PART TWO OF A THREE PART SERIES FOR THE GoPRO-ZAMBIA RESEARