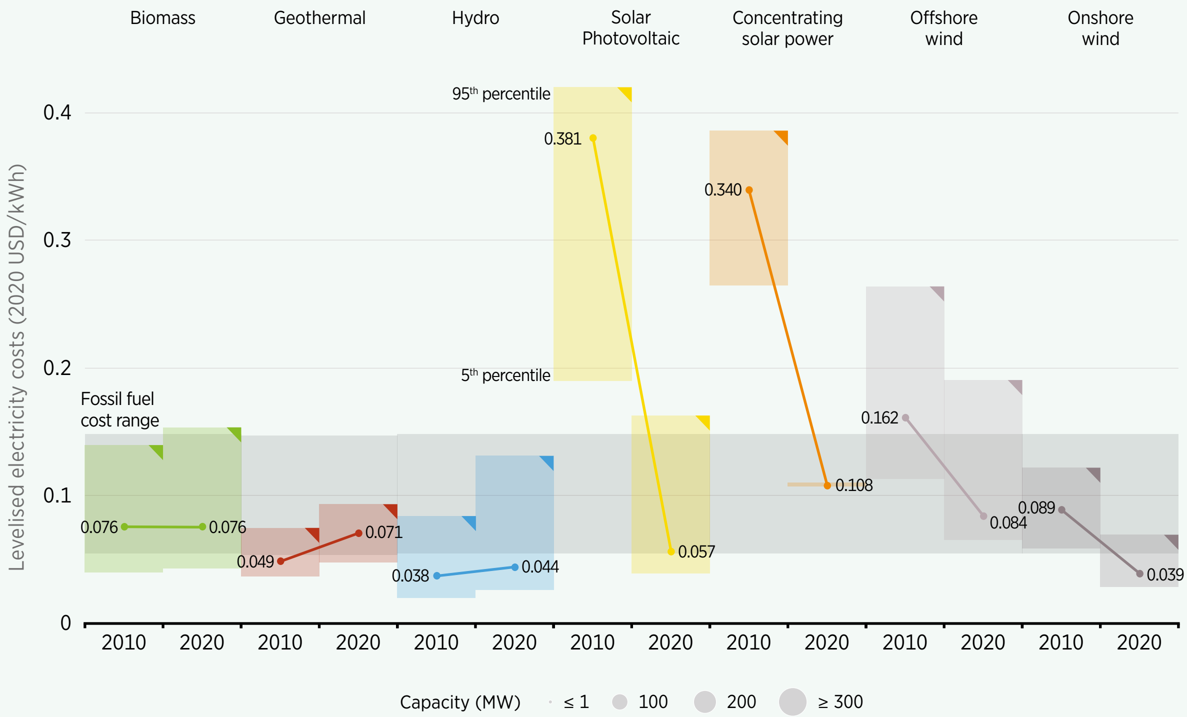
Renewable power generation cost trends, 2010-2020: A decade of falling costs

The decade 2010 to 2020 represents a remarkable period of cost reduction for solar and wind power technologies. The combination of targeted policy support and industry drive has seen renewable electricity from solar and wind power go from an expensive niche to head-to-head competition with fossil fuels for new capacity. In the process, it has become clear that renewables will become the backbone of the electricity system and help decarbonise electricity generation, with costs lower than a business-as-usual future.

New solar and wind projects are increasingly undercutting even the cheapest and least sustainable of existing coal-fired power plants. IRENA analysis suggests 800 GW of existing coal-fired capacity has operating costs higher than new utility-scale solar PV and onshore wind, including (2020) USD 0.005/kWhfor integration costs as illustrated in Figure 28. Replacing these coal-fired plants would cut annual system costs by (2020) USD 32 billion per year and reduce annual CO_2 emissionsby around 3 gigatonnes of CO_2 (IRENA, 2021b).

These cost reductions represent an opportunity for Nigeria, given its high level of renewable energy resources. These cost reductions are a key driver in their expansion in the TES in addition to the non-cost benefits they harness such as their ability to reduce pollution and exposure to fossil fuel price fluctuations.

Figure 28 Global levelised costs of electricity from newly commissioned, utility-scale renewable power generation technologies, 2010-2020



Source: IRENA (2021b).

- In the TES the share of renewables increases across all sectors, with the largest increase in the power sector, which in turn drives increased shares of renewables in the end-use sectors.

- Overall, modern renewable energy (*i.e.* renewable energy excluding traditional biomass) can provide 10% of Nigeria's energy supply in TFEC in 2030 and 44% in 2050, up from just 1% in 2015 and the 10% achieved by 2050 in the PES.

- Modern renewables in TFEC increase from 32 PJ in 2015 to 286 PJ in 2030 and 1077 PJ in 2050 in the PES. In the TES this reaches far higher levels of 714 PJ in 2030 and 3186 PJ in 2050, an increase on the PES of over 300%.

Table 7 Renewable energy shares in 2015, 2030 and 2050 given different cases for growth of modern renewables

		2015	PES 2030	TES 2030	PES 2050	TES 2050
	Electricity generation (share of TFEC)	9% (16%)	36% (19%)	44% (22%)	42% (18%)	84% (27%)
End-use sectors (excl. traditional biomass)	Residential	1%	11%	17%	24%	61%
	Transport	0%	2%	3%	7%	39%
	Industry	1%	2%	3%	2%	36%
	Commercial	6%	23%	29%	29%	66%
	Agriculture	1%	4%	5%	7%	69%
	TFEC	48%	43%	52%	40%	59%
	TFEC (excl. traditional biomass)	1%	8%	10%	10%	44%
	Total primary energy supply	**47%**	**37%**	**47%**	**33%**	**57%**

- By 2050, the power mix moves from being one dominated by distributed diesel and gasoline generators to a much more diverse mix of technologies that includes sizeable generation from solar PV (both centralised and decentralised), concentrated solar power (CSP) and bioenergy. Power generation from solar PV is now the largest generation source by 2050 (38% of generation – of which about 30% is centralised and 70% is decentralised), followed by hydropower (17% of generation) and natural gas (16% of generation). In the TES by 2030, 84% of generation is supplied from renewable sources, a doubling over the share in the PES by 2050 and up from 9% in 2015.

- Renewables use in the end-use sectors is also important in the TES, with about 10% of fuel use in all end-use sectors being met by modern renewables in 2030 and 44% in 2050, including bioenergy and solar thermal.

- This analysis identifies additional renewable energy potential across all sectors of the Nigeria energy landscape. However, the analysis shows that the largest potential, and where the largest growth occurs, is in the power sector, where it increases the share of renewables in end-use sectors. This is especially true in the residential sector, where electricity can supply 60% of energy demand by 2050, and the commercial sector, where it can supply 72% of demand.

- The power sector sees substantial growth due to untapped renewable potential, particularly for solar PV and hydropower. In both the PES and the TES, the share of renewable energy in TFEC that comes from renewable power is always over half. In fact, 73% of the renewables in total final energy consumed in the PES is supplied by electricity in 2050, driven primarily by the cost reduction anticipated in solar PV deployment.

Overall, modern renewable energy can provide 44% of Nigerian TFEC by 2050, quadrupling the share in the PES and up from just 1% in 2015, as shown in Table 7. At the sector level, the largest share is in the power sector where over 84% of electricity comes from renewable sources by 2050. Across the end-use sectors the share of renewable energy in fuels and direct uses varies from 36% to 69% inclusive of the renewable energy share of electricity.

Looking at how these percentages translate into energy supply when viewed in final energy terms, several key findings are evident. Renewable power in Nigeria represents a substantial share of its modern renewable energy. The renewable power mix changes, moving to being a much more diverse mix of technologies that includes the majority of generation coming from solar PV. In fact, while power generation from natural gas remains substantial, oil-fired generation is eliminated in the TES by 2030 and the largest source of generation is solar PV, which is closely followed by hydropower as the second largest mode of generation. Overall, renewable power generation in the country increases over tenfold, from just 10 TWh in 2015 to 144 TWh in REmap in 2030 and 469 TWh in 2050.

Despite the substantial potential of renewable power, direct renewable energy use must also be considered in buildings, industry and transport. In these end-use sectors, energy is needed in the form of fuels and direct use for thermal, cooking and transport applications. In fact, in final energy terms these non-electrical energy needs make up just under three-quarters of TFEC in the TES by 2050 and even more in the PES due to lower electrification of end uses. Therefore, a holistic view of energy is needed, taking account of the potential of renewables for heat, fuels and other direct uses.

Bioenergy is still an important source in end-use energy applications due to its ability to be used for heat and transport fuel. Traditional bioenergy is the primary source for heat and cooking purposes in buildings (both commercial and residential) in 2015 and remains substantial out to 2030 where it serves around 45% of energy demand in both the PES and TES. However, by 2050 this is substantially reduced and in the TES, serves just 16% of overall energy demand in buildings with the profound associated health and environmental benefits. The key enabler of this reduced use of traditional bioenergy is electrification of cooking and heating end uses. Modern biofuels are applied predominantly in the transport sector where in the TES by 2050 they serve 24% demand in the form of biodiesel and bioethanol.

Solar thermal is also an important source of renewable energy in the end-use sectors of buildings and industry. The technology can provide hot water for a variety of uses in different end-use sectors. In industry, solar thermal systems can provide low-temperature heat and preheating or other process heat uses. In the TES, sizeable additional potential has been identified, raising the share of industrial sector energy supply met with solar thermal to 29% whereas 0% is achieved in the PES.

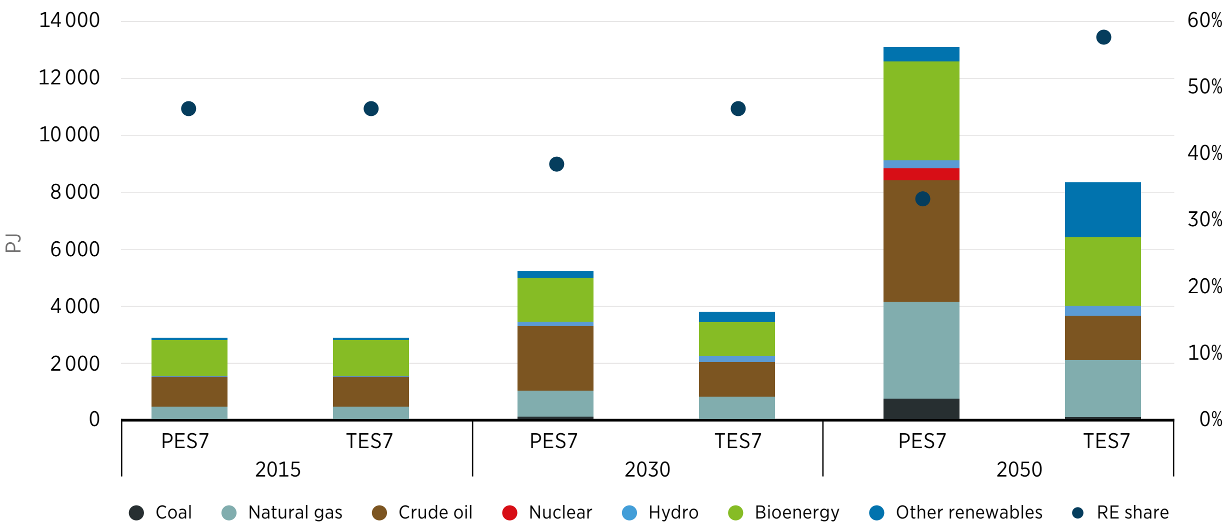
In total, the amount of modern renewable energy used in Nigeria increases from 32 PJ in 2015 to 286 PJ in 2030 and 1 077 PJ in 2050 in the PES, and increases further to 714 PJ in 2030 and 3 186 PJ in 2050 in the TES, an increase on the PES of over 300%. This would lead to modern renewable energy providing 10% of Nigeria's energy supply in TFEC in 2030 and 44% in 2050; by 2050 this equates to a quadrupling of the share achieved in the PES.

The proceeding sections present the energy systems of TES in more detail out to 2050 and contrasts it to the PES as derived using the TIMES modelling framework to allow for the differences between the scenarios to be more discernible and thus allow for potential policy comparison and assessment.

Primary energy supply

The TES substantially reduces the share of fossil fuels in the Nigerian primary energy supply mix on account of accelerated renewables deployment. The renewable energy shares in TES are about 47% in 2030 and 57% in 2050, as shown in Figure 29, resulting from the modelling performed in TIMES. Another defining characteristic of this scenario is the substantial energy savings of 22% by 2030 and 33% by 2050 when compared with the PES. This can be ascribed to the reduction in the consumption of crude oil, natural gas and traditional biomass (mainly at the residential sector). These reductions are achieved on account of high-energy efficiency strategies implemented across the various demand sectors that allow the same energy service demand to be met. Compared with the PES, the primary supply of crude oil declines by 48% (2030) and 64% (2050) due to the massive roll-out of alternative fuel vehicles in the transport sector in the TES. Additionally, due to higher penetration of clean and improved cookstoves in the residential areas, the supply of bioenergy in the primary energy supply reduces by 1.2% in 2030 and 10% in 2050 compared with the PES. It may be observed that there is no huge decline in bioenergy supply in the TES, which may seem counterintuitive; this is because despite the decline in bioenergy for cooking in the residential sector, there is very substantial growth in demand for bioenergy in the transport and power sectors. The results also indicate that due to the massive upscaling of renewable energy in this scenario, "other renewables", mainly composed of solar energy, will increase respectively, by 71% in 2030 and 171% in 2050 compared with the PES.

Figure 29 Comparison of primary energy supply in in the Planned and Transforming Energy Scenarios for 2015, 2030 and 2050



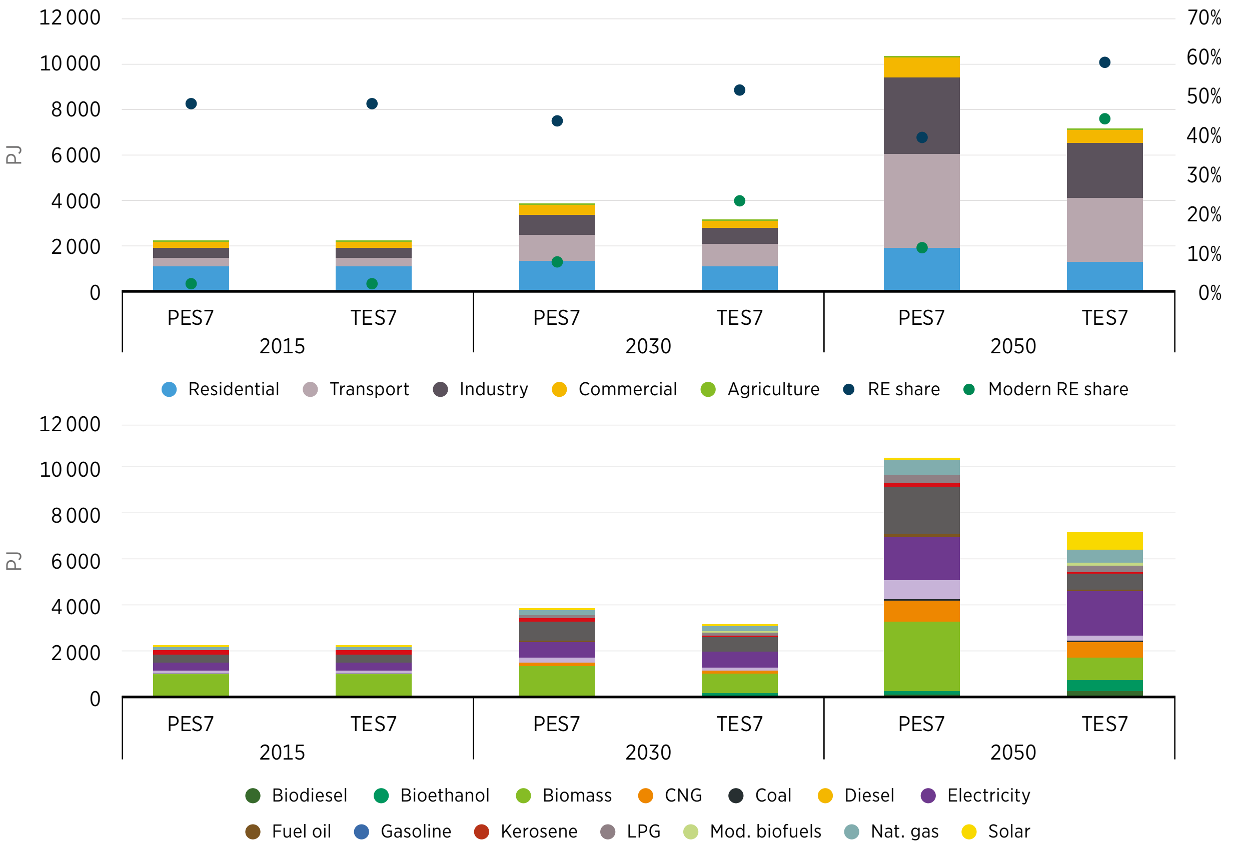
Final energy demand

Figure 30 shows the total final energy demand out to 2050 for both the PES and the TES, as derived using the TIMES Nigeria model. The total final energy demand under current and planned polices grows from 2 037 PJ in 2015 to 3 484 PJ in 2030 and 9 183 PJ in 2050, increasing over threefold. While the share of renewables in the PES is rather high at 45%, once traditional biomass usage is excluded, modern renewables in TFEC drops to below 10%. Conversely, in the TES, modern renewables meet just under 50% of demand with renewables supplying 60% overall. The total final energy demand of the transport sector grows at the fastest pace, with an average growth rate of 6.8%. In the TES, due to several demand-side management measures and fuel efficiency enhancements in the demand technologies, the final energy demand is 2 932 PJ by 2030 and 6 755 PJ by 2050 – savings of 16% and 26% respectively in comparison with the PES. These results help explain the overall energy implication of the demand management strategies implemented in the TES.

In both scenarios, the percentage share of the residential sector in final energy demand is largest in 2030, accounting for around 38% of the total energy demand. However, by 2050, the transport sector overtakes it and contributes the largest in final energy demand with a share of about 45%. The share of the residential sector is seen to fall over time since the size of its energy consumption grows slowly, while those of the commercial and agriculture sectors remain relatively constant across the modelling time frame. The lower portion of Figure 30 shows the final energy demand by fuel and reiterates the earlier discussions of reduced biomass usage; while traditional use of biomass decreases, the use of bioenergy in other sectors in terms of biodiesel and bioethanol drive its maintained importance in the TES. The much more efficient use of alternative and clean-burning fuels for cooking and water heating applications in the place of traditional biomass in particular reduce the energy input required by 26% compared with the PES in 2050 in addition to the tangential non-cost benefits in terms of health from reduced pollution and time saved from collection of wood which could be used for economically more productive uses.

The final energy demand trajectories for each demand sector are further described in the proceeding sections.

Figure 30 Comparison of final energy demand in the Planned and Transforming Energy Scenarios for 2015, 2030 and 2050



End-use sectors

Buildings

- **Residential**

Figure 31 compares the final energy demand of the residential sector by fuel, for both the Planned and Transforming Energy Scenarios, resulting from the modelling performed in TIMES. In the TES, the final energy demand of the residential sector rises to 1065 PJ by 2030 and 1281 PJ by 2050, which is about 20% and 33% lower than the demand in the planned case. This reduction can be clearly observed in electricity consumption, which is 23% lower by 2050. The demand reduction occurs due to higher diffusion of efficient appliances in the household sector such as very efficient refrigerators, water heaters, air conditioners, etc. It is worthwhile to note that 100% energy access by 2030 is achieved in this scenario. Though challenging to achieve when considering the latest developments, its achievement would have profound benefits and thus these efforts need to be accelerated to achieve universal access to clean cooking in Nigeria.

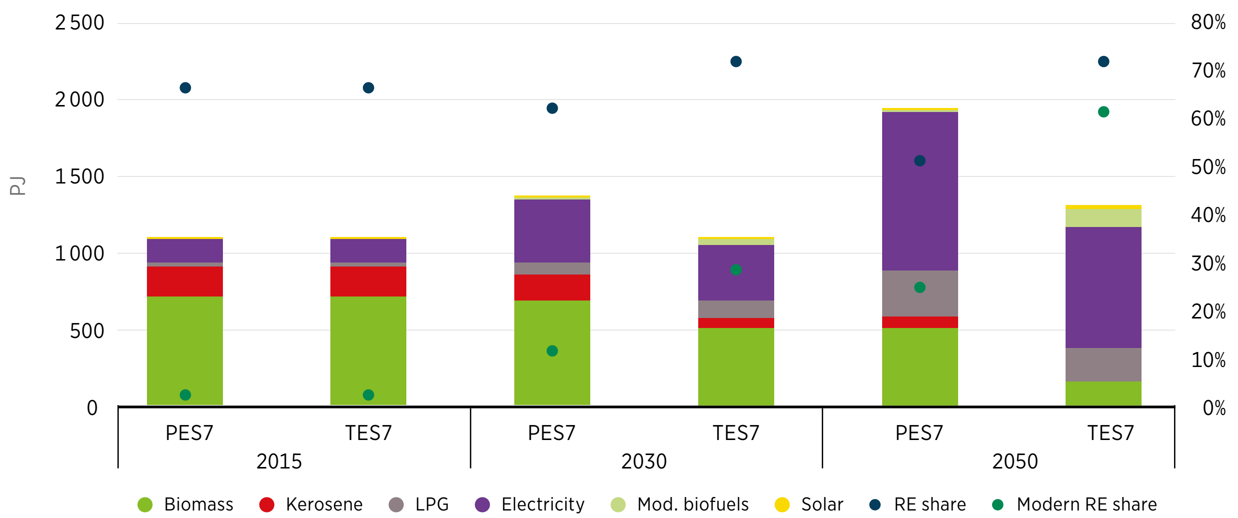
Thus, biomass consumption declines by 28% by 2030 and 71% by 2050 in the TES relative to the PES. It is also worth noting that improved cookstoves are up to three times more efficient than the conventional traditional cookstoves and substantially reduce the energy requirement for cooking. All these measures can help achieve a very substantial modern renewable share in sector which reaches 27% in 2030 and 61% in 2050.

Table 8 Indicators of progress in residential sector – status in 2015 and targets for 2030 and 2050

Residential	2015	TES 2030	TES 2050
TFEC (PJ)	1 064	1 065	1 281
Share of electricity use	15%	34%	60%
Renewable energy share	67%	72%	71%
Bioenergy share	65%	48%	20%
Solar thermal share	0%	1%	2%
CO_2 emissions (Mt per year)	15	12	14

While the TES sees 100% electricity and clean cooking access achieved in both rural and urban areas by 2030, there are differing diffusions of technologies in both areas to achieve this. It is also important to note that this would be very challenging to achieve at this point considering the current infiltration rate of these technologies by 2030. Cooking technologies have been diversified in this case with LPG stoves being the dominant choice for cooking. However, biogas has considerable uptake by rural households due to the local resource availability compared with that of urban households. Conversely, the penetration of electric stoves is assumed to be more pronounced in urban areas compared with rural areas due to closer proximity to the centralised grid. These show that differing policies and initiatives will be needed to provide accelerated energy access tailored to the specific needs of each area in the TES.

Figure 31 Comparison of final energy demand in the residential sector in in the Planned and Transforming Energy Scenarios for 2015, 2030 and 2050



The composition of overall energy demand in terms of end use in the sector remains broadly the same as in Figure 18 with only moderate shifts in the share mainly attributed to the improved efficiency of appliances used and electrification of end uses; most notably are efficient lighting, refrigerators and air conditioners, which rise in both rural and urban households to 50% by 2030 and to 100% by 2050.

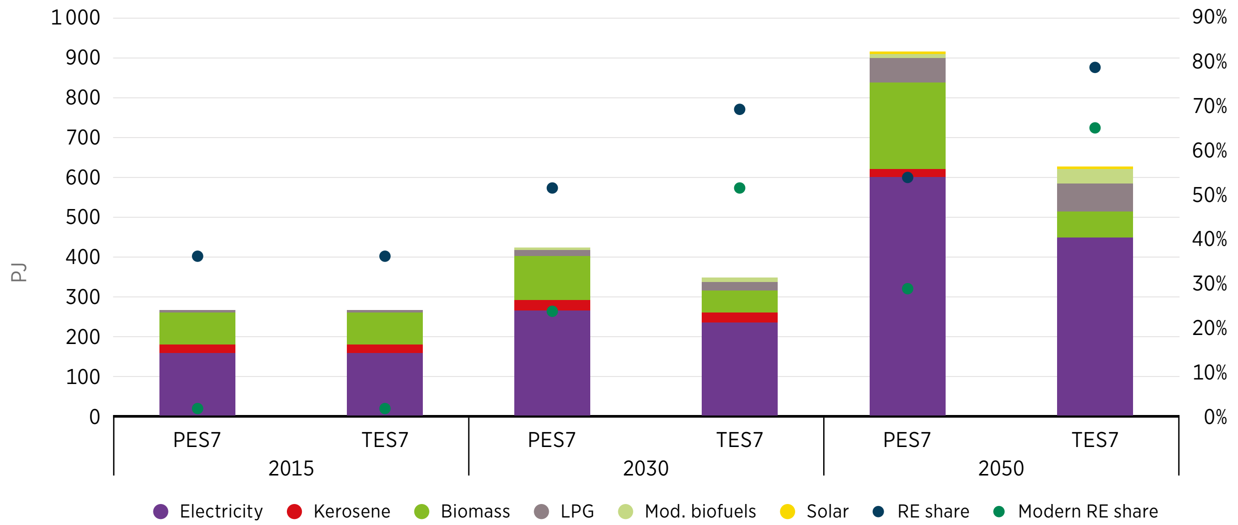
- **Commercial**

The TES for commercial buildings, similarly to residential buildings, sees final energy demand decrease, seeing drops of 18.2% in 2030 and 31.6% in 2050 in comparison with what is achieved under current plans and polices. In Figure 32 we can observe notable drops of 11% in 2030 and 25% in 2050 re observed in the usage of electricity due to increased penetration of more efficient electrical appliances and cookstoves in the sector. With respect to overall renewable share, they reach 68% in 2030 and 77% in 2050 but when considering only modern renewables, the share drops to 50% in 2030 and 66% in 2050. This drop is even more pronounced in the PES due to the maintained importance of traditional biomass in heating and cooking applications.

Table 9 Indicators of progress in commercial sector – status in 2015 and targets for 2030 and 2050

Commercial	2015	TES 2030	TES 2050
TFEC (PJ)	260	341	620
Share of electricity use	61%	68%	72%
Renewable energy share	35%	68%	77%
Bioenergy share	30%	20%	17%
Solar thermal share	0%	0%	0%
CO_2 emissions (Mt per year)	2	3	4

Figure 32 Comparison of final energy demand in commercial buildings in in the Planned and Transforming Energy Scenarios for 2015, 2030 and 2050



Transport sector

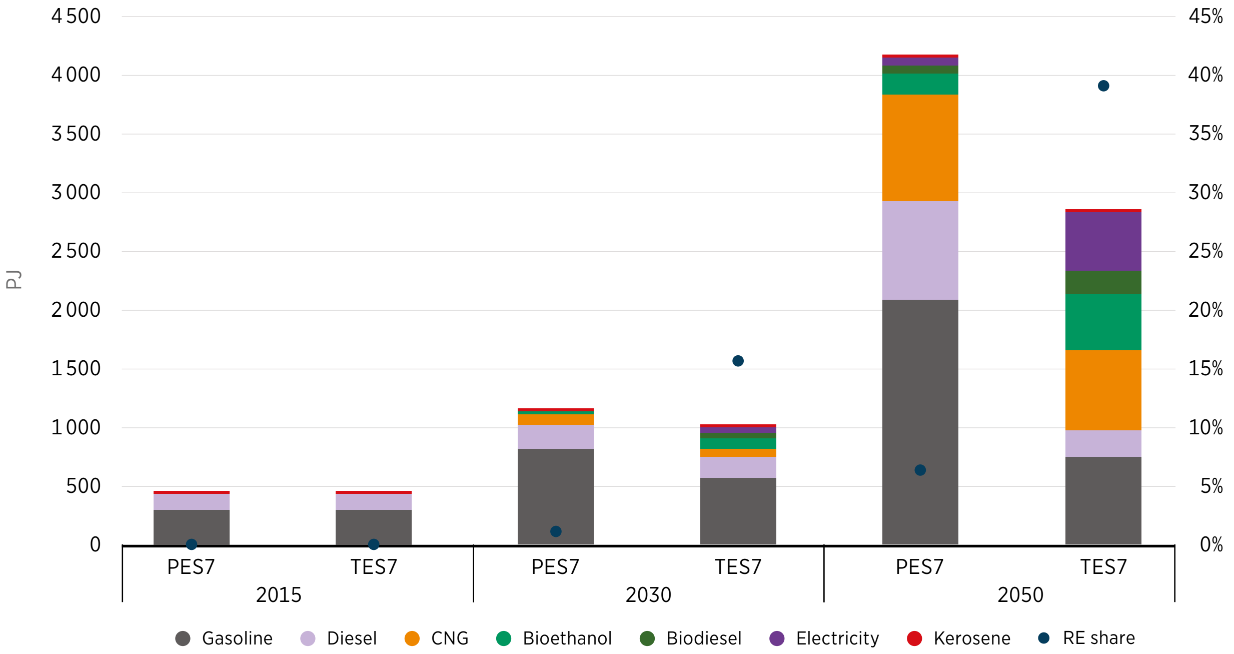
The TES sees final energy demand in transport rise to 1 002 PJ by 2030 and 2 846 PJ by 2050, which is lower than the PES by 12% and 32% respectively. Generally speaking, the share of biofuels and electricity in the sector increases substantially while the share of CNG use also moderately increases, which sees a substantial substitution of oil products in the PES. Consequently, the consumption of oil products declines by 29.5% in 2030 and 64.2% in 2050 compared with the PES. However, due to the substantial domestic resource and recent policy developments it can be seen that, even in the TES, CNG usage will continue to be a key part of the transport mix.

Table 10 Indicators of progress in transport sector – status in 2015 and targets for 2030 and 2050

Transport	2015	TES 2030	TES 2050
TFEC (PJ)	418	1 002	2 846
Share of electricity use in sector	0%	5%	18%
Bioenergy share	0%	13%	24%
Renewable energy share	0%	16%	39%
CO_2 emissions (Mt per year)	29	69	122

These shifts lead to renewable energy shares reaching 16% in 2030 of final consumption in the sector in the TES and 39% in 2050 as seen in Figure 33. To consider the renewable energy share in this way, however, obscures very substantial gains in terms of electrification of the vehicle fleet. EVs are much more energy-efficient (often about three times more) than conventional internal combustion engines and thus, the absolute energy consumption shares are not reflections of the vehicle fleet shares. Electric private cars and taxis reach 10% by 2030 and 35% by 2050 in the TES, while biofuel-based private cars could account for 20% in 2030 and 25% in 2050 but need substantially different efficiencies. Modal shift also plays a key role with a considerable improvement in public transport in terms of rail and bus transport, where electricity serves 40% (rail) and 35% (bus) by 2050 in the TES, further compounding the efficiency gains of this increased electrification.

Figure 33 Comparison of final energy demand in the transport sector in in the Planned and Transforming Energy Scenarios for 2015, 2030 and 2050



Box 3

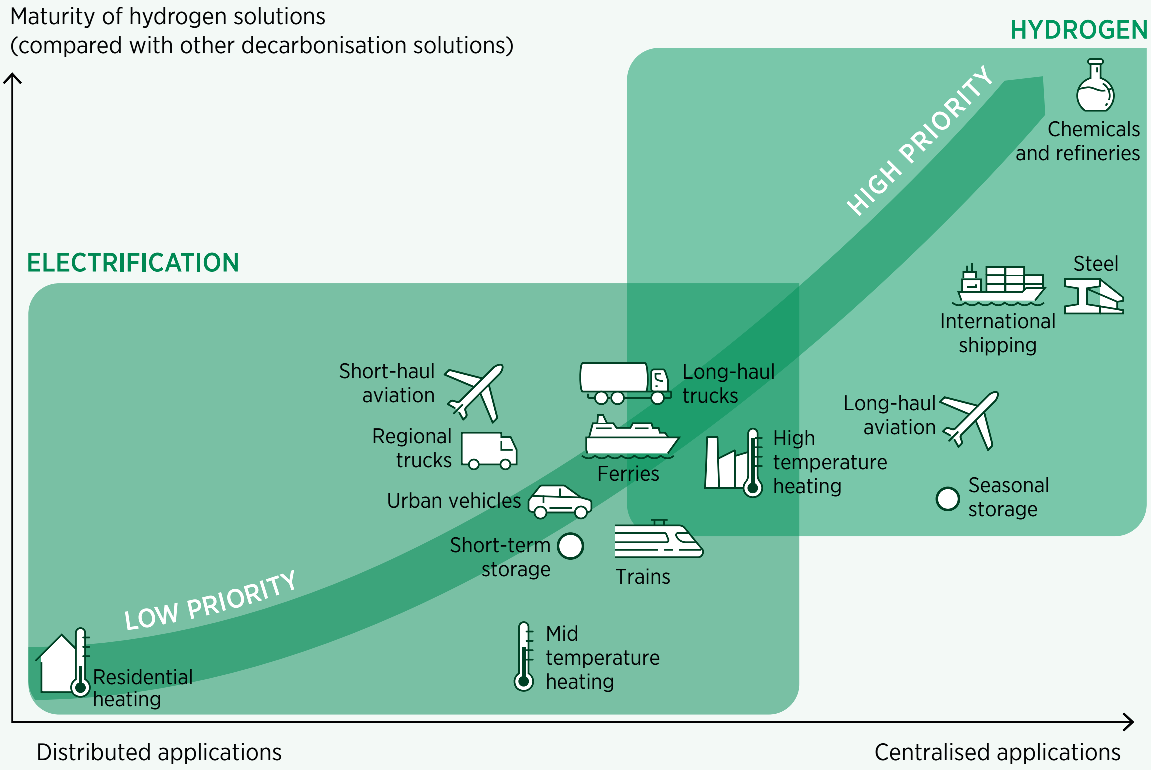
Hydrogen and its potential applications

Hydrogen as an energy carrier has the potential to play a pivotal role in the global energy transition, particularly in the hard-to-decarbonise sectors such as shipping, long-haul aviation, chemicals and seasonal storage in the power sector, where few cost-effective alternatives are available. However, its use has to be carefully considered due to its competition with other technologies across various sectors and local conditions and costs in each use case.

In a bid to encourage hydrogen adaptation, the federal foreign office of Germany established a hydrogen office in Abuja, Nigeria, on 9 November 2021 (Auswärtiges Amt, 2021). Given the region's solar energy resources in particular, the country has a strong possibility of producing green hydrogen for both domestic consumption and export, using some of the lowest-cost power sources available today (IRENA, 2021b). Additionally, the economy of Nigeria, as a significant exporter of fossil fuels, may benefit from a shift to green hydrogen production and export in terms of leveraging its existing expertise and skills base in the production of LPG, crude oil and natural gas. Technically, hydrogen can be used in many different sectors, but its extensive use may not be in line with the requirements of a decarbonised world, where energy consumption and capacity deployment will have to be carefully managed. In particular, the production of green hydrogen requires dedicated renewable energy that could be used for other end uses. Indeed, indiscriminate use of hydrogen could then slow down the energy transition. This calls for priority setting in policy making. Policy priority setting for green hydrogen relies on assessing different factors. Some of these factors can be similar between different countries globally, while others are country- or region-specific. Among the global factors are the technological readiness of the decarbonisation solutions and the potential size of local hydrogen demand.

These two factors are plotted in Figure 34: On the x-axis, the end uses are placed according to the estimated average daily hydrogen demand for industry, refuelling stations and combustion devices, with a power relationship. On the y-axis the end uses are placed according to the differences between the technological readiness levels of hydrogen-based versus electricity-based solutions. Industrial uses of hydrogen are among the highest priority end use, as alternatives are still missing in the foreseeable future and demand from these facilities can be large enough to allow economies of scale in production and infrastructure, making the shift to green hydrogen even more cost-effective in these applications.

Figure 34 Clean hydrogen policy priority



Source: IRENA (2022b).

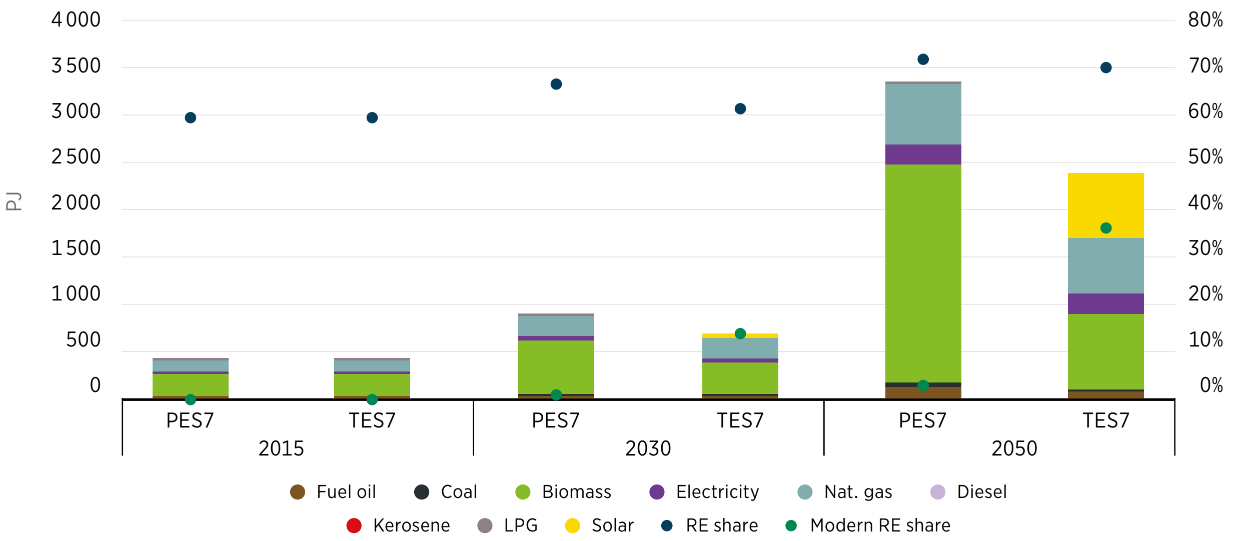
Industry sector

As in other sectors, the final energy demand of the industry sector sees substantial reductions in final energy demand in the TES when compared with the PES. Total industry energy demand is 682 PJ in 2030 and 2 393 PJ in 2050 in the TES, which amount to savings of 22% and 28% when compared with the planned case respectively. A large number of new, more efficient and advanced technologies are introduced in the industry sector, which allows older and less efficient technologies to be retired. Solar-based industrial process heat is set to replace many of the conventional fossil- and biomass-fired systems in large-scale industries (up to 50% by 2050). The TES also accounts for various strategies to help reduce the specific energy consumption of all the technologies/processes in the sector. This sees the share of modern renewables reach 14% in 2030 and 36% in 2050. The relatively lower share of renewable energy in TES is on account of the reduction of biomass consumption in the sector. However, the move from inefficient biomass-fired boilers to using appliances which are more efficient facilitates a much higher share of modern renewables, as shown in Figure 35.

Table 11 Indicators of progress in industry sector – status in 2015 and targets for 2030 and 2050

Commercial	2015	TES 2030	TES 2050
TFEC (PJ)	405	682	2 393
Share of electricity use in sector	8%	8%	8%
Bioenergy share	58%	49%	34%
Solar thermal share	0%	8%	29%
Renewable energy share	59%	63%	71%
CO_2 emissions (Mt per year)	2	3	7

Figure 35 Comparison of final energy demand in the industry sector in the Planned and Transforming Energy Scenarios for 2015, 2030 and 2050



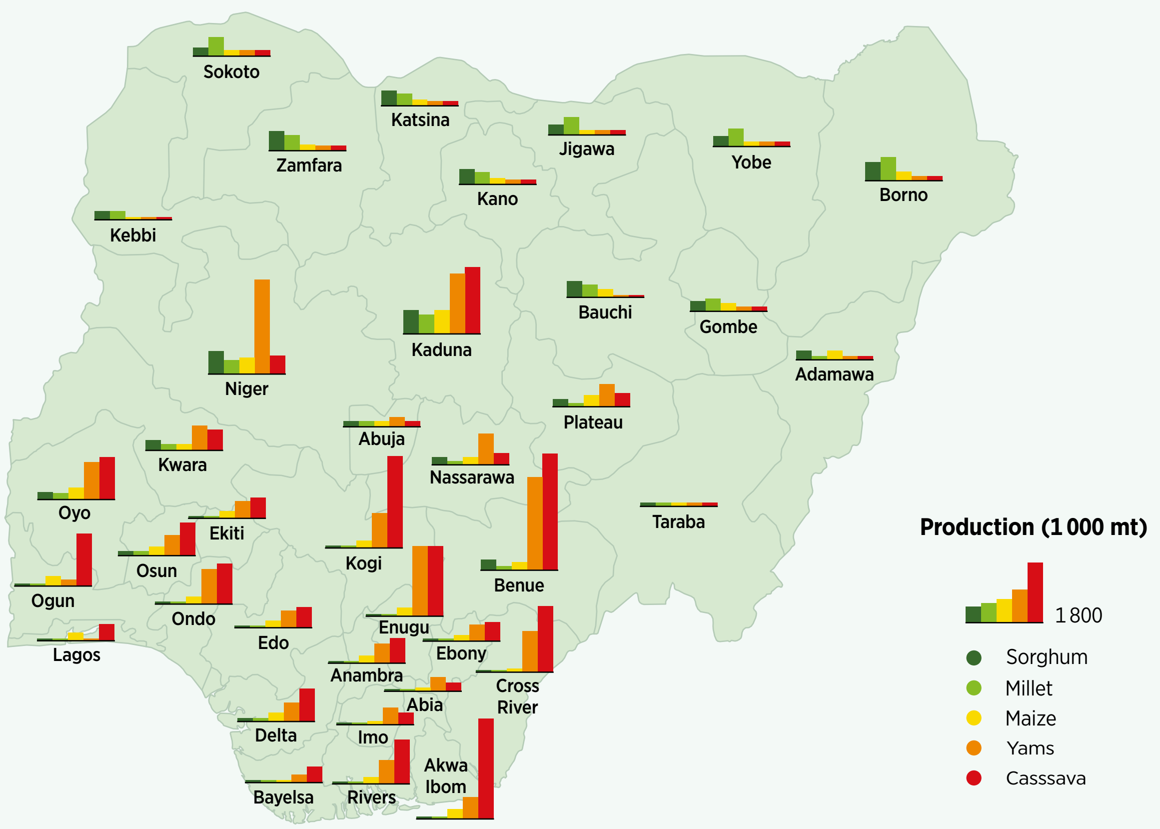
For the TES to be realised there are a variety of measures and initiatives required to incentivise the roll-out of such technologies and ensure stakeholders are made fully aware of the benefits of these technologies. These measures should include training in the installation and manufacture of such technologies, technology transfer, and information campaigns demonstrating the gains to be made by using such technologies.

Box 4

Potential for further use of Nigeria's rich bioenergy potential

Nigeria is richly endowed with bioenergy resource potentials of many varieties that are yet to be fully harnessed. Biodegradable agricultural and municipal solid wastes hold great potential for meeting the growing energy needs of the country while having the dual benefit of reducing pollution by producing biogas using anaerobic digestion.

Figure 36 Production of organic crops by state in Nigeria



Source: FAO (2019)

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply the expression of any opinion on the part of IRENA concerning the status of any region, country, territory, city or area or of its authorities, or concerning the delimitation of frontiers or boundaries.

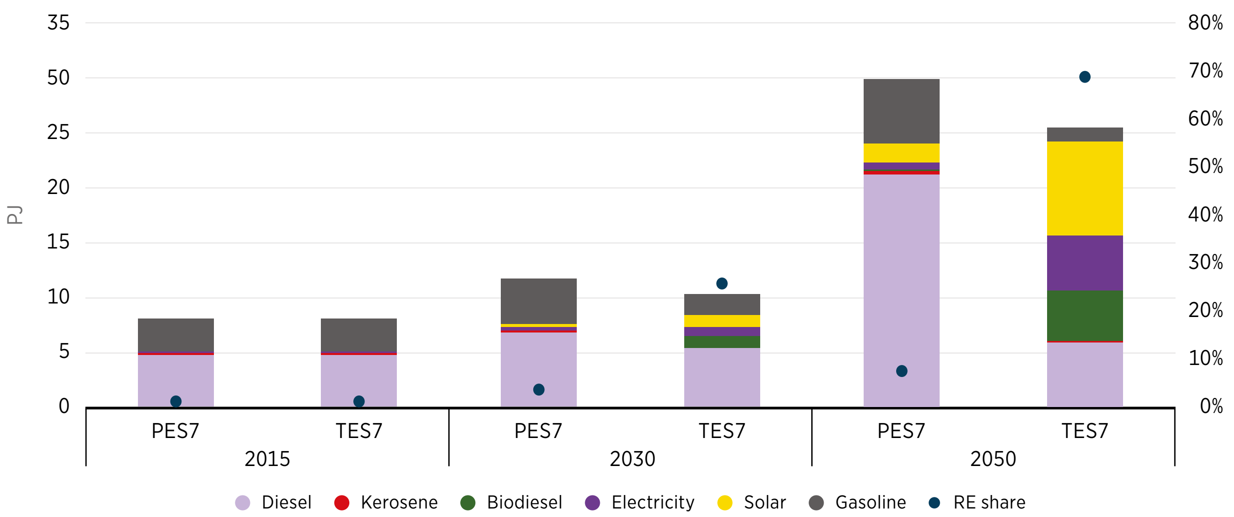
Nigeria has substantial volumes of waste that can be anaerobically digested to produce biogas that can be upgraded to biomethane for cleaner combustion. Figure 36 shows the distribution of organic crop production in Nigeria; waste products associated with this production could be used as a biogas feedstock. Post-harvest losses are problematic not only for perishable crops, but also for grain, livestock and fish production. It is estimated that following the harvest, around 25% of fruits, 40% of vegetables and 15-20% of the grain are lost (Okoro *et al.*, 2020). This resultant energy produced from these wastes, if anaerobic digestion were developed at scale, could be used to replace significant amounts of natural gas usage directly without any significant changes in end use necessarily (such as in high-temperature heating applications) across the Nigerian energy system in the transportation, commercial, residential, industrial and agricultural sectors.

The exploration of alternative energy sources such as anaerobic digestion will be important in diversifying the energy mix of Nigeria in the context of its increasing energy demand and economic expansion. This potential is expected to rise in the future due to increasing levels of waste generation, driven mainly by income growth, migration and urbanisation. This biogas could also be used to produce hydrogen in the reforming of biogas vapour, making it a potentially useful component of in the decarbonisation of difficult-to-decarbonise sectors.

Agriculture sector

The agriculture sector represents a small share of energy demand (representing less than 0.5% of energy use in both the PES and the TES) but is a crucial part of the Nigerian economy with a very substantial share of the population employed in the sector at 35% in 2019 (World Bank, 2021). However, increased mechanisation is expected to allow the sector to diversify. The TES sees final energy demand drop by 16.7% in 2030 and 2050 when compared with the planned case. Solar-based and electric pumpsets replace diesel/gasoline pumpsets, which substantially increases energy efficiency of the sector and allows it to achieve a renewable share of 70% by 2050 as shown in Figure 37.

Figure 37 Comparison of final energy demand in the agriculture sector in in the Planned and Transforming Energy Scenarios for 2015, 2030 and 2050



Power sector

The TES, just as the name implies, sees a profound transformation of the total installed capacity mix with substantial penetration of renewable energy technologies. Here, the total installed capacity reaches 62 GW by 2030 and 178 GW by 2050. This equates to a 10% increase by 2030 and a 31% increase by 2050 in comparison with current and planned policies. From Figure 38, it is observed the share of fossil capacity drops substantially in this case to around 22.8% by 2030 and 8.4% by 2050 on account of the massive penetration of renewable capacity, mainly solar, in the system. The overall aim of the TES framework is to promote the aggressive but realistic deployment of renewable energy beyond that seen in the PES. The TES sees an elimination of coal generation capacity, no new nuclear capacity additions and a substantially reduced expansion of natural gas generation capacity that is facilitated by maximising the use of Nigeria's wealth in terms of domestic renewables.

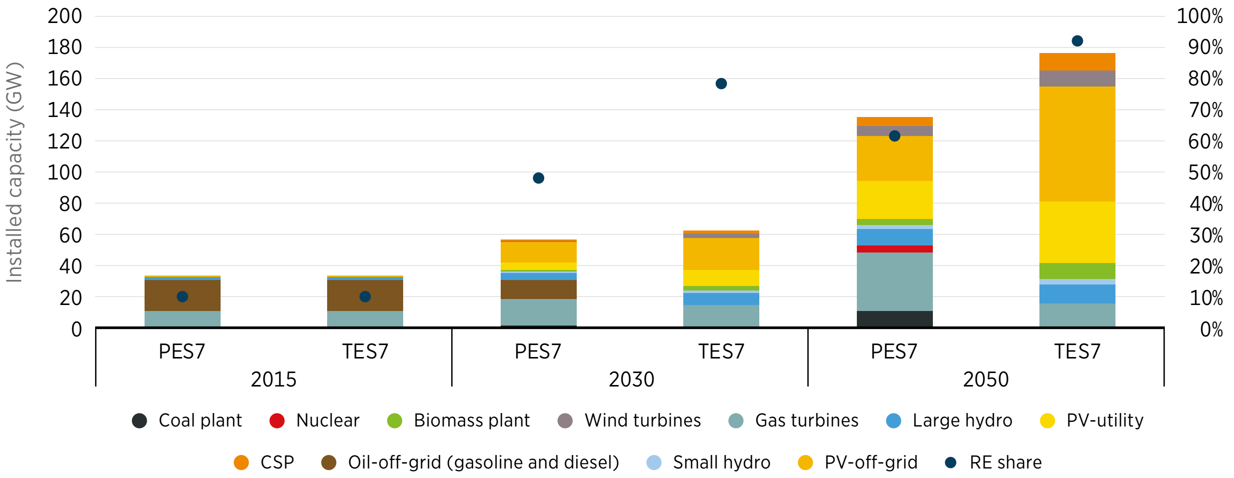
Table 12 Indicators of progress in power sector – status in 2015 and targets for 2030 and 2050

	2015	TES 2030	TES 2050
Consumption (TWh)	96	192	536
Share of TFEC	16%	23%	27%
Solar generation share	1%	36%	51%
Bioenergy generation share	0%	8%	11%
Renewable generation share	9%	70%	84%
Battery capacity (GW)	1	21	75

In the TES, the share of renewables in the total capacity mix is 77% in 2030 and 92% in 2050. Just as in the PES, with the decentralisation of renewable energy systems in the country, off-grid PV systems with battery storage continue to account for a substantial share of the total installed capacity of renewables. Also, due to the more constrained operation of variable renewable energy (VRE) such as PV, the capacity needed to deliver the same amount of electricity is higher, leading to a considerably higher generation capacity in the TES. While the system operation will need to change to integrate such a high share of VRE, the substantial amount of off-grid batteries with PV would help ensure a reliable supply.

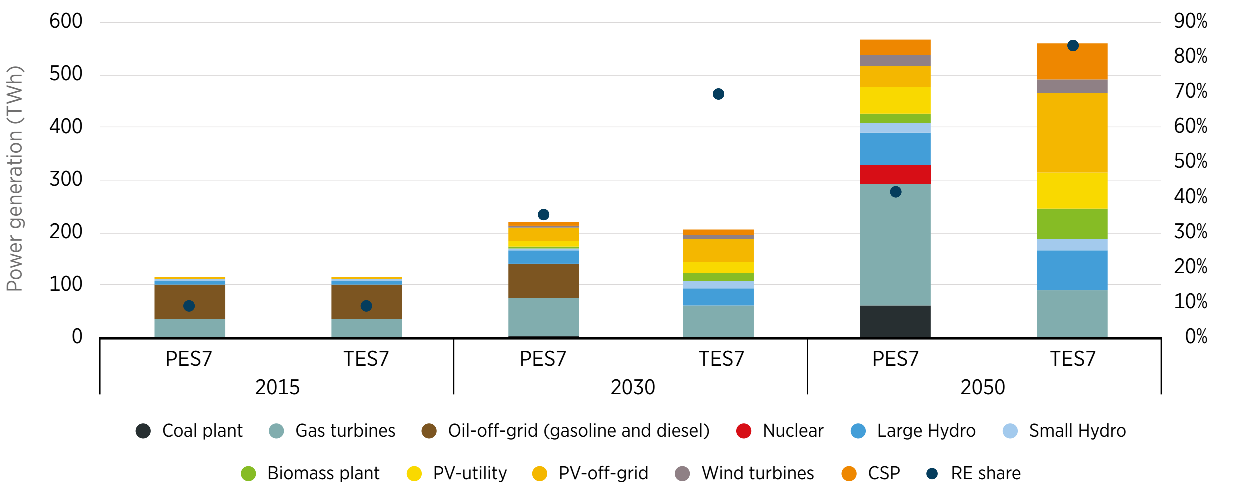
While the system operation will need to change to integrate such a high share of VRE, the substantial amount of off-grid batteries with PV would help ensure a reliable supply.

Figure 38 Comparison of power generation capacity in in the Planned and Transforming Energy Scenarios for 2015, 2030 and 2050



These changes in capacity have corresponding shifts in total electricity production, which reaches 206 TWh in 2030 and 561 TWh in 2050 as illustrated in Figure 39. These values correspond to reduction of around 6% in 2030 and 1% in 2050 in comparison with the planned case. Despite the substantial growth in demand-side management as well as efficiency improvements, there is no substantive reduction in electricity demand, particularly by 2050. This is due to the higher electrification of end uses implemented in this scenario (*e.g.* electric cookstoves and EVs) which, in turn, increases the electricity demand. Consequently, owing to the electrification of end uses in this scenario, the profound effect of efficiency improvements and demand-side management are not well-pronounced in terms of electricity production. The renewable share in power generation reaches 70% of total generation in this scenario by 2030 and 84% by 2050. Off-grid PV remains the dominant source of renewable electricity production in both 2030 and 2050. In addition, once off-grid capacity is excluded, the centralised share of VRE in the system reaches 13% by 2030 and 17% by 2050, which has been achieved in many regions of the world with operational practices for such integration being well-established.

Figure 39 Comparison of power generation in in the Planned and Transforming Energy Scenarios for 2015, 2030 and 2050



Box 5

Potential for further development of Nigeria's rich offshore wind potential

There is significant wind potential in Nigeria which, if developed, could diversify the energy mix, improve energy security and lead to significant job creation. Although wind speeds are generally low in the country, in the southern part of the country, coastal locations such as Lagos, Rivers, Bayelsa, Ondo, and Akwa Ibom states have the potential to harness wind energy (Adedipe, Abolarin and Mamman, 2018). Due to the higher wind speed in these coastal areas, offshore wind farms here can produce significantly more power per turbine than onshore sites. Offshore wind speeds also tend to be steadier that those onshore, which can improve the consistency in the power output of these sites.

In terms of employment, offshore wind has much potential for Nigeria; the development of a typical 500 MW offshore wind farm requires around 2.1 million person-days of work. Manufacturing takes up 59% of the labour requirements of such a project, followed by operation and maintenance (24%) and installation and grid connection (11%). Factory workers account for more than half of the labour needed in manufacturing (IRENA, 2018b).

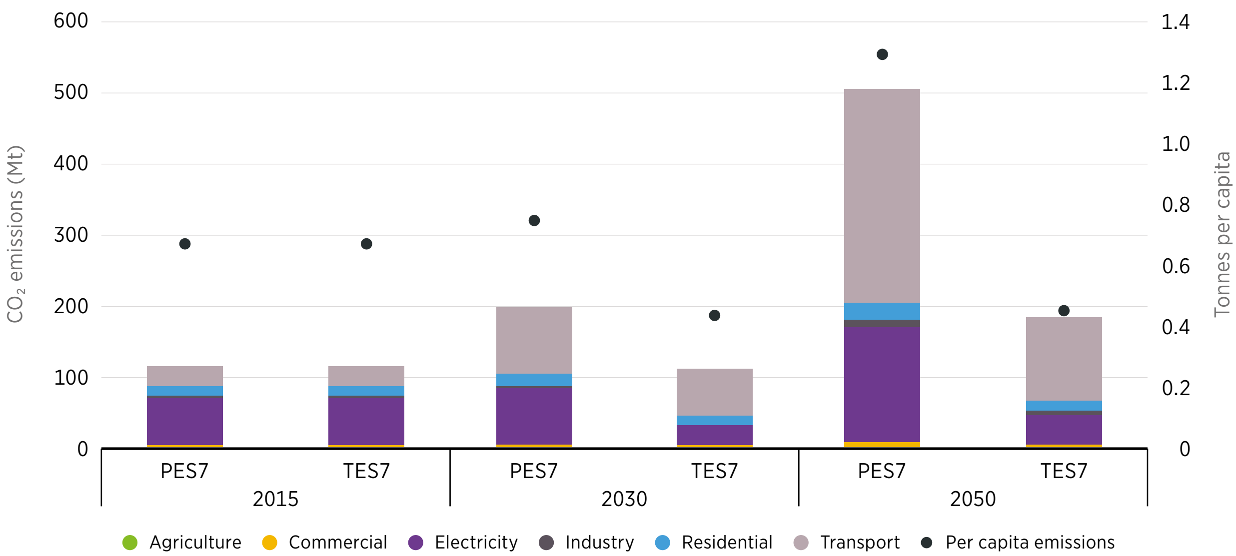
Additionally, given that Nigeria has a significant oil and gas sector, which has many natural synergies with offshore wind development, specifically in terms of skills and occupational patterns, it is important to consider in a national context. Offshore wind turbine foundations, array cables and substations are fundamentally the same as oil and gas platforms in terms of structure and layout, which would allow for a leveraging of existing national expertise in the development of these projects (IRENA, 2018b). Successful job migration between sectors, however, depends on dedicated retraining policies. Specific policy measures, such as upgrading and supplier development programmes, support for joint ventures, or industrial promotion schemes, may be needed to strengthen the industrial capacity of domestic firms.

Another factor to consider in this regard is the recent volatility of oil markets, which featured negative oil prices in 2020 and near record highs in 2022, serving as a reminder of the volatility of markets for oil – and other fossil fuels – and of the geopolitics associated with the current energy system and its underlying revenue streams. Many oil companies have woken up to this challenge and are actively developing new lines of business activity. The findings of IRENA's recent paper "International oil companies and the energy transition" suggest more needs be done to meet energy transition needs (Asmelash and Gorini, 2021). Such decisive shifts towards low-carbon energy, such as offshore wind, are vital to help fossil fuel-producing companies and countries find their place as the energy companies of the future.

Carbon emissions

The TES profoundly affects CO_2 emissions. Total CO_2 emissions reach 115 Mt in 2030 and 189 Mt in 2050, representing savings of around 42.8% and 63.4% respectively compared with the PES as shown in Figure 40. Just as in the PES, the transport sector accounts for the largest source of CO_2 emissions in the TES, accounting for around 60% of the total CO_2 emissions in 2030 and 65% in 2050. It may also be observed that there is a substantial drop (75.4%) in CO_2 emissions from the electricity sector on account of the aggressive deployment of renewable energy technologies, most notably solar PV, in the TES. Agriculture remains the lowest source of CO_2 emissions within the energy sector with a share of less than 0.5% across the two scenarios across the modelling time frame.

Figure 40 CO_2 emissions of the Planned and Transforming Energy Scenarios

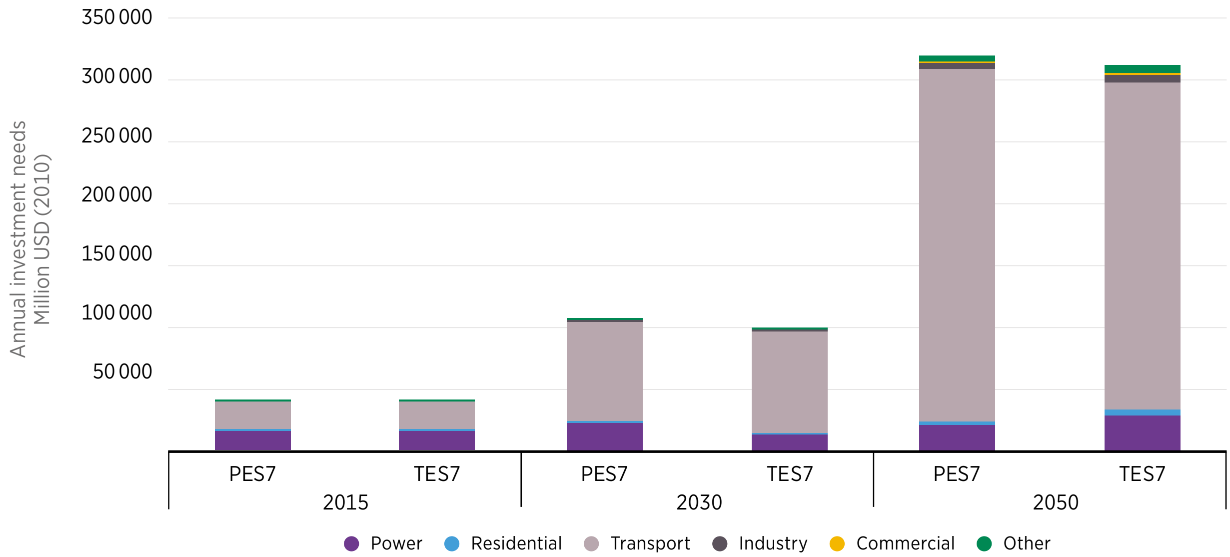


Investment needs

The TES shows itself to be a cost-effective scenario with less capital investment required than for the PES. The overall results point out that investments in energy-efficient technologies and renewables are cost-effective. The TES has lower investment costs than the PES, USD 1.22 trillion (2010) compared with USD 1.24 trillion (2010) between 2015 and 2050, while delivering the same energy service.

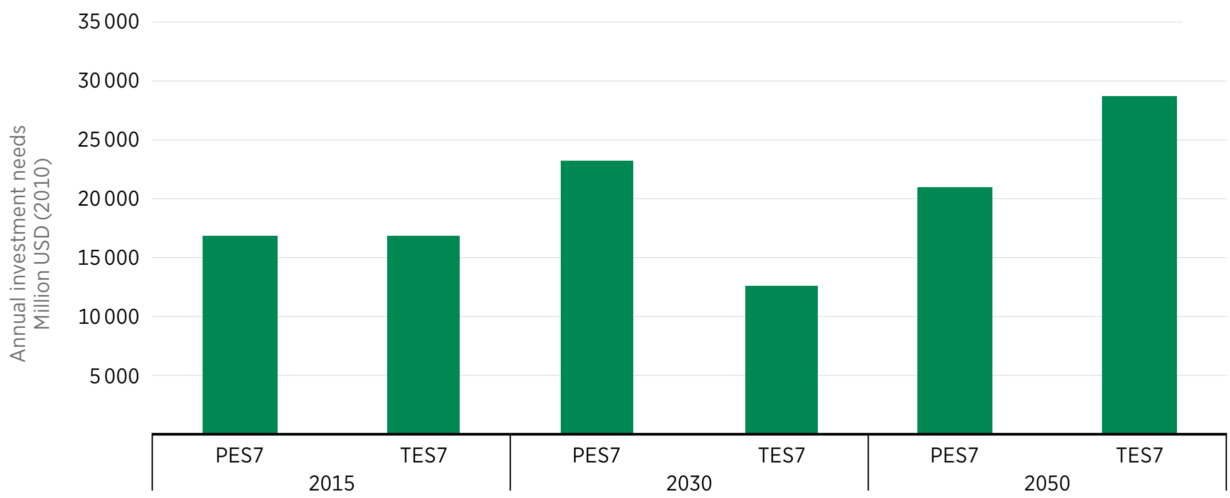
It can be seen that the transport sector contributes the most to the investments in the economy-wide energy system in Figure 41 for the three milestone years presented, which consists of investments predominantly from private individuals. The transportation sector represents the largest portion of investment predominantly due to the cost of the vehicles required to meet an expanding demand for personal transport with higher incomes. Due to the aggregated nature of some sectors in the model, their investment needs may not have been adequately captured. It is also key to mention that these investment costs exclude the costs of negative externalities which would be incurred in the planned case such as those for premature mortality associated with air pollution and reduced modern energy access.

Figure 41 Annual investment needs of the Planned and Transforming Energy Scenarios



For the power sector, Figure 42 shows more clearly the annual investment for the power sector for the same three milestone years. For policy makers, this direct investment in the power sector is particularly important to consider given much of this investment will need to be borne by national bodies and will be key in delivering the TES across all end-use sectors.

Figure 42 Annual investment needs of the power sector in Planned and Transforming Energy Scenarios



The annual investments estimated here are based on technical feasibility and techno-economic modelling of the energy system, which rely on parameters which are inherently uncertain, and thus cannot fully reflect real-world factors such as complex political and social factors or financial leakage in the system that shape real-world investment requirements. As a result, the real investment requirements may be higher than those analysed here. Nevertheless, the TES can transform the energy system of Nigeria into one which is more cost-effective, cleaner and modern while accelerating national development.

Box 6

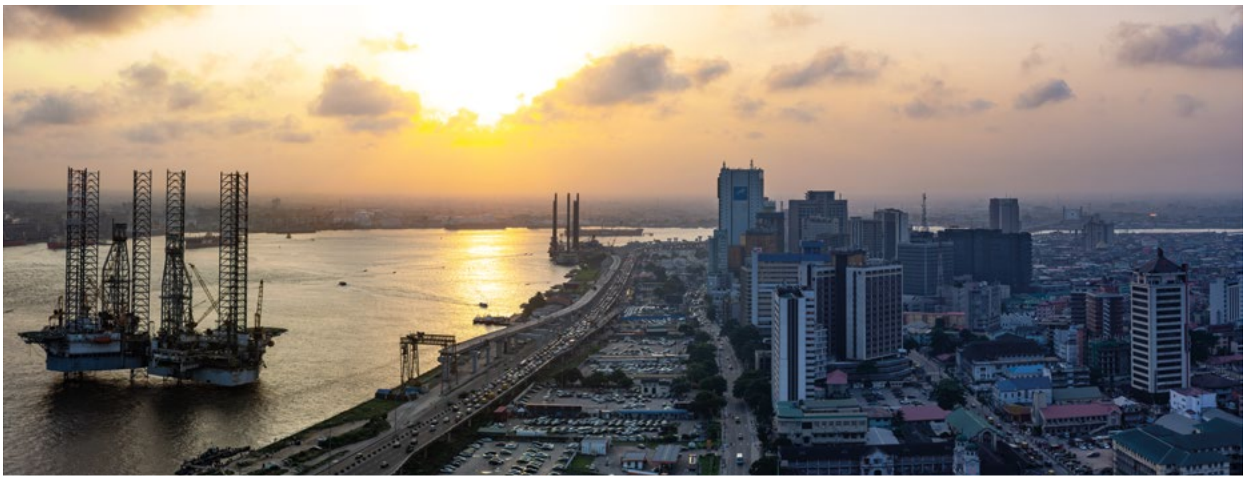
Financing solutions for the future of energy in Nigeria

Achieving the TES will require a shifting of and scaling-up of investments in Nigeria in the short term to avoid locking in investment in fossil fuel infrastructure with long lifetimes. In the year 2050, in terms of primary energy requirement, the TES uses over 40% less natural gas and 65% less oil than the PES, which has a profound implication for infrastructure investment for these uses of resources.

Safeguarding Nigeria's future energy needs will be dependent on today's choices to put the country on a trajectory to sustainable and cleaner energy solutions. The sheer scale of the renewable energy resources at Nigeria's disposal and cost reductions in these technologies mean that for these technologies to play the role envisaged in the TES, financial solutions will need to be developed to meet these needs and redirected away from the highly fossil fuel-dependent PES.

A well-functioning and comprehensive financial planning framework is needed for successful scaling-up of clean energy projects and solutions across the whole energy system of Nigeria, such as that which was presented by the World Economic Forum (World Economic Forum, 2021) after a range of consultations with several financiers and stakeholders. Frameworks such as this can help ensure targeted delivery of finance to clean energy solutions that are aligned with national needs and sectors that not only address climate change issues but also can be implemented in a manner which propels development. This framework will need to capture and tailor solutions to the local context of energy and digital technologies that will support the energy needs of Nigerians, spanning financing instruments, business models, fund disbursement, technical assistance, capacity building, sector-based targeting and risk mitigation strategies.

Although development finance will be key to enabling the successful application of such a framework, financial de-risking mechanisms (such as blended finance) are needed to enable investments beyond development finance. Risk mitigation tools can be a useful strategy for reducing a variety of perceived and real investment risks and, as a result, securing investments from both the private and public sector. Some financing mechanisms that helps with risk mitigation include government guarantees, partial risk/credit guarantees, liquidity guarantees and political risk insurance (IRENA and AfDB, 2022). These mechanisms can help insure investments in both the public and commercial sectors, such as the EUR 800 million worth of guarantees granted by the European Commission under its External Investment Plan (Convergence News, 2018; IRENA and AfDB, 2022).

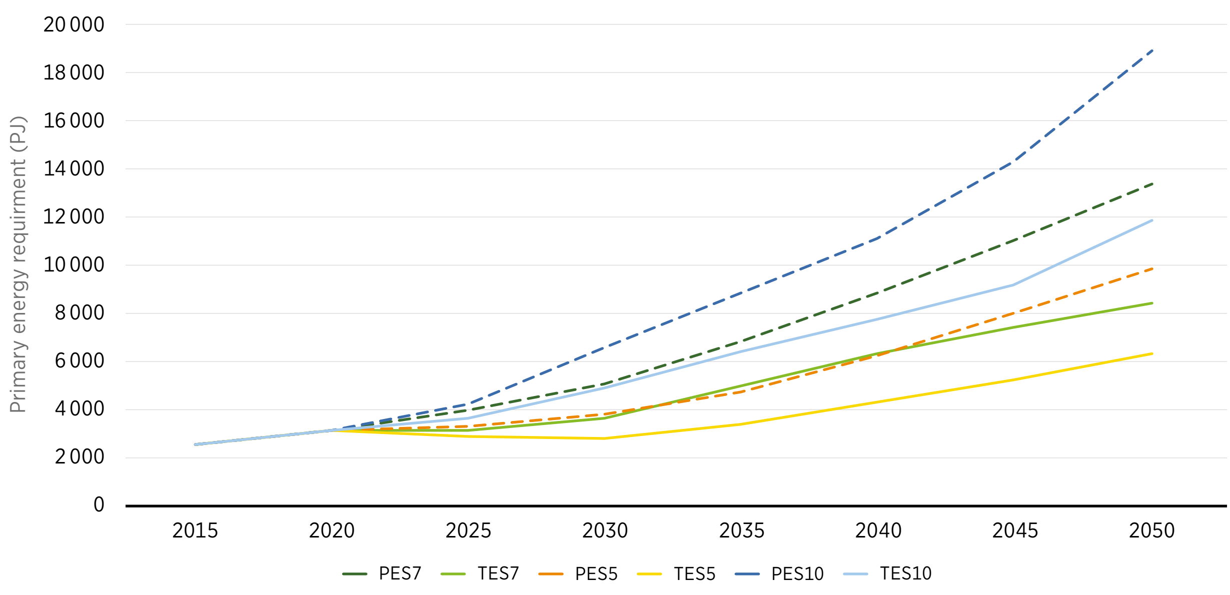


4.3 Impact of different growth rates

The differences between the Planned and Transforming Energy Scenarios become more pronounced when the impacts of various economic conditions are considered. Out to 2050, there is uncertainty as to how the economy will perform and how this could affect the scenarios in this study. This section explores the impacts of different growth rates to the central 7% average growth rate (where the PES and TES are referred to as PES7 and TES7), with additional pessimistic and optimistic average economic growth rates of 5% (where the PES and TES are referred to as PES5 and TES5) and 10% respectively (PES10 and TES10), considered out to 2050. It should be noted that these differences in demand projection are based on a linear regression without any other adjustments.[6]

Figure 43 displays the primary energy requirement out to 2050 and how this varies by growth scenario. The renewable energy share of primary energy is broadly consistent within each respective PES and TES, regardless of growth rate. Without the adoption of more efficient appliances, cooking methods, vehicles and electrification of end uses, the primary energy demand expands substantially, and this is compounded by increased economic growth rates. As show in Figure 43, by 2050 the PES10 is nearly 60% more energy demanding than the TES10, where energy efficiency allows for a lower energy demand to drive the same level of development for the Nigerian economy, substantially decoupling economic growth and energy demand. However, the primary energy requirement for each respective PES and TES scenario does increase with economic growth, but the TES allows this growth to be mitigated by at least 34% in all cases with respect to the planned case, reducing the footprint and costs of the energy system.

Figure 43 Primary energy requirement across all scenarios considered

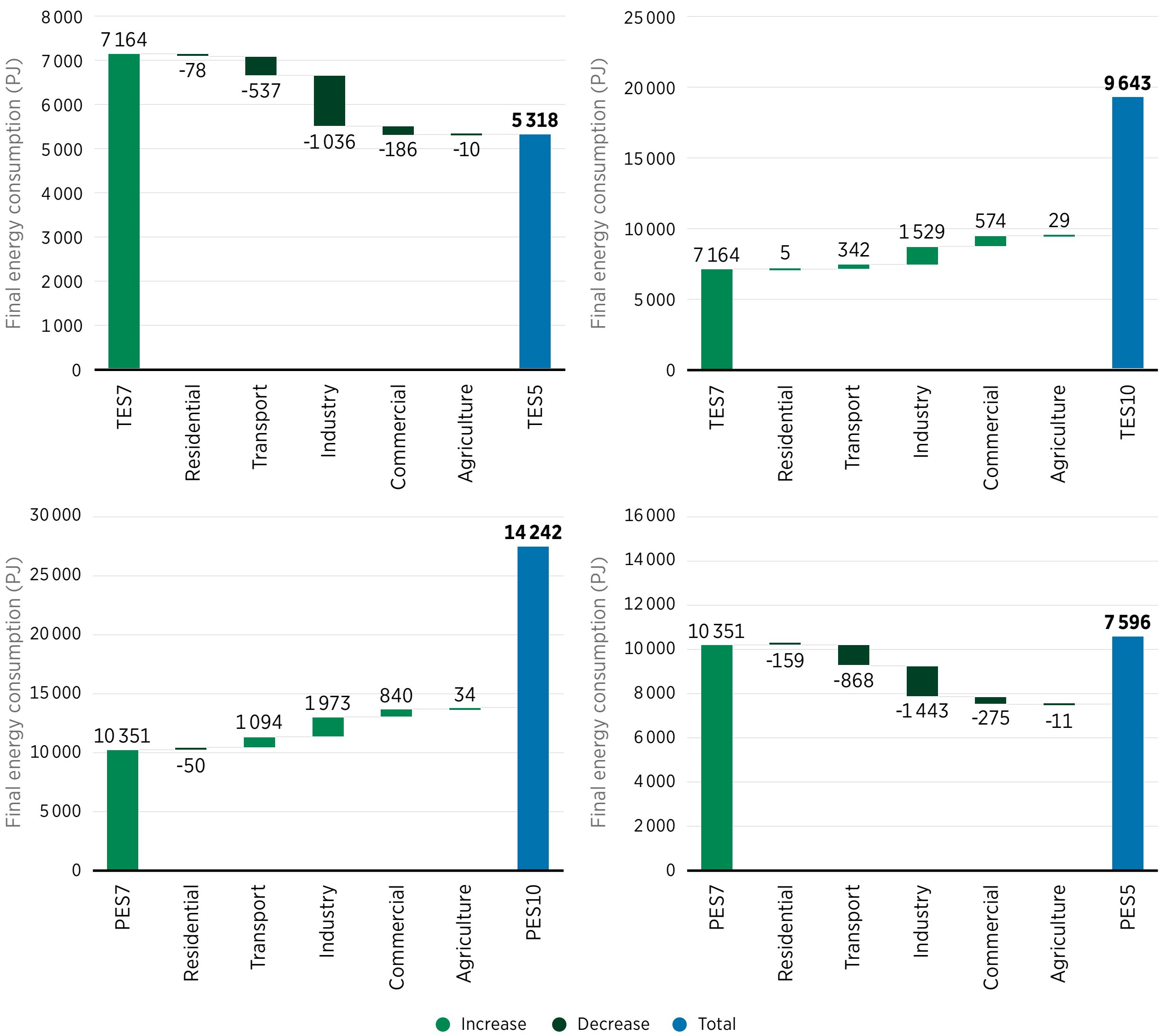


Note: TJ = terajoules.

[6] *The model relies on exogenously estimated energy service demands based on the GDP values agreed upon by IRENA and the ECN. The context of the analysis wasn't based on implementing a CO_2 constraint but on evaluating the energy system and emission impacts of energy efficiency, renewable energy and energy access polices.*

Figure 44 presents TFEC and how this varies between scenarios for both the PES and the TES. In terms of energy consumption, it is the industry sector that is impacted most by reduced economic activity, followed by transport and the commercial sector. Residential and agricultural energy use are only modestly impacted due to these energy uses being largely non-discretionary in nature.

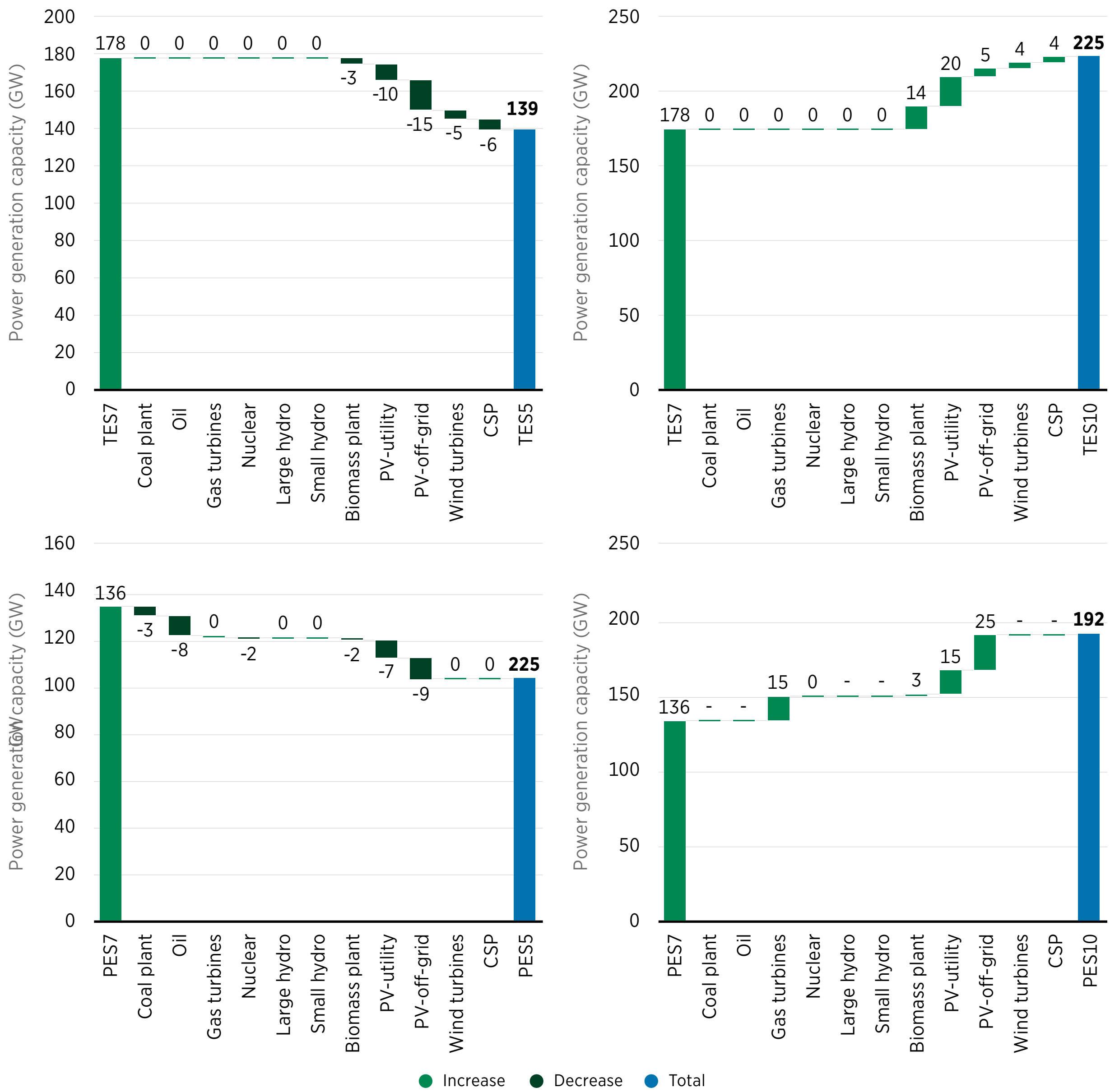
Figure 44 Final energy consumption changes between different growth scenarios in 2050



Depending on whether it is the PES or TES, this translates to differing reductions in energy demand due to the different underlying technology mixes servicing different levels of energy service demands in these different scenarios. This translates to varying reductions in different fuel uses depending on the referenced scenario (PES or TES). For example, in the PES there remain considerably higher levels of biomass use than the TES but in the PES5 this is half the level of the PES10 (about 2 000 PJ versus 4 000 PJ); the vast majority of this reduction is from the industrial sector. In the TES, electricity demand is the most affected by the growth rate; in the TES5 this is approximately 40% lower than in the TES10 (about 1 600 PJ versus 2 700 PJ).

Figure 45 shows the penetration of different technologies by scenario for the power sector and how they change in each respective scenario. Hydropower and solar PV play prominent roles in the power sector of each PES and TES level regardless of economic growth rate and represent "no regret" investment options. Hydropower reaches between 13 GW and 15.5 GW by 2050 across all scenarios and solar PV reaches at least 38 GW in the lowest case in PES and between 90 GW and 140 GW across the TES cases. The low variation in hydro capacity merely emphasises the benefits it holds for the power system, while solar PV's greater variation between the PES and the TES emphasises its need for policy support in scaling roll-out. The solar PV'svariation in the TES (as seen in Figure 45) in particular displays the benefits of its modularity as a technology and the sheer resource Nigeria has in scaling it to meet demand growth. In the buildings sector, this is also true for a shift away from traditional biomass in cooking towards cleaner cooking technologies such as electric cooking stoves.

Figure 45 Power generation capacity change between different growth scenarios



While the variation in energy consumption for each scenario and growth rate is quite substantial, as shown in Figure 44, the impact on emissions is even more so. Figure 46 presents how the CO_2 emissions are affected by the technology deployment of each scenario and economic growth. Every transformative scenario is far less emitting than any of the planned scenarios; each is at least 60% lower than its corresponding planned case. This is a crucial conclusion to draw, particularly in light of targets of the Paris Agreement and Nigeria's NDC and the policy choices that could help achieve its goals.

Figure 46 CO_2 emissions for each scenario considered

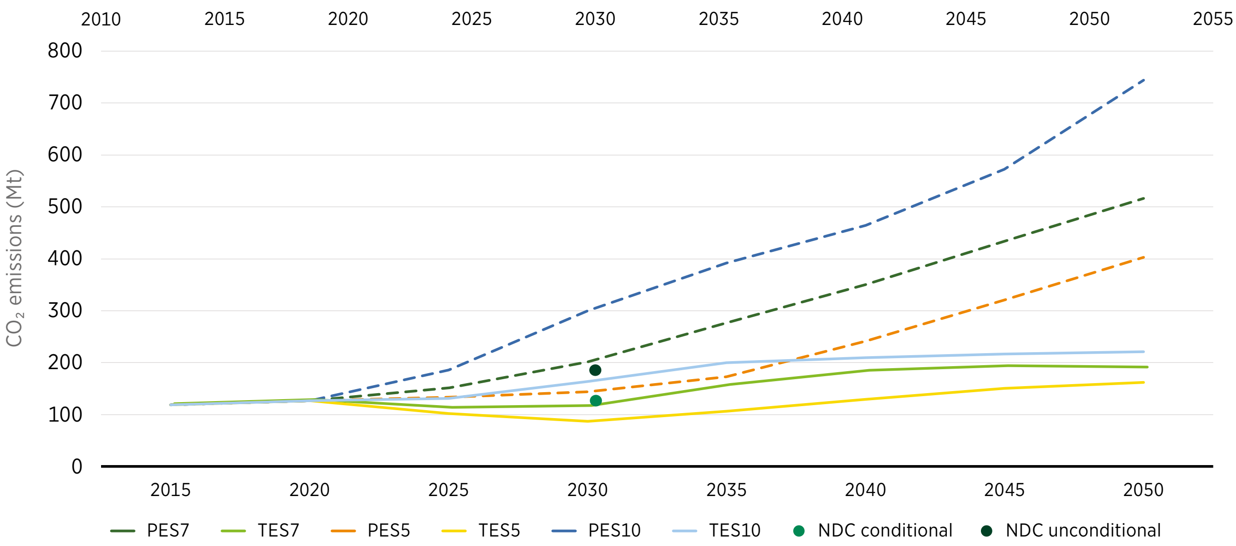
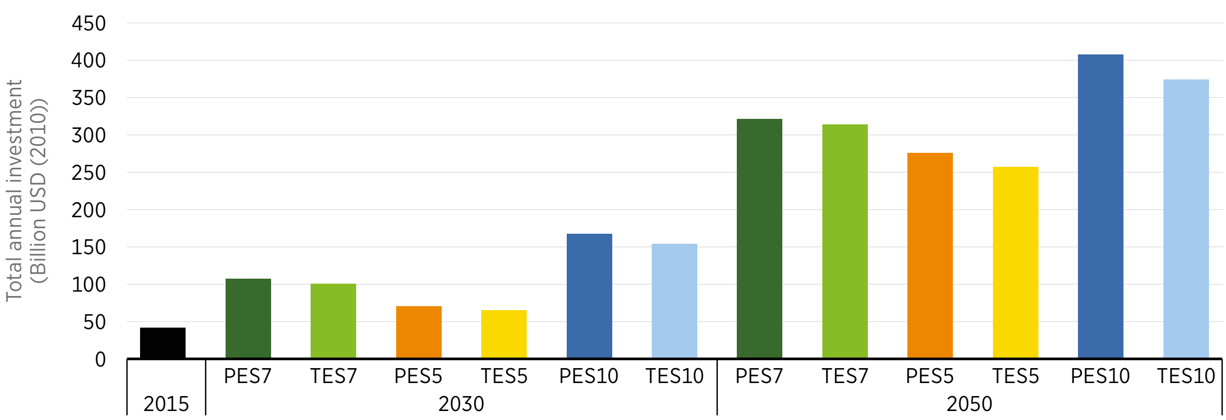


Figure 47 identifies the differing investment requirements for the PES and the TES for differing economic growth rates, in each case further proving the economic benefits of the TES. Regardless of the growth rate considered, the investment required to achieve this scenario is more cost-effective than the planned case even without considering the positive externalities of pursing a cleaner energy future with higher levels of access to clean cooking and electricity and greater availability of public transport with all the positive impacts of social mobility which could in turn spur even greater economic development.

Figure 47 Total annual investment for each scenario considered



Note that the investment values presented in Figure 47 correspond to investments in each of the milestone years of the model (which ran in blocks of five years) so these values correspond to investments in the preceding five-year band. An average investment per year between 2015 and 2030 in addition to between 2015 and 2050 is presented in Table 13. It shows that the average annual investment from 2015-50 is greater than 2015-30 due to the relatively higher additional energy investments needed post-2030.

Table 13 Average annual economy-wide investments (billion USD [2010])

Scenario	2015-30	2015-50
PES7	17.1	35.5
TES7	16.1	34.7
PES5	13.8	26.8
TES5	13.2	26.0
PES10	22.7	44.8
TES10	21.1	42.4

Table 14 displays some of the key implications of economic growth on the TES levels. Most notable are the impacts on power capacity (especially solar PV) and solar thermal applications, particularly in industry. For power, this owes to the efficiency of electricity as an energy carrier. Nigeria's vast solar resource see's renewable power meeting a significant share of demand in the transport and commercial sectors which are substantially impacted by the growth rate considered. The same is also true for solar thermal, which scales easily to meet a higher or lower demand in industry to medium- and low-grade heat applications. The scaling of these technologies and others lead to differing investment needs among the three growth scenarios considered. This scaling is due to the higher or lower energy service d emands which are met through using these technologies, which are modular and cost-effective and consistently deployed across scenarios.

Table 14 Key implications of economic growth rates on TES levels

	Key implications of growth rates
Power generation capacity needs	Electricity demand expands and contracts with higher and lower economic growth rates. There is 26% more generation capacity needed in TES10 (225 GW) compared with TES7 (178 GW), including 25 GW more solar PV. However, in TES5 this capacity need is 22% lower than under the 7% growth rate at 139 GW; again, much of this results from lower deployment of solar PV due to its low cost and modularity.
Solar thermal in industry	Economic growth impacts industrial expansion leading to significantly higher deployment of solar thermal heating, reaching 900 PJ in the 10% growth rate scenario compared with 400 PJ in the 5% growth scenario and 700 PJ in the central 7% growth scenario
Traditional biomass use	Use of traditional biomass is greatly affected by economic growth rate, especially in the PES but also the TES with significant implications for the environment. For the PES by 2050, PES7 sees 1 029 PJ biomass use while this drops to 655 PJ in PES5 and rises to 1 317 PJ in PES10.
Investment needs	The economic growth rates dramatically affect the investment needs, reaching USD 122 billion (2010) in the central 7% TES level, which rises to USD 149 billion in TES10 and drops to USD 91 billion (2010) in the TES5 case.

05 ACTIONS NEEDED NOW

Actions needed now

Nigeria is at a key point in time to capitalise on its abundant renewable energy resources to meet the growing needs of its population while simultaneously addressing socio-economic challenges. To do so requires a broad and comprehensive set of policies for all the sectors of its economy which will facilitate the transition away from fossil fuels with all the economic and health benefits that would follow. Renewable energy technologies will be key in achieving a sustainable energy mix for Nigeria.

Broad-based national planning will be required to plan and manage the energy transition so that the benefits outweigh the costs and are evenly distributed across the country. Accelerating the energy transition and maximising its benefits require an integrated energy planning approach that combines targets and commitments with holistic and long-term plans including the deployment of energy transition technologies, the phasing-down of fossil fuels (and their direct and indirect subsidies) and the thorough consideration of their socio-economic impacts. An integrated long-term plan should be developed in co-ordination among different ministries and national bodies. The energy plan must consider the different transition pathways including electrification, the deployment of green gases, sustainable biomass and solar thermal among key enabling infrastructure. The plan must be based on specific needs, macroeconomic conditions, availability of resources, the infrastructure already in place, and the level of development of different regions, accessibility and cost of technologies. Developing and implementing an integrated long-term plan requires strong co-ordination and a robust institutional structure. This is especially the case when it comes to electrification with renewables, as it calls for the synchronisation of the deployment of renewable power plants with measures to deploy electricity-powered technologies in in a timely fashion.

Among other measures, a fiscal system is needed that facilitates the adoption of energy transition solutions while disincentivising new investments in fossil fuel technologies and supporting a national phase-down and -out of these technologies aligned with a climate compatible pathway. Policies and measures are also needed to facilitate access to finance, foster innovation and raise awareness among consumers – and citizens in general – to support the uptake of transition-related technologies. Development of financing mechanisms for distributed renewables and technologies (microfinance, margin money finance, etc.) in addition to information campaigns will also be key to roll-out of a whole host of goals achieved in the Transforming Energy Scenario (TES) in terms of clean cooking, distributed solar photovoltaic (PV) and battery installations.

A long-term, integrated energy plan is also necessary to co-ordinate the deployment of renewables-based solutions with measures to raise energy efficiency and develop the needed infrastructure, while minimising stranded assets. Based on the long-term energy plans, corresponding investments are needed to upgrade existing and develop new infrastructure, often as a prerequisite to attracting private investments in energy-transition-related solutions. Such an integrated energy plan can help minimise stranded assets for a given climate ambition by developing national strategies that leverage existing infrastructure and expertise.

This section highlights the key barriers identified throughout the Renewable Energy Roadmap (REmap) process and the corresponding actions to overcome them. The adoption of these recommended actions would contribute to the widespread use of renewable energy throughout Nigeria. In order to ensure the realisation of the huge renewable energy ambitions outlined in the TES, the proceeding policies and measures are recommended.

5.1 Power

- **Improve the existing financing mechanisms and explore further regulatory options**. Despite the demonstrated benefits of renewables, the adoption of renewable energy technologies in Nigeria is still growing at a slow pace compared with what is obtainable in other countries within the region, such as Egypt, Kenya and South Africa. Fostering innovative **financing mechanisms** for distributed renewables and utility-scale technologies such as blended finance and microfinance will help deliver higher penetrations. Especially in the **substitution of diesel generators by stand-alone solar systems and mini-grids** which have a higher upfront cost but significantly lower operation cost. The government's existing policies/programmes in this regard are already on the right track but need to be actively implemented. Furthermore, the existing Renewable Purchase obligation (RPO) mechanisms need to be strengthened and made workable. Having clear and transparent RPO target formulation while setting standardised and transparent procedures to determine the targets and making such targets mandatory while ensuring strict enforcement are important elements towards promoting renewable energy technologies in the country.

- **Improve and expand the regulatory framework for decentralised renewable energy solutions.** Nigeria has been successful with a progressive regulatory regime for mini-grids (both off-grid and on-grid) backed by various dedicated financing schemes (such as the results-based financing facility and minimum subsidy tender). It is important that this framework architecture continue to evolve as technologies develop and new applications emerge with participation of both public and private sectors.

- **Accelerate electrification of end uses and promote policies that would support it**. The energy transition both globally and in Nigeria requires electrification, but it must happen in an orderly and well-managed fashion. Proactive policy making is necessary to avoid some initial pitfalls. Delaying action policies can lock in fossil fuel solutions and reduce opportunities for sector coupling. Ineffective policies can create additional barriers (*e.g.* transitional barriers or reputational barriers) that will reduce the attractiveness of electrified solutions and increase the challenges of achieving the energy system outlined in the TES.

- **Modernise the transmission and distribution infrastructure.** The analysis shows that the Nigerian grid needs to be prepared for the integration of large-scale renewables. Efforts should be placed on strengthening the existing central grid and more efforts should be placed on developing interstate/intercity regional transmission capacity for optimum utilisation of available power. The TES requires relatively higher deployment of renewable energy technologies into the existing system. Planning for integration of renewables into the grid is a key requirement for the success of renewable power. Investments are essential to support infrastructure and renewable energy development and should be accorded high priority. As Nigeria's transmission system is not very mature, it presents an opportunity for the country to develop its power transmission system in a modern fashion. Moreover, a smart grid will go a long way to support the management of intermittent solar and wind. As Nigeria's decentralised supply system grows, it becomes pertinent to integrate it into the central grid. In some cases, decentralised generators can produce surplus energy that can become wasted if not supplied to the central grid. Here, a smart grid system will help to accommodate this surplus and provide the needed compensation accordingly. Furthermore, electricity theft is a major issue in the Nigerian electricity sector. A smart grid system will help to curtail this issue. Additionally, greater use of distributed PV can reduce the need for transmission and provide valuable upstream benefit.

- **Invest in renewable over fossil energy.** The analysis shows that it is cost-effective to invest in renewable energy technologies over fossil fuels such as coal, owing to the declining costs of renewables (all TES levels). The Nigerian Energy Masterplan and Vision 30-30-30 seek to integrate coal into the Nigerian electricity supply mix. However, there is currently no existing coal power plant in the country. While acknowledging that plans are under way for the deployment of coal-based technologies, the current scenario also presents an opportunity for Nigeria to develop its electricity system in a more sustainable manner by leapfrogging fossil-based technologies and focusing more on cost-effective renewables. Beyond environmental sustainability issues, Nigeria is still a developing country in dire need of financial resources to drive its developmental agenda. Thus, there is no room for wastage of resources on technologies that are not cost-effective. It will be to Nigeria's benefit in terms of environment and economics to abandon the current coal plans and invest more in renewable energy. Such targets and goals for renewables need to be translated into policies and measures. Quantified quotas for renewable power can be considered, along with a system for issuing and tracking energy attribute certificates. Structured procurement policies such as feed-in tariffs, premiums and auctions are instrumental to address context-specific barriers and risks and to serve specific objectives.

- **Develop a robust database for renewable energy potentials and a corresponding pipeline of bankable projects.** Apart from solar and hydro, there is a considerable dearth of information regarding the potential of renewable resources in the country. There is a need for comprehensive assessment of wind energy potential in the country for both on- and offshore wind. As observed from the analysis, the potential for geothermal, wave and tidal energy is yet to be quantified and thus, no plans yet to develop these renewable energy resources in the country. It is recommended that the federal government perform a detailed assessment to have a robust database of Nigeria's renewable energy potential. This will help to support planning for renewable energy development and also show the possible locations for renewables deployment.

IRENA's Global Atlas for Renewable Energy is a free web-based platform that could help in addressing this; it provides users with data and tools to assess their renewable energy potential (IRENA, 2022a).

5.2 Buildings

- **Improve upon existing efforts to promote clean cooking**. Despite the decades of efforts to promote clean cooking in Nigeria, around 80% of Nigerians still do not have access to clean cooking facilities. This can be attributed to a lack of affordable alternatives which subdues the ability of households to transition to clean cookstoves. Although traditional biomass fuels (fuelwood, dung, crop residues, etc.) are freely available, the low efficiencies, environmental impacts and health implications associated with their use do not make them a sustainable option in the long-term. While the Nigerian government has developed various programmes to enhance clean cooking, it is recommended that future government initiatives ensure that programmes for improved cookstoves, which are aimed at expanding cooking options via modern renewables (modern biofuels and electricity) are introduced. This should take place within a clean cooking policy framework that makes it a clear priority in a cross-ministerial approach that tackles cost and finance barriers, bolsters sustainability and supply chains, and creates awareness about impacts and solutions. It is thus timely that the federal government has recently established a committee to develop a national policy on clean cooking and meeting universal access (Nigerian Alliance for Clean Cookstoves, 2022).

- **Improve upon existing appliance efficiency and lighting programmes.** The majority of electricity consumed in the residential and commercial sectors is through lighting, refrigeration, air conditioning and miscellaneous electrical appliances. For lighting, the replacement of incandescent light bulbs with light-emitting diodes (LEDs) and other efficient lights can bring about large energy savings as observed in the TES for the residential/commercial sector. Towards this end, the cost of LED and other efficient lights needs to be reduced to make them more affordable by promoting their large-scale manufacturing. In addition, bulk procurement and establishment of "buy back" schemes have worked elsewhere to implement the switch to compact fluorescent lamps (CFLs) and LED light bulbs. The analysis also shows that even with a conservative estimate of efficiency improvement possibilities, there exists substantial scope for savings in residential and commercial refrigeration and air conditioning. For this, it is necessary to make available efficient types as against locally made technologies, provide incentives to purchase from government-certified outlets and generate awareness among consumers. In this regard, the government needs to support the Standards Organisation of Nigeria with all the necessary funding required to maintain and enhance its appliances standard programmes. Enhanced capacity building across the industry and stakeholder groups in areas like consumer behaviour related to appliance use, manufacturers, and suppliers are required in continuing to meet minimum energy performance standards for appliances. Furthermore, there is a need to promote solar thermal for hot water application. Households, hospitals, hotels and schools use hot water for different purposes, especially for bathing. It is recommended that efforts already aimed at expanding the use of solar water heaters in the residential/commercial sectors be improved upon, which could be achieved through provision of financial incentives and customised loans to promote renewables for direct use.

- Promote energy efficiency policies such as stricter building codes, support for building retrofits and appliance standards, which are critical conditions for the efficient uptake of renewable cooling in buildings and industrial processes. Such measures are mostly cost-efficient in the medium term and can improve the cost-competitiveness of renewable heating and cooling applications. The benefits of these policies can be compounded if combined with measures to encourage the uptake of digital monitoring and control technologies which enable smart building operation.

5.3 Transport

- **Faster adoption of biofuels.** Nigeria has a biofuel policy in place, but it needs to be improved and implemented appropriately. The major setback to the implementation of alternative fuels in Nigeria's transport sector is the lack of availability of the fuels which thereby reduces the choices available to Nigerian consumers. For example, in the case of private vehicles, where ethanol and biodiesel can be fuel choices, the lack of large-scale availability of the fuel reduces the fuel choices available to Nigerian consumers. Furthermore, Nigeria's biofuel target as per the National Renewable Energy Action Plan is focused on using first-generation biofuels. To provide wider alternatives, it is recommended that efforts are improved to promote the adoption of second- and third-generation biofuels.

- **Policies aimed at transport electrification and acceleration of the adoption of electric vehicles (EVs) should be put in place.** In a country where only 64% of the population have access to electricity for basic services such as lighting, it becomes very difficult to have additional electricity to serve EVs. First, as a key priority, the electricity grid should to be strengthened to accommodate the impact wide adoption of EVs would have on the grid. Measures that can be applied are financial and fiscal incentives to increase uptake of EVs; bans on internal combustion vehicles; setting clear and ambitious national targets for electric cars, buses and trains; and mandating EV charging stations in new buildings. Furthermore decentralised charging stations powered by renewables (solar PV) and established at various locations in the country to cater for EV charging needs while also serving as a source of revenue for the business owners. Moreover, via the vehicle-to-grid option and vice versa, EVs could help to provide storage infrastructures needed for both TES5 and TES7 where renewable power is deployed aggressively. A key milestone to addressing this challenge will be the development of a dedicated EV policy that outlines the programmes and measures that will be used to improve EV diffusion in the country.

- **Enhancement of public transportation offerings and rail infrastructure driven by renewables will be key to achieving the modal shifts and energy efficiency needed in transportation.** The analysis also shows that modal shift will play a key role in reducing transport energy demand as observed in the TES Railways currently account for less than 5% of land transport demand in Nigeria. While efforts are under way to revamp the sector, without any focused and aggressive actions such as the development and financing of an integrated national long-term multimode transportation plan, the share of railways will remain insubstantial in the future transport system. Efforts to improve the existing rail network would necessitate large infrastructure and upfront investment costs, but at the same time would have important implications on the long run, on both energy and emissions. The development of high-speed railways and dedicated freight corridors would lead to a major shift of both passenger and freight movement from road to rail. Being the most energy-efficient mode of transportation, its attractiveness would increase once it is technologically and operationally efficient, too, providing better services as compared with road. Modal shifts in freight and passenger transport go beyond railways, however, and encouraging switches to public transport, biking and walking will require infrastructure roll-out to match such ambition so that they are seen as a safe and reliable alternative to cars.

5.3 Industry

- **Develop local renewable energy technologies manufacturing industries.** Despite the huge decline in the costs of renewable energy technologies globally, the cost of renewable energy technologies in Nigeria remains relatively high compared with global averages. Some of the key reasons for this are the costs of financing, the fact that most renewable energy technologies are imported into the country and a lack of an enabling environment for local renewable energy technologies manufacturing. A key recommendation here is to develop an enabling environment to support renewable energy technologies manufacturing industries in the country through expanding the local demand for renewable energy technologies. Effective measures to create such an enabling environment include industrial upgrading programmes, supplier development programmes, promotion of joint ventures, development of industrial clusters and investment promotion schemes. To ensure the full-fledged development of a nascent industry, policy support should be time-bound and include broader aspects beyond deployment, human resources and industrial development. Beyond cost matters, Nigeria has high levels of unemployment. Developing local renewable energy technologies manufacturing industries will help ameliorate the problem by creating employment opportunities such as solar panel production. These employment opportunities are significant; manufacturing the main components of a 50 megawatt solar PV plant requires 50 225 person-days where the production of solar cells requires most work (almost half of the total) (IRENA, 2017).

- **Focus on energy efficiency improvement in small and medium-sized enterprises (SMEs)** by providing financial/fiscal incentives to boost their capacities to adopt state-of-the-art technologies. Policies and measures need to be developed to support the electrification of industry including regulations to expose consumption to price signals (*e.g.* time-of-use tariffs); public support for research, development and demonstration in the direct and indirect use of electricity in industrial processes; the relocation and co-location of energy-intensive industry to sites with low-cost renewable electricity with high load factors; and incentives or requirements for the use of efficient cooling systems through mandates and financial incentives.

- **Promote the adoption of solar heating technologies** in large industries where there are available spaces to deploy them. For SMEs, industrial clusters should be promoted by designating specific clusters across various regions and making them an integral component of regional economic development strategy, which would enable multiple SMEs to derive process heat from a few solar thermal installations.

5.4 Agriculture

- The feasibility, sustainability and scalability of decentralised renewable energy solutions in the agri-food sector highly depend on appropriate institutional and policy frameworks. Clear and targeted measures are needed such as designing development plans tailored to local conditions, levelling the playing field for renewables solutions by addressing market distortions, and putting in place specifications and standards to ensure market differentiation between high- and low-quality products to support a strong market development and ensure users' confidence in the technologies (IRENA, 2016). Such measures would support renewable energy markets by incentivising local enterprises, stimulating demand, thereby promoting productive uses.

- **Improve the affordability of solar irrigation pumps.** While solar irrigation pumps are already cheaper than diesel and gasoline pumpsets in terms of levelised cost of energy, their initial capital outlay remains relatively higher. This scenario makes it challenging for Nigerian farmers (predominantly poor and peasant farmers) to purchase solar pumpsets as they remain financially disadvantaged. To make solar pumpsets competitive, the Nigerian government needs to provide targeted subsidies and grants as well as robust financing mechanisms to make the capital requirement for solar irrigation pumps lower than their diesel and gasoline counterparts. Furthermore, due to the predominant use of diesel and gasoline pumps in the sector, some farmers have become accustomed to using these conventional technologies and thus may find it difficult to shift even when they have the resources to do so. This implies that there should be a focus on clear promotion of the benefits of solar-based irrigation pumps in addition to training in their installation and use. The government, as well as the government workers, need to promote awareness of solar irrigation pumps and their associated benefits, especially in the rural areas.

- **Policies to promote the adoption of efficient pumpsets.** Conventional irrigation pumps in Nigeria are mainly the inefficient types. To improve efficiency in this sector, regulatory measures are needed that will require farmers to use minimum energy pumpsets and prohibit inefficient pumpsets from being sold, as well as better technical support and capacity building for all stakeholders.

- **Incentives to promote adoption of alternative fuel tractors.** The Nigerian tractor subsector is dominated by diesel-powered tractors. To promote the use of biodiesel and electric tractors, the government needs to establish policies that will discourage the use of diesel-powered tractors. For example, the government may establish policies that provide additional agricultural inputs (seedlings, fertiliser, micro grants) for farmers who employ biodiesel and electric tractors for their farm traction needs.

REFERENCES

Adedipe, O., Abolarin, M.S. and Mamman, R.O. (2018), 'A review of onshore and offshore wind energy potential in Nigeria', in *IOP conference series: materials science and engineering*. IOP Publishing, p. 012039.

Adeyanju, G.C. *et al.* (2020), 'Exploring the potentials, barriers and option for support in the Nigeria renewable energy industry', *Discover Sustainability*, 1(1), p. 7. Available at: https://doi.org/10.1007/s43621-020-00008-5.

AfDB (2020), *Press Release: African Development Bank to provide underserved communities in Nigeria with sustainable energy solutions*. Available at: www.afdb.org/en/news-and-events/press-releases/african-development-bank-provide-underserved-communities-nigeria-sustainable-energy-solutions-34855.

AfDB (2021), *Multinational - Nigeria-Niger-Benin-Burkina Faso Power Interconnection Project*. Available at: https://projectsportal.afdb.org/dataportal/VProject/show/P-Z1-FA0-146 (Accessed: 19 October 2021).

AfricaNews (2020), *Nigeria commences Lagos-Ibadan railway operations, Africanews*. Available at: www.africanews.com/2020/12/09/nigeria-commences-lagos-ibadan-railway-operations/ (Accessed: 6 September 2021).

Africanvault (2015), 'Top 20 Oil Producing Countries in Africa', *African Vault*, 26 September, Available at: https://africanvault.com/oil-producing-countries-in-africa/ (accessed: 9 January 2020).

All On (2016), *Nigeria: Energy needs assessment and value chain analysis*.

Asmelash, E. and Gorini, R. (2021), *International oil companies and the energy transition*, Technical Paper 2001/1, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Technical-Papers/Oil-companies-and-the-energy-transition.

Auswärtiges Amt (2021), *Hydrogen diplomacy: Germany opens Hydrogen Office in Nigeria - Federal Foreign Office*.

Ayetor, G.K. *et al.* (2021), 'Vehicle regulations in Africa: Impact on used vehicle import and new vehicle sales', *Transportation Research Interdisciplinary Perspectives*, 10, p. 100384. Available at: https://doi.org/10.1016/j.trip.2021.100384.

Badger, J. *et al.* (2015), 'The Global Wind Atlas: An EUDP project carried out by DTU Wind Energy'.

Brimmo, A.T. *et al.* (2017), 'Sustainable energy development in Nigeria: Wind, hydropower, geothermal and nuclear (Vol. 1)', *Renewable and Sustainable Energy Reviews*, 74, pp. 474–490. Available at: https://doi.org/10.1016/j.rser.2016.11.162.

Central Bank of Nigeria (2020), *Framework for the implementation of intervention facility for the national gas expansion programme*. Available at: www.cbn.gov.ng/out/2020/ccd/guidelines%20for%20national%20gas%20%20expansion%20programme%20final.pdf.

Cervigni, R. (2013), *Assessing low-carbon development in Nigeria: an analysis of four sectors*. World Bank Publications.

Clean Cooking Alliance (2021), *Clean Cookstoves Development and Testing Center, Nigeria*, *Clean Cooking Alliance*. Available at: https://cleancookingalliance.org/sector-directory/clean-cookstoves-development-and-testing-center-nigeria/ (Accessed: 26 August 2021).

Clowes, W. (2021), 'Nigeria Starts $3 Billion Upgrade of Key Railway Line', *Bloomberg.com*, 9 March. Available at: www.bloomberg.com/news/articles/2021-03-09/nigeria-starts-3-billion-rehabilitation-of-key-railway-line (accessed: 6 September 2021).

Convergence News (2018), *European Commission shifts to private capital mobilization - Blog - Convergence News | Convergence*. Available at: www.convergence.finance/news-and-events/news/5eIWx3mlnqYAa6CE6QSYqA/view (accessed: 17 November 2021).

Daramola, A. and Fagbemi, T. (2019), 'Air travel and airline operations in Nigeria: Market potentials and challenges', *Aviation and Its Management: Global Challenges and Opportunities*, p. 5.

Department for International Development (2019), *Importation Guide for Solar PV Products and Technologies in Nigeria*. Available at: www.ace-taf.org/wp-content/uploads/2020/01/ACE-NIGERIAN-IMPORTATION-GUIDE-2019122001.pdf.

Dioha, M.O. (2018), 'Modelling the impact of Nigeria household energy policies on energy consumption and CO 2 emissions', *Engineering Journal*, 22(6), pp. 1–19.

Dioha, M. O. and A. Kumar (2020), 'Exploring sustainable energy transitions in sub-Saharan Africa residential sector: The case of Nigeria', *Renewable and Sustainable Energy Reviews*, 117, p. 109510.

Dioha, M. O. and A. Kumar (2020), 'Exploring the energy system impacts of Nigeria's Nationally Determined Contributions and low-carbon transition to mid-century', *Energy Policy*, 144, p. 111703. Available at: https://doi.org/10.1016/j.enpol.2020.111703.

ECN (2013), *Nigeria Energy Balance*, Energy Commission of Nigeria.

ECN (2014a), *Energy Implications of Vision 20: 2020 and Beyond*, Energy Commission of Nigeria.

ECN (2014b), *National Energy Master Plan*, Energy Commission of Nigeria.

ECN (2014c), *National Energy Masterplan (Draft Revised Edition)*, Energy Commission of Nigeria.

ECN (2015a), *NECAL2050 Report -Nigeria Energy Calculator 2050 Report*, Energy Commission of Nigeria.

ECN (2015b), *Nigeria Energy Calculator 2050 (NECAL 2050) report*, Energy Commission of Nigeria.

Elinwa, U.K., Ogbeba, J.E. and Agboola, O.P. (2021), 'Cleaner energy in Nigeria residential housing', *Results in Engineering*, 9, p. 100103. Available at: https://doi.org/10.1016/j.rineng.2020.100103.

Emodi, N.V. and Yusuf, S.D. (2015), 'Improving electricity access in Nigeria: obstacles and the way forward', *International Journal of Energy Economics and Policy*, 5(1), pp. 335–351.

ENERGY VOICE (2020), *Nigeria launches autogas push - News for the Oil and Gas Sector.* Available at: www.energyvoice.com/oilandgas/africa/283135/nigeria-launches-autogas-push/ (Accessed: 6 December 2020).

Esan, A.B. *et al.* (2019), 'Reliability assessments of an islanded hybrid PV-diesel-battery system for a typical rural community in Nigeria', *Heliyon*, 5(5), p. e01632. Available at: https://doi.org/10.1016/j.heliyon.2019.e01632.

ETSAP (2017), *E-TechDS – Energy Technology Data Source.*

European Automobile Manufacturers' Association (2021), *Motorisation rates in the EU, by country and vehicle type | ACEA - European Automobile Manufacturers' Association*. Available at: www.acea.be/statistics/tag/category/vehicles-per-capita-by-country.

FAO (2019), *Food Loss and Food Waste.* Rome.

FMITI (2014), *Nigeria industrial revolution plan. Federal Ministry for Industry Trade and Investment.*

García-Gusano, D. *et al.* (2016), 'The role of the discount rates in energy systems optimisation models', *Renewable and Sustainable Energy Reviews*, 59, pp. 56–72.

GCC (2021), *Nigeria's new railway from Lagos to Ibadan to start operating tomorrow, Global Construction Review*. Available at: www.globalconstructionreview.com/nigerias-new-railway-lagos-ibadan-start-operating/ (accessed: 6 September 2021).

George, L. (2020), 'Crowded Lagos to ban motorbikes from most of Nigerian metropolis', *Reuters*, 27 January. Available at: www.reuters.com/article/us-nigeria-transportation-ban-idUSKBN1ZQ2GF (accessed: 6 September 2021).

George, L., Payne, J. and Zhdannikov, D. (2021), 'EXCLUSIVE Nigeria's Dangote in talks with traders for oil refinery loan', *Reuters*, 15 September. Available at: www.reuters.com/business/energy/exclusive-nigerias-dangote-talks-with-traders-oil-refinery-loan-2021-09-15/ (Accessed: 18 October 2021).

GET-invest.eu (2019), 'Renewable Energy Potential'. Available at: www.get-invest.eu/market-information/nigeria/renewable-energy-potential/ (accessed: 10 January 2020).

Global Alliance for Clean Cookstoves (2016), *2016 PROGRESS REPORT CLEAN COOKING: KEY TO ACHIEVING GLOBAL DEVELOPMENT AND CLIMATE GOALS*.

Global Solar Atlas (2020), *Solar PV Resource Availability.* Available at: https://globalsolaratlas.info.

Gujba, H., Mulugetta, Y. and Azapagic, A. (2013), 'Passenger transport in Nigeria: Environmental and economic analysis with policy recommendations', *Energy Policy*, 55, pp. 353–361.

Gujba, H., Mulugetta, Y. and Azapagic, A. (2015), 'The household cooking sector in Nigeria: Environmental and economic sustainability assessment', *Resources*, 4(2), pp. 412–433.

Gupte, E. (2020), *Nigeria's President confirms removal of gasoline subsidies*. Available at: www.spglobal.com/platts/en/market-insights/latest-news/oil/060520-nigerias-president-confirms-removal-of-gasoline-subsidies (accessed: 6 September 2021).

HEI and IHME (2018), *State of global air 2018: A special report on global exposure to air pollution and its disease burden.* Available at: www.stateofglobalair.org/sites/default/files/soga-2018-report.pdf.

Idris, W.O., Ibrahim, M.Z. and Albani, A. (2020), 'The status of the development of wind energy in Nigeria', *Energies*, 13(23), p. 6219.

IEA (2021), *Nigeria - Countries & Regions - IEA. Nigeria Energy Statistics*.

IEA and IRENA (2021), *Biofuels blending mandate – IEA/IRENA Policies Database, IEA*. Available at: www.iea.org/policies/5696-biofuels-blending-mandate (accessed: 6 September 2021).

IEA, IRENA, UNSD, World Bank, WHO (2022), *Tracking SDG 7: The Energy Progress Report.* Available at: https://trackingsdg7.esmap.org/data/files/download-documents/sdg7-report2022-full_report.pdf.

IHA (2021), *Nigeria Country Profile*. Available at: www.hydropower.org/country-profiles/nigeria (accessed: 24 August 2021).

Investopedia (2019), *World's Top 10 Oil Exporters, Investopedia*. Available at: www.investopedia.com/articles/company-insights/082316/worlds-top-10-oil-exporters.asp (Accessed: 9 January 2020).

IRENA (2016), *Renewable Energy Benefits: Decentralised Solutions in the Agri-food Chain*. International Renewable Energy Agency, Abu Dhabi. Available at: www.irena.org/publications/REagrifood/.

IRENA (2017), *Renewable Energy Benefits: Leveraging Local Capacity for Solar PV*. International Renewable Energy Agency, Abu Dhabi.

IRENA (2018a), *Planning and prospects for renewable power: West Africa*. International Renewable Energy Agency, Abu Dhabi.

IRENA (2018b), *Renewable Energy Benefits: Leveraging local capacity for offshore wind*. International Renewable Energy Agency, Abu Dhabi.

IRENA (2021a), *Renewable Capacity Statistics 2021*. International Renewable Energy Agency, Abu Dhabi.

IRENA (2021b), *Renewable Power Generation Costs in 2020*. Abu Dhabi. International Renewable Energy Agency, Abu Dhabi.

IRENA (2022a), *Global Atlas for Renewable Energy*. Available at: https://globalatlas.irena.org/about.

IRENA (2022b), *Green hydrogen for industry: A guide to policy making*. International Renewable Energy Agency, Abu Dhabi.

IRENA, A.D. (2014), *REmap 2030: A Renewable Energy Roadmap*. International Renewable Energy Agency, Abu Dhabi.

IRENA and AfDB (2022), *Renewable Energy Market Analysis: Africa and Its Regions*. International Renewable Energy Agency, Abu Dhabi.

IRENA and AfDB (2022), *Energy Transition Central to Africa's Economic Future*. International Renewable Energy Agency, Abu Dhabi.

Karniliyus, J. and Egieya, J. (2014), 'Uranium development in Nigeria', in *International Symposium on Uranium Raw Material for the Nuclear Fuel. Cycle: Exploration, Mining, Production, Supply and Demand, Economics andEnvironmental Issues - IAEA CN-216*.

Latham & Watkins (2016), *Nigerian Power Sector: Opportunities and Challenges for Investment in 2016*.

Ley, K., Gaines, J. and Ghatikar, A. (2015), *The Nigerian energy sector–an overview with a special emphasis on renewable energy, energy efficiency and rural electrification*. GIZ. www.giz.de/en/downloads/giz2015-en-nigerian-energy-sector.pdf.

Loulou, R., Remne, U., *et al.* (2005), 'Documentation for the TIMES Model - PART I 1–78', *Energy Technology Systems Analysis Programme (ETSAP)* [preprint].

Loulou, R., Remme, U., *et al.* (2005), 'Documentation for the times model part II', *Energy Technology Systems Analysis Programme* [preprint].

Murty, M. and Goldar, B. (2006), 'Economic Evaluation of Investment Projects', *Report of Project Sponsored by Planning Commission, Government of India* [preprint].

NACC (2021), *Strategy Plan for Nigerian Alliance for Clean Cookstoves*. Available at: https://rise.esmap.org/data/files/library/nigeria/Clean%20Cooking/Supporting%20Documentation/Nigeria_NACC-Strategy-Plan-July-2015-June-2016.pdf.

NBS (2020), *Nigeria Living Standards Survey: A Survey Report by the Nigerian National Bureau of Statistics (in collaboration with the World Bank).*

NERC (2016), *Regulation for mini-grids 2016*.

NERC (2021), *NERC Transmission System Overview*. Available at: https://nerc.gov.ng/index.php/home/nesi/404-transmission (Accessed: 26 August 2021).

NESP (2015), *The Nigerian energy sector: An overview with a special emphasis on renewable energy, energy efficiency and rural electrification*. Nigerian Energy Support Programme (NESP), Abuja.

Nigerian Alliance for Clean Cookstoves (2022), *FG moves to develop national policy on clean cooking*. Available at: https://naccnigeria.org/.

NNPC (2007), *Draft Nigerian bio-fuel policy and incentives. Abuja. NNPC: Nigerian National Petroleum Corporation.*

Obeta, M. (2014), 'The characteristics of inland water transport in Nigeria', *IOSR Journal of Humanities and Social Science (IOSR-JHSS)*, 19(3), pp. 119–126.

Ogunmodimu, O. and Okoroigwe, E.C. (2018), 'Concentrating solar power technologies for solar thermal grid electricity in Nigeria: A review', *Renewable and Sustainable Energy Reviews*, 90, pp. 104–119. Available at: https://doi.org/10.1016/J.RSER.2018.03.029.

Ogunmodimu, O.O. (2013), 'CSP technology and its potential contribution to electricity supply in northern Nigeria', *International Journal of Renewable Energy Research (IJRER)*, 3(3), pp. 529–537.

Ohiare, S. (2015), 'Expanding electricity access to all in Nigeria: a spatial planning and cost analysis', *Energy, Sustainability and Society*, 5(1), p. 8.

Ohunakin, O.S. *et al.* (2013), 'Energy and cost analysis of cement production using the wet and dry processes in Nigeria', *Energy and Power Engineering*, pp. 537–559.

Okoro, E.E. *et al.* (2020), 'Sustainable biogas production from waste in potential states in Nigeria – alternative source of energy', *Journal of Contemporary African Studies*, 38(4), pp. 627–643. Available at: https://doi.org/10.1080/02589001.2020.1825650.

Olawale, S. (2020), 'Top 20 Largest Economies In Africa 2020', 9 January. Available at: https://naijaquest.com/largest-economies-in-africa/ (accessed: 9 January 2020).

One Earth (2021), *Supporting Women Entrepreneurs to Scale Clean Cookstoves across Nigeria, One Earth*. Available at: www.oneearth.org/projects/supporting-women-entrepreneurs-to-scale-clean-cookstoves-across-nigeria/ (Accessed: 26 August 2021).

Onokala, P.C. and Olajide, C.J. (2020), 'Problems and Challenges Facing the Nigerian Transportation System Which Affect Their Contribution to the Economic Development of the Country in the 21st Century', *Recent Advances and Emerging Issues in Transport Research – An Editorial Note for the Selected Proceedings of WCTR 2019 Mumbai*, 48, pp. 2945–2962. Available at: https://doi.org/10.1016/j.trpro.2020.08.189.

Opara, T. (2011), *Environmental Pollution : FG bans 2-stroke motorbike engines, targets EURO III standard, Vanguard News*. Available at: www.vanguardngr.com/2011/08/environmental-pollution-fg-bans-2-stroke-motorbike-engines-targets-euro-iii-standard/ (accessed: 6 September 2021).

Oxfam (2021), *Improving the fuel wood balance in the communities | Oxfam in Nigeria*. Available at: https://nigeria.oxfam.org/what-we-do-sustainable-livelihoods/improving-fuel-wood-balance-communities (accessed: 26 August 2021).

Oyedepo, O.S. *et al.* (2015), 'Analysis of Energy Utilization in Selected Industries in Southwestern Nigeria', *Energy Engineering*, 112(6), pp. 47–74. Available at: https://doi.org/10.1080/01998595.2015.11494386.

Pai, S. *et al.* (2021), 'Meeting well-below 2°C target would increase energy sector jobs globally', *One Earth*, 4(7), pp. 1026–1036. Available at: https://doi.org/10.1016/j.oneear.2021.06.005.

PWC (2017), *Nigeria's Refining Revolution*.

Reed, E. (2020), *Nigeria launches autogas push - News for the Oil and Gas Sector*. Available at: www.energyvoice.com/oilandgas/africa/283135/nigeria-launches-autogas-push/.

Roche, Y.M. *et al.* (2019), 'Achieving Sustainable Development Goals in Nigeria's power sector: assessment of transition pathways', *Climate Policy*, pp. 1–20. Available at: https://doi.org/10.1080/14693062.2019.1661818.

SE4ALL (2021), *Nigeria Country Data*. Available at: www.se4all-africa.org/seforall-in-africa/country-data/nigeria/ (accessed: 25 August 2021).

Simonyan, K.J. and Fasina, O. (2013), 'Biomass resources and bioenergy potentials in Nigeria', *African Journal of Agricultural Research*, 8(40), pp. 4975–4989.

Sobamowo, G.M. and Ojolo, S.J. (2018), *Techno-Economic Analysis of Biomass Energy Utilization through Gasification Technology for Sustainable Energy Production and Economic Development in Nigeria, Journal of Energy*. Available at: https://doi.org/10.1155/2018/4860252.

Solar Business Hub (2018), *Sokoto state government awards contract to construct 250 solar-powered water schemes in rural areas, Solar Business Hub*. Available at: https://solarbusinesshub.com/2018/01/24/sokoto-state-government-awards-contract-to-construct-250-solar-powered-water-schemes-in-rural-areas/ (accessed: 6 September 2021).

Solar Plaza (2017), *Establishing a foothold in the Nigerian solar PV market.* Available at: www.solarplaza.com/channels/ markets/11771/establishing-foothold-nigerian-solar-pv-market/.

Statista (2022), *Population forecast in Nigeria in selected years between 2025 and 2050*. Available at: www.statista.com/statistics/1122955/forecast-population-in-nigeria/.

Tambari, I.T., Dioha, M.O. and Failler, P. (2020), 'Renewable energy scenarios for sustainable electricity supply in Nigeria', *Energy and Climate Change*, 1, p. 100017. Available at: https://doi.org/10.1016/j.egycc.2020.100017.

TCN and PMU (2017), *Nigeria power sector recovery plan - transmission infrastructure gap analysis.*

UCT Energy Research Centre (2019), *SATIM Github Data Repository*. Available at: https://github.com/ERC-data.

U.S. Department of Trade (2021), *Nigeria - Country Commercial Guide*. Available at: www.trade.gov/country-commercial-guides/nigeria-electricity-and-power-systems (accessed: 24 August 2021).

Wijeratne, D. *et al.* (2016), *Powering Nigeria for the Future*. PWC. Available at: www.pwc.com/gx/en/growth-markets-centre/assets/pdf/powering-nigeria-future.pdf.

World Bank (2018), *Press Release: Nigeria: World Bank Approves $486 Million to Improve Nigeria Electricity Transmission Network and Infrastructure*. Available at: www.worldbank.org/en/news/press-release/2018/02/15/nigeria-world-bank-approves-486-million-to-improve-nigeria-electricity-transmission-network-and-infrastructure.

World Bank (2020), *Nigeria in Times of COVID-19: Laying Foundations for a Strong Recovery.* Available at: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/695491593024516552/nigeria-in-times-of-covid-19-laying-foundations-for-a-strong-recovery.

World Bank (2021), *Nigeria | Data*. Available at: https://data.worldbank.org/country/nigeria (accessed: 9 January 2020).

World Economic Forum (2021), *Finding financing solutions for the future of energy in Africa*, *World Economic Forum*. Available at: www.weforum.org/agenda/2021/09/financing-solutions-for-the-future-of-energy-for-africa/ (accessed: 17 November 2021).

Yetano Roche, M. (2017), 'True cost of electricity: comparison of costs of electricity generation in Nigeria'.

Yetano Roche, M. *et al.* (2020), 'Achieving Sustainable Development Goals in Nigeria's power sector: assessment of transition pathways', *Climate Policy*, 20(7), pp. 846–865.

APPENDIX A

Key stakeholders at the stakeholder engagement workshop held in Abuja in January 2020:

I. The Hon. Minister of Science and Technology, Dr. Ogbonnaya Onu

II. Barr. Joseph N. Ekumankama, the representative of the executive governor of Ebonyi state, Ministry of Investment and Abuja Liaison

III. Prof. Eli Jidere Bala, Director General/CEO, Energy Commission of Nigeria

IV. Mr Usman Gur Mohammed, Managing Director, Transmission Company of Nigeria

V. Engr. Ben Oyebero, representative of Minister of Power

VI. Dr. Reuben Bamidele, representative of United Nations Industrial Development Organization

VII. Engr. Usman Ibrahim, Vice-Chairman, Manufacturing Association of Nigeria.

VIII. Prof. A.A. Zuru, former Vice-Chancellor of Usmanu Danfodiyo University Sokoto and a representative of academia at the REmap workshop

IX. Prof. Abubakar S. Sambo, former Director-General, Energy Commission of Nigeria, and the Chairman, Special Task Force on Power

X. Dr. Bassey Kufre, representative of Central Bank of Nigeria

XI. Dr. Musa Zarmai and Dr. Kafayat Adeyemi, representatives of University of Abuja

XII. Dr. Joy Ogaji, Executive Secretary of Association of Power Generation Companies

XIII. Prof. I.J. Dioha, President of Solar Society of Nigeria

XIV. Directors of Energy Centres

XV. All Directors and Deputy Directors of Energy Commission of Nigeria.

Panelists and participants at the final REmap Nigeria review workshop held in Abuja in December 2022.

Panelists

1. **Prof. A. S. Samb**, Usmanu Danfodiyo University, Sokoto (UDUS)
2. **Engr. Prof. I.N. Itodo**, Renewable Energy and Energy Efficiency Associations (REEE-A)
3. **Engr. R.T. Yaro**, Rural Electrification Agency (REA)
4. **C. Okebugwu**, Department of Climate Change (DCC)
5. **Elder Boma V. Benebo**, Soboms Nig. Ltd
6. **Engr. A. D. Abubakar**, FMP

Participants

7. **Prof. Eli Jidere Bala**, Energy Commission of Nigeria (ECN)
8. **Ochida Ahubi Suzan**, Federal Ministry of Defence (FMOD)
9. **Mrs. C.I. Enadaghe**, Federal Ministry of Finance, Budget and National Planning (FMFBNP)
10. **Otu Abdulrazak**, National Assembly of Nigeria (NASS)
11. **Barua Murtala Abbas**, Nigerian Institute of Transport Technology (NITT)
12. **Amoriokhai Andrew**, Nigerian Nuclear Regulatory Authority (NNRA)
13. **Emechebe I. Azubike**, United Nations Industrial Development Organization (UNIDO)
14. **Victoria Gyang pivol**, FMEvir-DCC
15. **Baba Abba Aji**, Biofuel Refiners Asso. Nigeria
16. **Nick Eke**, Soboms Nig. Ltd.
17. **Dr. Joy Ogaji**, Association of the Power Generation Companies (APGC)
18. **Mohammed Magana**, Public Works Department (PWD)
19. **Pewe Samagi**, Bureau of Public Enterprises (BPE)
20. **Blessing Nkwocha**
21. **Engr. Temitope Dina**, Federal Ministry of Power (FMOP)
22. **Engr. Shuaibu Aliyu**, National Agency for Science and Engineering Infrastructure (NASENI)
23. **Paul Ogburu**, Biofuel Reniners Association of Nigeria
24. **J. Okafor Kosisochukwu**, Manufacturers Association of Nigeria (MAN)
25. **Ezeafulukwe Ifeoma**, Senate Committee of Science and Tech.
26. **Edern Nengimote**, Nigerian Nuclear Regulatory Authority (NNRA)

27. **Dr. Yakubu Agbidye**, Jatropha Growers Processors and Exporters Association of Nigeria (JAGPEAN)
28. **Bode Fadipe** (Esq), Association of Power Generation Companies (APGC)
29. **Engr. Maiyaki Ohida**, Nigerian Society of Engineers (NSE)
30. **Dr. Oghuma Patrick**, FMSTITA-PS
31. **Mrs Monilola Udoh**, Federal Ministry of Science, Technology & Innovation (PS-FMSTI)
32. **Mrs Abimbola Ajayi**, PA-PS FMSTI
33. **Engr. Bassey Emmanuel**, FMOMSD
34. **Sola Martyns Yellowe**, National Environmental Standards and Regulations Enforcement Agency (NESREA)
35. **Engr. Ibrahim Magaji**, Federal Ministry of Water Resources (FMWR)
36. **Elder Benebo Boma**, Soboms nig
37. **Engr. E. Nosike**, FMP
38. **Isah Babagana**, Ministry of Petroleum Resources (MPR)
39. **Dike Benjamin**, The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)
40. **Husceeni Sheffima**, Ministry of Defence (M.O.D)
41. **Mrs. Omolara Ogunbiyi-Samuel**, Federal Ministry of Finance (FMF)
42. **Compt. Y. M. Gaya**, Nigeria Customs Service (NCS)
43. **Engr. H.I. Ndukwe**, Transmission Company of Nigeria (TCN)
44. **Pius Oloruntoba**, Nigerian Bulk Electricity Trading, (NBET)
45. **Oyeka O. Patrick**, Ministry of Mines and Steel Development (MMSD)
46. **Deinsam D. Ogan**, MMSD
47. **Dr. O.O.E. Ajibola**, National Center for Energy Efficiency and Conservation (NCEEC)
48. **Mr. R.N. Efunkoya**, NCEEC. Lagos
49. **Ibrahim Usman**, National Centre for Petroleum Research and Development (NCPRD) Bauchi
50. **Engr. Dr. J. C. Asogwa**, Energy Commission of Nigeria (ECN)
51. **Alhassan Haruna**, ECN
52. **Hajara Babatunde**, ECN
53. **S. A Maje**, ECN
54. **Osaghae G. Nosa**, ECN
55. **Ibrahim Idako**, ECN
56. **B.M. Liman**, ECN
57. **Ogar J. A.**, ECN
58. **Agebee J. A.**, ECN
59. **Ndaceko Usman I.**, ECN
60. **Mela K. N.**, ECN
61. **Nathan Awuapila**, ECN
62. **Mrs. Maria Mimi Abam**, ECN
63. **B.F.I Sulu**, ECN
64. **Abdulkabir Aliyu**, ECN
65. **B.G Tella**, ECN
66. **John Ben**, ECN
67. **Ahmed Tijjani**, ECN
68. **Bamaiyi Usman**, ECN
69. **Damian Anokwuru**, ECN
70. **Engr. Felix Olu**, ECN
71. **Ibrahim Aminu**, ECN
72. **Ayanleke Olubisi**, ECN
73. **Elamah Abdulazeez**, ECN
74. **Engr. J.S Olayande**, ECN
75. **Abdelnasser Abdallah**, ECN
76. **Suleiman Y. Destiny**, ECN
77. **Tijjani Abba**, ECN
78. **Sanusi Sani**, ECN
79. **Patrick E. Okon**, ECN
80. **M. A. Mundu**, ECN
81. **Nnah U. C.**, ECN
82. **Dr. Bappah Umar A.**, ECN, NCPRA
83. **Josemarcel Felicity C.**, ECN
84. **Engr. Mohammed Alkali Goni**, ECN
85. **Abbas Musa**, ECN
86. **Aliyu Habeeba A.**, ECN
87. **Segun Ogunfowora**, ECN
88. **Bassey Atakpa**, ECN

89. **Cletus D. Nnah**, ECN
90. **Adewale A. Bernard**, ECN
91. **Rotimi G. Alayande**, ECN
92. **D.H. Bamaiyi**, ECN
93. **Shehu S. Mustafa**, ECN
94. **Dango Hauwa Purdi**, ECN
95. **Mrs. F.T. Abiodun**, ECN
96. **Kenneth Enebuse**, ECN
97. **Kingsley Nwanji**, ECN
98. **Engr. Promise U. Chukwu**, ECN
99. **Dr. I.F. Okafor**, National Centre for Energy Research and Development (NCERD)
100. **Adeola I. Eler**i, ECN
101. **Ewa Jemaima**, ECN
102. **Abioye O.**, ECN
103. **Adisa Bukola G.**, ECN
104. **Mrs Amina Isa Saddik**, ECN
105. **Joshua Ovey Steadfast**, ECN
106. **Yerima I. Yusuf**, ECN
107. **Anasigwe Esther N.**, ECN
108. **Nafiu Tijjani**, ECN
109. **Adedayo O.**, ECN
110. **Usman Shehu Garba**, ECN
111. **Ikeme Chinwe**, ECN
112. **Nyikyaa Doreen**, ECN
113. **Ebiye Philip Tuaweri**, Soboms Nigeria Ltd.
114. **Azubuike Gift Black**, Federal Ministry of Petroleum Resources (FMPR)
115. **Kola Lawal**, Blue Camel Energy Ltd.
116. **Jumoke Delano**, Abuja Electricity Distribution Company (AEDC)
117. **Latifah Aspitah Isah**, Aspital Global Nigeria Ltd.
118. **Engr. Chidinma Edu**, National Environmental Standards and Regulations Enforcement Agency (NESREA)
119. **Oluseye Akinboyewa**, Nigerian Electricity Regulatory Commission (NERC)
120. **Eluma G. Mathias**, FMSTI
121. **Engr. Oladapo Agbola**, Ministry of Petroleum Resources
122. **Sam-Ikpe Ephram E.**, Association of Generation Companies
123. **Maimuna Mustapha Yahuza**, Assistant Director P and PC

APPENDIX B

The TIMES Nigeria model

The overall approach employed in this study was to use an integrated energy system model to analyse how Nigeria's growing energy service demands can be supplied under various scenarios out to 2050.

This study largely relies upon energy system analysis using TIMES (The Integrated MARKAL EFOM System) modelling framework for Nigeria (Loulou, Remne, *et al.*, 2005). The main output of TIMES are the energy system configurations to meet energy service demands, which are exogenous to the model and further detailed below. The model considers primary energy supply, final energy consumption, energy flows, greenhouse gas emissions, capacities of technologies and marginal emissions abatement costs.

The TIMES Nigeria model employed for this exercise has been set up for 40 years extending from 2015 to 2050 at five-year intervals and follows the same structure as was initially presented by Dioha and Kumar in (Michael O. Dioha and Kumar, 2020). In the model, the Nigerian energy system has been split into five major energy-consuming sectors: transport, industry, commercial, residential and agriculture. Each of these five sectors is further split into subsectors to reflect the sectoral end-use demands, as TIMES is a demand-driven model and thus shapes energy supply technology configurations to meet these demands.

On the supply side of the energy system, the model considers the several available energy resources that are produced locally and those that are imported in order to satisfy the various end-use demands. The energy resources encompass conventional energy such as oil and natural gas as well as renewable sources such as solar, wind, hydro and biomass. Furthermore, the annual limit of extraction of each of these fuels is represented by constraints imposed on the supply side.

To capture inter-fuel and inter-technology substitutions within the model, the relative energy prices and technology costs (investment costs, operation and maintenance [O&M] costs) of various forms were defined. Furthermore, various technical parameters (*e.g.* technical efficiency, capacity factor, lead time, lifetime) of conversion and process technologies are incorporated in the model. Nigeria-specific capital costs and O&M costs for various technologies included in the model database have been obtained from various sources. Wherever Nigeria-specific costs are not available, international costs are used. Moreover, future reduction in the cost of emerging technologies has also been assumed based on an understanding of the particular technology development.

Cost assumptions

Table 15 shows the various economic costs considered for energy resources in the model. To reflect the price differentiation across several energy-consuming sectors/segments/uses, the study did not consider the implications of subsidies and taxes. The energy prices for the future are taken from various sources (both local and international). Fossil fuel prices were mainly adapted from projections from the United States Energy Information Administration. A discount rate of 12% has been applied to account for energy resources produced locally. It is worthwhile to state that there has been uncertainty in fossil fuel prices in recent years for several reasons. Thus, the projections here are subject to oil market volatility.

Given the wide range of technologies modelled in TIMES Nigeria, there was no central cost data source. Various websites, interviews, manufacturers' quotations, stakeholders and calculations have been used to arrive at the cost of technologies and production of energy resources used in TIMES Nigeria model. However, care was taken to ensure that the cost data used reflect the true cost of the technologies in Nigeria. Table 16 shows the cost assumptions used for electricity generation technologies which were derived from ETSAP (2017), UCT Energy Research Centre (2019) and Yetano Roche (2017). For a more detailed breakdown of these costs for further end uses please consult the Appendix of Dioha and Kumar (2020) which has a ful model description.

Table 15 Cost assumptions for production of energy resources (USD 2010/gigajoule)

Item	2015	2030	2050
Agricultural residue	2.10	3.30	4.90
Biodiesel	31.30	34.20	35.70
Bioethanol	19.80	20.80	21.70
Biogas	14.00	15.20	16.80
Coal	1.88	2.46	2.64
Crude oil	8.08	13.39	16.38
Diesel	16.64	26.58	29.16
Fuel oil	6.78	14.59	17.05
Fuelwood	1.00	1.00	1.00
Gasoline	18.90	27.44	30.16
Kerosene	10.10	20.51	24.70
Liquefied petroleum gas (LPG)	14.87	17.82	21.34
Natural gas	2.14	3.55	4.18
Uranium	0.11	0.11	0.11

Table 16 Capital cost assumptions for electricity generation of technologies (USD 2010/kilowatt)

Item	2015	2030	2050
Coal plant	1 800	1 600	1 300
Gas turbines	1 000	800	800
Captive fossil	600	600	600
Nuclear	5 880	5 550	4 550
Large hydro	1 900	1 500	1 200
Small hydro	3 100	2 900	2 200
Biomass plant	2 900	2 600	2 000
Utility-scale photovoltaic (PV)	1 100	800	400
Off-grid PV (including storage)	2 800	2 400	1 300
Wind turbines	1 760	1 500	900
Concentrated solar power (CSP) (including storage)	5 050	4 300	3 000

Macroeconomic drivers

On the demand side of TIMES Nigeria model, econometric models were developed based on various macroeconomic drivers that are used to understand the changing patterns of end-use demands. The socio-economic form of any country serves as the basis of its development trajectory and also plays a key role in determining its future energy demand trajectory and corresponding emissions. Population and gross domestic product (GDP) are the commonest forces influencing the patterns of growth, production and consumption choices in an economy. Moreover, socio-economic analysis is imperative to examine the associated costs and benefits of undertaking alternative choices and understanding the macroeconomic implications on the economy. Accordingly, this study examines how these drivers may influence final energy consumption in the Nigerian economy.

Population and its structure

Population census in Nigeria is under the purview of the National Population Commission. The last census conducted in the country was in 2006. Then, Nigeria's population was estimated at around 140 million people. In this study, the future projections of Nigeria's population are taken from the United Nations 2019 Medium Variant World Population Prospect. Accordingly, in 2015, the total population of Nigeria was estimated at around 181 million people. This value is expected to grow by over 100% to reach around 401 million people by 2050 (Table 17). In a similar time frame, the rate of urbanisation is expected to rise from 48% to about 70%. Data on characteristics of Nigerian households are usually collected by the National Bureau for Statistics (NBS) through its household living standard measurement surveys. The survey reports have been used in deciding the sizes for rural and urban households in Nigeria. The total number of households has been projected to increase from 16 million rural and 18 million urban in 2015 to around 24 million rural and 70 million urban by 2050.

Table 17 Population projection for Nigeria

Year	Total population (million)	Urbanisation level (%)
2015	181	48
2020	206	52
2025	233	56
2030	263	59
2035	295	62
2040	329	65
2045	365	67
2050	401	70

Gross domestic product

The GDP trajectories used in this study were requested at the Renewable Energy Roadmap (REmap) workshop held in Abuja in January 2020 with key stakeholders spanning the Nigerian energy sector and the Honourable Minister of Science and Technology to help enable a deeper understanding of scenarios developed. The central scenario used for this study is 7% per year average growth rate (a rate which was decided upon in consultation with stakeholders) with two additional growth rate scenarios also considered – a 5% per year average growth pessimistic case and 10% per year average growth optimistic case. The GDP projections are assumed to take effect from 2021 while the actual reported GDP values by the NBS and Central Bank of Nigeria have been used for the three growth scenarios for the period 2015-19 (NBS, 2020). The GDP of 2020 has been impacted by COVID-19 pandemic and this was reflected in the study with a negative GDP growth rate (-3.2%) as projected by the World Bank (World Bank, 2020). The GDP structure is assumed to be consistent across all the scenarios as presented in Table 18 below for the central growth scenario.

Table 18 7% GDP growth rate and sectoral distribution

Year	GDP (trillion 2010 constant price, Nigeria naira [NGN])				Percentage share (%)			GDP per capita (NGN, 2010)
	Agriculture	Industry	Services	Gross	Agriculture	Industry	Services	
2015	16	16.4	36.7	69	23.1	23.7	53.2	381 215
2020	17.1	16.4	35.6	69.1	24.8	23.8	51.5	335 437
2025	22.2	30.4	44.3	96.9	22.9	31.4	45.7	415 880
2030	28.5	53	54.4	135.9	21	39	40	516 730
2035	40	76.3	74.4	190.7	21	40	39	646 441
2040	53.5	107	107	267.4	20	40	40	812 766
2045	71.3	150	153.8	375.1	19	40	41	1 027 671
2050	94.7	210.4	220.9	526	18	40	42	1 311 721

Year	GDP (billion 2010 constant price, USD)				Percentage share (%)			GDP per capita (USD, 2010)
	Agriculture	Industry	Services	Gross	Agriculture	Industry	Services	
2015	102	105	236	443	23.1	23.7	53.2	2 450
2020	109	105	229	443	24.8	23.8	51.5	2 156
2025	142	195	285	96.9	22.9	31.4	45.7	2 673
2030	183	340	349	872	21	39	40	3 320
2035	257	490	478	1.225	21	40	39	4 154
2040	344	687	687	1.718	20	40	40	5 223
2045	458	964	988	2.411	19	40	41	6 604
2050	609	1.352	1.420	3.380	18	40	42	8 430

Discount rate

The choice of a social discount factor plays a key role in determining the robustness of energy scenarios arising from a social perspective within the context of a technology-rich cost-optimisation model (García-Gusano *et al.*, 2016). The discount factor is applied in the case of public-sector investment projects. In the case of no uncertainty, the projects can be ranked on the basis of net present values. The project with the highest net present value is chosen in such a case. A high social discount factor would prioritise projects with immediate net benefits whereas a low factor will indicate to prioritise projects with long-term net benefits (Murty and Goldar, 2006). Given that Nigeria is a developing country, lacking in major infrastructure investment, there is a strong case for using a higher discount factor. Consequently, a discount factor of 10% (inflation-adjusted) has been used for this study.

Energy service demands

To estimate the energy service demands across various demand sectors, econometric techniques such as regressions, process models and end-use methods were employed. The population and GDP projections were used as the main driving force for estimating the end-use demands in each of the energy-consuming sectors. The energy use on the demand side is disaggregated into five sectors namely i) residential; ii) transport; iii) industry; iv) commercial; and v) agriculture. Each demand sector has different end-use energy demand and technologies meeting these, as described below.

Residential sector

The residential sector consumes energy for cooking, lighting, air conditioning, refrigeration and hot water and for operating other miscellaneous electrical appliances. The energy sources consumed by the Nigerian residential sector mainly include traditional biomass (firewood, crop residue and animal dung), electricity, kerosene and LPG (Dioha, 2018). Traditional solid biomass fuels are mainly used for cooking in rural areas of the country. However, with the current efforts to improve clean cooking access in the country, these fuels are gradually being replaced with modern cooking fuels such as LPG and modern biofuels. Thus, commercial energy use in the residential sector is also increasing on account of the change towards more energy-intensive lifestyles as well as the transition to commercial energy forms as urbanisation grows.

In the analysis, the category of "other electrical appliances" comprises energy demand for appliances such as fans, computers, televisions, phones, washing machines, etc. Population growth and the dynamics of demographic shifts across rural and urban classes of households have a direct influence on energy demands in the future and are captured appropriately. Demand for the various energy services were computed separately for rural and urban households based on diffusion rates of these appliances across the two classes of household and the estimated appliance usage norms.

Transport sector

In the transportation sector, the demand is disaggregated into mode-wise passenger-kilometre demand and freight-kilometre demand and using various econometric demand estimation models based on several socio-economic variables, such as per capita GDP, total GDP (constant price) and population. For passenger-kilometre demand, the study considered demand for motorcycle, private car, taxi, light bus, coach, passenger train, boat and aeroplane. For freight-kilometre demand, this study considered demand for truck and freight train. To project the future passenger- and freight-kilometres demand from each mode, their respective projected vehicle population numbers is multiplied with the average occupancy rates and the dynamic utilisation rates.

Industry sector

Demand for the industry sector was estimated for four energy-consuming subsectors, namely cement, fertiliser, steel and paper. The other energy-consuming industries include the small-scale industries, such as beverages, foundry, ceramics, leather etc., and are classified in one subsector collectively named "other industries". The production output of each industrial subsector was used as a proxy for demand and projected into the future using econometric techniques. We used linear regression techniques for future projections for each of the major industry subsectors, taking production as the dependent variable and other macroeconomic variables (total GDP and sectoral GDPs) as the regressor. Due to a wide range of products within the "other industries", in place of projection of physical production, the projection for final energy demand has been used.

Commercial sector

The commercial sector comprises various institutional and industrial establishments such as restaurants, banks, hotels, shopping malls, public departments supplying basic utilities etc. The majority of the energy use in the commercial sector is mainly associated with services such as cooling, lighting and cooking. In the commercial sector, energy service demand is projected based on the total floor area of the commercial sector and using the value added by the services sector as an explanatory variable. Energy demand for providing civic services such as street lighting, public waterworks and sewage systems are internalised in the analysis.

Agriculture sector

Traditionally, Nigeria has been an agricultural economy. Agriculture is still a major source of employment, although its share in GDP was around 22% in 2019. In the agriculture sector, final energy demand is estimated for irrigation pumping, traction and kerosene applications. The demand for irrigation pumping is calculated by estimating the irrigation pump demand of the agriculture sector. Demand for traction is calculated by estimating the number of tractors that will be required in future. Kerosene application demand was estimated based on the historical growth of kerosene in the sector. Crop production was used as the main driver of energy service demands in the sector.

POWER		
Coal	PES	Nigeria's proven reserve of coal is about 639 million tonnes (Mt) while the inferred reserve is about 2.75 billion tonnes. The coal-fuelled electricity generation target in Nigeria's Vision 30-30-30 is to achieve generation capacity of 0.424 gigawatts (GW) by 2020 and 3.2 GW by 2030. Currently, there is no coal plant in Nigeria; however, there are plans under way to use the domestic coal resources in Enugu and Kogi states for power generation in the country. Permission has been granted for the development of at least one coal power plant. It proposed to use the less innovative technology (subcritical technology) and does not include carbon capture and sequestration. In view of the interest in coal as per the Vision 30-30-30 as well as stakeholders' review, it is assumed that 0.4 GW of coal-powered generation would be available by 2030 and 10 GW by 2050.
	TES	The TES envisages a Nigerian energy system without coal power plants. Since construction is yet to start, the scenario suggests that there is no need to invest in coal power generation to avoid carbon lock-in as Nigeria moves towards a more sustainable energy mix in the future. Accordingly, the TES assumed that coal would not be deployed in the Nigerian energy system.
Gas	PES	The gas-fuelled available on-grid generation capacity target in Vision 30-30-30 is 13 GW. In 2015, Nigeria had about 10.6 GW of total installed gas capacity. However, less than 5 GW is available for grid electricity owing to inadequate gas supply. Nigeria's proven natural gas reserves is around 202 trillion standard cubic feet, representing a huge opportunity for domestic gas utilisation. In this scenario, the maximum total installed capacity of natural gas power plants is assumed as 18 GW by 2030 and 38 GW by 2050. This modest projection is based on the current interest of the government towards decentralising electricity generation in the country. Thus, limiting investment in conventional centralised power plants.
	TES	While Nigeria pushes for more utilisation of domestic natural gas for electricity generation, the TES suggests that Nigeria has other domestic renewable resources to invest in beyond natural gas. Thus, investment in natural gas is slowed after 2030 which therefore leads to a capacity of around 14 GW by 2030 and 15 GW by 2050. Further, capacity utilisation of existing power plants is increased up to 85%.
Nuclear	PES	Exploration of uranium– the main source of nuclear energy in the country – is still in progress and the proven reserve is yet to be quantified (ECN, 2014c). Government agencies and independent researchers have tried to quantify uranium reserves in Nigeria. At the end of various exploration programmes in 2001, the reserve of uranium in Nigeria was put at around 200 tonnes, with grades ranging from 0.63-0-9% at a vertical depth of 130-200 metres (Karniliyus and Egieya, 2014). Currently, there is no nuclear power plant in Nigeria. However, there are plans under way for establishing one. While the Nigerian Electricity Vision 30-30-30 envisaged the development of a nuclear power plant by around 2025, it has been assumed that only after 2030 can a nuclear power plant be deployed in Nigeria. The scenario assumes a maximum of 1 GW by 2030 and 5 GW by 2050. Stakeholders' opinions with respect to uncertainties and delays in land acquisitions, public acceptance, international diplomacy, slow development and commercialisation of nuclear technologies forms the backbone for such modest projections.

<table>
<tr><th colspan="3">POWER</th></tr>
<tr><td>Nuclear</td><td>TES</td><td>The TES also envisages an atom-free energy system in Nigeria. Since nuclear power is yet to be developed, the scenario suggests that there is no need to invest in expensive nuclear power technologies where there are other relatively cheaper renewables to employ towards the same purpose of power generation. Accordingly, the TES assumes that nuclear would not be deployed in the Nigerian energy system.</td></tr>
<tr><td rowspan="2">Hydro</td><td>PES</td><td>Nigeria has a large hydro potential of around 24 GW. However, this potential is yet to be exploited. In 2015, Nigeria had about 1.9 GW installed capacity of large hydro. There are projects under way such as the Lokoja – 0.75 GW, Makurdi – 1 GW, Zungeru – 0.7 GW plant in Niger state and the 3.05 GW Mambilla hydropower plant in Taraba state which are aimed at complementing the existing large hydro systems. The large hydro electricity generation target in the National Renewable Energy Action Plan (NREAP) is to more than double the existing capacity up to 4.7 GW by 2030. In view of the government plans to rehabilitate and expand the capacities of the existing hydro plants, the capacity of large hydro plants is assumed to reach 5 GW by 2030 and 10 GW by 2050. It is assumed that the 3.05 GW Mambilla hydroelectric project will come on board before 2030 and further expansion of large hydro projects will continue even after 2030.

Nigeria potential for small hydro is around 3.5 GW. However, the existing small hydro capacity is just around 0.068 GW. The NREAP target for small hydro is 1.2 GW by 2030. With the renewed interest in small hydro plants as per the NREAP, it is assumed that the NREAP target will be realised and the capacity of small hydro increases to 1.2 GW in 2030 and up to 3.0 GW by 2050.</td></tr>
<tr><td>TES</td><td>The overall purpose of the TES framework is to promote the aggressive deployment of renewable energy beyond the PES. Thus, it is assumed that the technical potential of large and small hydro is realised faster compared with the PES case. Accordingly, large hydro capacity reaches 7 GW in 2030, 12 GW by 2040 and remains constant to 2050. Similarly, small hydro capacity reaches 2.2 GW in 2030, 3.5 in 2035 and remains constant to 2050.</td></tr>
<tr><td>Solar</td><td>PES</td><td>The annual average total solar radiation varies from around 25.2 megajoules per square metre (MJ/m^2) per day in the northern region to around 12.6 MJ/m^2/day in the southern region (Emodi and Yusuf, 2015). Nigeria has a theoretical potential for electricity production from solar PV technology in the range of 207 000 gigawatt hours r annum if only 1% of the land area were used for solar PV installation (NESP, 2015).

Centralised grid-connected solar PV
Currently, Nigeria has no grid-connected solar PV plant. However, there are serious plans under way to connect solar PV plants to the central grid. Several solar projects have received licences to be grid-connected such as the 100 megawatt (MW) facility in Bauchi state and many others in different states of the country. The target of the NREAP is to achieve grid-connected solar PV of 2 GW by 2020 and 5 GW by 2030. The target of 2020 is yet to be achieved. Adapted from the NREAP and modified by stakeholders' opinions, it is assumed that efforts in this regard will be improved and grid-connected solar PV capacity will be 5 GW in 2030 and reach 25 GW by 2050.

Decentralised solar PV
There exist off-grid solar PV systems scattered across the country in the forms of solar water pumping systems, solar home systems, solar street lights and mini-grids. There is no reliable estimate of the totalled installed capacity of decentralised systems in the country. However, 2015 estimates show that there is around 0.01 GW of decentralised systems (Roche et al., 2019). Development of decentralised renewables is assumed to progress in line with government policies and programmes. As per the Nationally Determined Contribution (NDC) targets, 13 GW of decentralised solar PV is assumed to be met by 2030 while 30 GW is to be met by 2050.

CSP
Deployment of CSP requires areas with huge direct normal irradiation (DNI) potential. High DNI is experienced in the northern region and it varies from 6.0 kilowatt hours per square metre (kWh/m^2) per day (2 190 kWh/m^2/year) to about 7.5 kWh/m2/day (2 737.5 kWh/m^2/year), stretching from Adamawa to Sokoto (Ogunmodimu and Okoroigwe, 2018). The NREAP target is to achieve 0.05 GW of CSP by 2020 and 1 GW by 2030. Presently, there is no CSP plant in Nigeria. Based on the current plans and stakeholders' review, CSP capacity is modelled as 1 GW in 2030 and 5 GW in 2050.</td></tr>
</table>

POWER		
Solar	TES	Given the abundant solar radiation and land available in the country, additional solar capacities are not considered as a challenge, provided the financial resources needed for the same are available. **Centralised grid-connected solar PV** Maximum capacity is assumed that grid-connected solar PV capacity will be 10 GW in 2030 and reach 40 GW by 2050. To account for the huge growth in demand in TES10, the capacity was further expanded to 60 GW by 2050. **Decentralised solar PV** Maximum capacity of 22 GW of decentralised solar PV is assumed to be met by 2030 and 75 GW by 2050. To account for the huge growth in demand in TES10, the capacity was further expanded to 80 GW by 2050. **CSP** CSP is assumed to penetrate up to a maximum of 2 GW by 2020 and 12 GW by 2050. To account for the huge growth in demand in TES10, the capacity was further expanded to 16 GW by 2050.
Wind	PES	The wind energy potential in Nigeria is very modest, with annual average speeds of about 2 metres per second (m/s) at the coastal region and 4 m/s at heights of 10 metres in the far northern region of the country. Based on wind energy resource mapping carried out by the Ministry of Science and Technology, wind speeds of up to 5 m/s were recorded in the most suitable locations, which reveals only a moderate and local potential for wind energy. The highest wind speeds can be expected in the Sokoto region, the Jos Plateau, Gembu and Kano/Funtua. From the study, Maiduguri, Lagos and Enugu also indicated fair wind speeds, sufficient for energy generation by wind farms. Apart from these sites, other promising regions with usable wind potential are located on the Nigeria western shoreline (Lagos region) and partly on the Mambila Plateau. Thus, Nigeria is located in the poor-to-moderate wind regime. Wind energy deployment in Nigeria should be focused in the northern region. Apart from the coastal and offshore locations, the wind speed in southern Nigeria is relatively low, while higher wind speeds are experienced in the northern region (Emodi and Yusuf, 2015). Currently, there is no estimate of offshore wind potential in Nigeria. However, the Federal Ministry of Power says that it is conducting an offshore wind mapping. For this study, it is assumed that only onshore wind turbines will be deployed in Nigeria. The target of the NREAP is to achieve 0.17 GW of grid-connected wind capacity by 2020 and 0.8 GW by 2030. Currently, there is no grid-connected wind plant in Nigeria. However, there are wind projects under development for grid connection such as the 10 MW facility in Katsina and the 100 MW in Plateau state. Owing to the poor wind regime in the country as well as stakeholders' opinion, wind-based capacity is pegged at 0.8 GW in 2030 and will reach a maximum capacity of 7 GW by 2050.
	TES	Wind-based capacity is pegged at maximum of 2.5 GW in 2030 and will reach a capacity of 10 GW by 2050, assuming they will be installed in the windy northern parts of Nigeria. To account for the huge growth in demand in TES10, the capacity was further expanded up to 14 GW by 2050.
Biomass	PES	Exploiting the huge potential of biomass resources in the country, especially in the form of agricultural residues for power generation, will go a long way to resolve the current energy crisis in Nigeria (Simonyan and Fasina, 2013). While there exist many biomass options for power generation, this study considers only agricultural residues as feedstock for biomass power plants (ECN, 2015b). The annual potential of agricultural residues is estimated at around 145.62 Mt (Simonyan and Fasina, 2013). To date, there has not been any significant plan to establish a biomass power plant in the country. The NREAP target is to achieve around 0.3 GW capacity of biomass electricity by 2020 and 1.1 GW by 2030. In this study, maximum biomass-based generation (using agricultural residue as fuel) is modelled as 1 GW by 2030 and 4 GW by 2050.
	TES	Maximum biomass-based generation (using agricultural residue as fuel) will be 3 GW by 2030 and 11 GW by 2050. To account for the huge growth in demand in TES10, the capacity was further expanded up to 24 GW by 2050.

Sector	Scenario	Description
POWER		
Other renewables (tidal/ wave/ geothermal)	PES	Potentials yet to be quantified and no policy/target yet.
INDUSTRY		
	PES	The National Energy Efficiency Action Plan (NEEAP) target for high-energy-consuming sectors (*e.g.* industrial sectors) is that efficient energy will increase by at least 50% compared with baseline. However, the NEEAP does not provide baseline values and it does not have specific targets for key appliances/process in the various subsectors of industry. Hence, in the PES framework, efficiency improvement is considered as per the historical trend and in line with the conventional technological options in the Nigerian manufacturing sector. The efficiencies of industrial processes are assumed to improve autonomously and stably by 1% annually over the modelling time frame. Owing to the continuous liberalisation of the Nigerian market, it is assumed that large-scale industries such as cement and fertiliser industries will improve their energy efficiency levels by adopting state-of-the-art and advanced technologies. In the cement sector, the use of wet process is minimised and phased out by 2050 and the use of dry processes with 4-6 stage preheater + precalciner is expanded to account for 100% of cement production processes by 2050. Generally, it is assumed as per the NEEAP that the specific energy consumption (SEC) of these large-scale industrial subsectors will improve but it has been implemented in the model by the adoption of new and advanced technologies (which have better SEC) over the modelling time frame. The "other industries" which mainly consists of SMEs is assumed not to adopt energy-efficient technologies at a faster pace owing to their limited financial capacities. Most of them belong to the category of the unorganised informal industrial sector. Moreover, their fragmented nature and lack of technical know-how remains a barrier to their swift adoption of energy-efficient technologies. However, in TIMES Nigeria model, the "other industries" subsector is parameterised using dummy technologies owing to the dearth of data. Hence, the plethora of industrial products in the sector is not captured and the cost of improving energy efficiency is not well-represented. It is assumed that the SEC (efficiency of the dummy techs) will improve autonomously by 1% annually. Note that due to the aggregated nature of the subsector by using dummy technologies, the adoption of new and advanced technologies is impossible.
	TES	It is assumed that a large number of new, more efficient and advanced technologies are introduced in the industry sector, thus retiring the older ones. Solar-based industrial process heat is set to replace some of the conventional fossil- and biomass-fired systems in the large-scale industries (up to 50% by 2050). Due to space-constraint in small and medium-sized enterprises (SMEs), the penetration of solar process heat was limited. SEC of the large-scale industries and the energy intensities of the SMEs is assumed to improve by 30% by 2030 and 100% by 2050, beyond the autonomous improvements in efficiencies assumed in the PES.
TRANSPORT		
	PES	Nigeria's transport sector is dominated (around 98%) by fossil gasoline and diesel. The National Biofuel Policy (NNPC, 2007) and the NREAP push for the expansion of biofuels usage in the transport sector. Using first-generation biofuel, the target of the NREAP is to achieve 57.34% ethanol as share of gasoline consumption by 2030 and 17.45% biodiesel as share of diesel and fuel oil consumption by 2030. In the model, this has been implemented by varying share of vehicles running on different fuel types but based on stakeholders' consultation. The NDC and Sustainable Energy for All (SEforALL) actions envisage the use of domestic gas resources for automobiles. On 1 December 2020, the Nigerian government launched its National Gas Expansion Programme, which is aimed at the distribution of auto-gas across gas stations to promote the wider use of gas in vehicles (ENERGY VOICE, 2020).

TRANSPORT	
PES	Generally, the PES assumes a modest increase in the shares of compressed natural gas (CNG) and biofuels dependent vehicles. Owing to the current biofuel policy, it is assumed that the penetration of biofuels vehicles will be favoured more in comparison with electric vehicles (EVs). Thus, a slight penetration of EVs is considered. Similarly, it is worth mentioning that autonomous improvements (0.2% annual improvements) in fuel economy are considered across the modelling time frame. The following presents the numerical assumptions used in the model. Note that the shares here refer to the shares in the total vehicle fleets and not the shares of new buys. As earlier noted, gasoline and diesel dominate the current system (98%), so we won't be discussing them further – the focus will be on the key alternative vehicle fuel type implemented in each scenario. **Boat:** Boats are 100% run by diesel. The share of biodiesel-powered boats increases from 0% in 2015 to 2% in 2030 and 10% in 2050. **Truck:** Trucks are run 90% by diesel and 10% by gasoline. The share of biodiesel trucks increases from 0% in 2015 to reach at least 3% in 2030 and 8% in 2050. The share of CNG/LPG-powered trucks reaches 5% in 2030 and 12% in 2050. **Rail:** Currently, the existing few networks of the Nigeria rail transport system are based on fossil diesel. Consequently, a lag has been applied to account for the time required to develop infrastructures needed to accommodate electric-powered trains. The share of electric trains in passenger and freight rail movement increases from 0% in 2015 to 2% in 2030 and 20% in 2050. **Light bus:** Light bus is run 98% by gasoline and 2% by diesel. The share of CNG/LPG light buses increases from 0% in 2015 to reach a maximum of 10% in 2030 and 30% in 2050. Also, penetration of biofuel-powered light buses (at least 1% by 2030; 12% by 2050) and electric light buses (0.2% by 2030; 8% by 2050) are accounted for. **Coach:** Coaches are run 50% by diesel and 50% by gasoline. The share of CNG/LPG coaches increases from 0% in 2015 to reach a maximum of 10% in 2030 and 30% in 2050. Also, penetration of biofuel-powered coaches (at least 1% by 2030; 12% by 2050) and electric coaches (0.2% by 2030; 8% by 2050) are accounted for. **Motorcycle:** Motorcycles run almost 100% by gasoline. The share of electric motorcycles increases from 0.01% in 2015 to account for 2% by 2030 and 10% by 2050. **Private car:** Private cars run 98% by gasoline. The share of CNG/LPG private cars increases from 0.001% in 2015 to reach 10% in 2030 and 30% in 2050. Also, penetration of biofuel-powered private cars (at least 1% by 2030; 12% by 2050) and electric private (0.2% by 2030; 10% by 2050) are accounted for. **Taxi:** Taxis run 98% by gasoline. The share of CNG/LPG taxis increases from 0.001% in 2015 to reach 10% in 2030 and 30% in 2050. Also, penetration of biofuel-powered taxis (at least 1% by 2030; 12% by 2050) and electric private (0.2% by 2030; 10% by 2050) are accounted for. This scenario does not favour the penetration of EVs in Nigeria's transport system due to the lack of a dedicated EV policy in the country.
TES	The transport sector in this scenario has been modelled in a way such that gasoline- and diesel-run vehicles are increasingly replaced by biofuels, electricity and CNG-powered vehicles. **Boat:** The share of biodiesel-powered boats reaches 10% in 2030 and 30% in 2050. Similarly, the share of electric boats reaches 10% in 2030 and 30% in 2050. **Truck:** The share of biodiesel powered truck reaches at least 20% in 2030 and remains constant to 2050; electric trucks reach 10% in 2030 and 30% in 2050; CNG/LPG-based trucks reach 14% in 2030 and 30% in 2050. **Rail:** The share of electric-based traction in passenger and freight rail movement rises to 12% in 2030 and 40% in 2050. **Light bus:** The share of electric light buses reaches 11% by 2030 and 35% by 2050. Biofuel-powered light buses account for 20% in similar time frames. **Coach:** The share of electric coaches reaches 10% by 2030 and 35% by 2050. Biofuel-powered coaches account for 20% in the same time frames.

TRANSPORT	
TES	**Motorcycle:** Electric motorcycles are encouraged and their share is assumed to rise to 20% by 2030 and 50% by 2050. **Private car:** The share of electric private cars reaches 10% by 2030 and 35% by 2050. Biofuel-powered private cars account for 20% in 2030 and 25% in 2050. **Taxi:** The share of electric taxis reaches 10% by 2030 and 35% by 2050. Biofuel-powered taxis account for 20% in 2030 and 25% in 2050. **Modal shift** is also considered as a demand-side management strategy. By 2050, 40% of freight will be on rail; 20% of private car demand shifts to public transport as well as non motorised means and 40% of interstate passenger road movement goes to rail. Along with the penetration of these alternative fuels/technologies in the sector, we have also assumed improvements in the fuel economy of vehicles (additional 0.2% annual improvements) beyond the autonomous improvements considered in the PES.
RESIDENTIAL	
PES	In the residential sector, several factors have been considered towards the assumptions made on the level of energy access and penetration of efficient and advanced appliances. 100% access to electricity is achieved by 2030 in urban areas but achieved by 2035 in rural areas. Clean cooking systems include LPG, modern biofuel stoves, improved wood and electric stoves. In the analysis, 100% access to clean cooking devices is not achieved in both rural and urban areas. **Rural cooking:** In 2015 the shares of cookstoves in rural areas are as follows: LPG stove (3.5%), kerosene stove (20%) and fuelwood and other stoves (76.5%). The share of LPG stoves for rural areas are modelled as 20% in 2030 and 50% in 2050; improved wood stoves as 16% (2030) and 31% (2050); electric stoves as 3% (2030) and 5% (2050). Other technologies – kerosene, modern biofuels, traditional three-stone and solar cookstoves – account for the remaining percentages. **Urban cooking:** In 2015 the shares of cookstoves in urban areas are as follows: LPG stove (8.4%), kerosene stove (59.2%) and fuelwood and other stoves (32.4%). The share of LPG cookstoves for urban areas are modelled as 30% in 2030 and 70% in 2050; improved wood stove as 10% (2030) and 5% (2050); electric stove as 7% (2030) and 15% (2050). Other technologies – kerosene, modern biofuels, traditional three-stone and solar cookstoves – account for the remaining percentages. The NREAP target for number of residential houses with solar thermal systems is 7% by 2030. However, as at 2020, the share of residential houses fitted with solar water heaters is less than 1%. It is assumed that 3% of households will be fitted with solar water heaters by 2030 and 10% by 2050. In 2015, it was assumed that 20% of the existing stock of refrigerators and air conditioners are the efficient types. The share of efficient refrigerators and air conditioners are assumed to rise in both the rural and urban households to about 40% in 2030 and 70% in 2050. It is also assumed that 100% electrification is realised after 2035 (in rural areas) and the use of kerosene lantern for lighting stops. It is assumed that efficient lighting technologies such as compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs) penetrates into the rural households at a faster rate while incandescent bulbs are phased out completely by 2030.
TES	100% energy access is achieved in both rural and urban areas with a portfolio of clean cooking technologies by 2030. While LPG stove is the preferred choice for cooking in the TES, cooking technologies have been diversified. It is worthwhile to mention that biofuels (biogas) are more easily adopted by rural households due to the availability of resource compared with urban households. On the contrary, the penetration of electric stoves is assumed to be more pronounced in urban areas compared with rural areas. **Rural cooking:** The share of modern biofuels (gas and liquid) cookstoves for rural areas is 10% in 2030 and 20% 2050. Improved wood stove: 22% (2030) and 31% (2050). Electric stoves account for 10% (2030) and 30% (2050). Other technologies – kerosene, LPG, traditional three-stone and solar cookstoves – account for the remaining percentage.

RESIDENTIAL	
TES	**Urban cooking:** The share of maodern biofuels (gas and liquid) cookstoves for urban areas in 5% in 2030 and 20% in 2050. Improved wood stove: 12% (2030) and 10% (2050). Electric stoves account for 15% (2030) and 40% (2050). Other technologies – LPG, kerosene and solar cookstoves – account for the remaining percentage. It is assumed that 5% of households will be fitted with solar water heaters by 2030 and 20% by 2050. The share of efficient refrigerators and air conditioners is assumed to rise in both rural and urban households up to 50% by 2030 and to 100% by 2050. About 50% of the lighting requirement is satisfied by CFLs and LEDs in 2030 and 100% in 2050. Energy intensity (*i.e.* efficiency of "1" used to parametrise the dummy technologies) of other miscellaneous electrical appliance is assumed to improve by 40% in 2030 and 100% in 2050.
COMMERCIAL	
PES	The energy service demands of the commercial sector are split into demand for lighting, air conditioning, cooking and other electrical appliances. The NEEAP and NREAP push for energy efficiency improvements and the use of renewable energy in the service sector. Here, analysis has been done based on improvements in energy efficiency via the adoption of more efficient and advanced technologies. Similarly, analysis for renewable energy has been done based on the use of renewables for satisfying various energy service demands. The share of efficient/advanced air conditioners is assumed to rise from 25% in 2015 to 55% in 2030 and 80% in 2050. For lighting, it is assumed that LEDs account for 30% of lighting in 2030 and 50% in 2050. The share of LPG stoves for cooking increases from 10% in 2015 to reach 20% in 2030 and 35% in 2050; improved woodstoves from 10% in 2015 to 20% in 2030 and 35% in 2050; electric stoves from 1% in 2015 to 5% in 2030 and 10% in 2050. For other electrical appliances, an annual reduction of 0.5% in technological efficiency is assumed.
TES	The share of efficient/advanced air conditioners is assumed to rise to 60% in 2030 and 100% in 2050. LEDs account for 40% of lighting in 2030 and 60% in 2050. The share of electric stoves for cooking reaches 10% (2030) and 25% (2050); modern biofuel stoves 10% (2030) and 20% (2050); improved woodstove 20% (2030) and 35% (2050). For other electrical appliances, an annual reduction of 1% in technological efficiency is assumed.
AGRICULTURE	
PES	Energy in the agriculture sector is primarily needed for irrigation and land preparation. In 2015, the share of gasoline irrigation pumps was 55%, diesel was 45% and grid-based irrigation pumps was 5%. The share of solar-based pumps is very marginal. It is assumed that the share of solar-based irrigation pumpsets reaches 5% by 2030 and 10% by 2050. The share of advanced electric grid-powered pump sets in irrigation is assumed to gradually increase to 8% by 2030 and 25% by 2050. These pumps are modelled to be twice as efficient than the diesel and gasoline pumps currently in use. The share of biofuels-powered tractor increases from 0% in 2015 to 5% by 2030 and 15% by 2050. Furthermore, the share of efficient diesel-based tractors in the sector is assumed to gradually improve.
TES	The share of solar-based irrigation pumps reaches 15% by 2030 and 50% by 2050. The share of advanced electric grid-powered pumpsets in irrigation is assumed to increase to 13% by 2030 and 30% by 2050. The share of biofuels-powered tractors reaches 20% by 2030 and 40% by 2050. The share of electric tractors reaches 5% by 2030 and 20% by 2050.

IRENA

International Renewable Energy Agency

www.irena.org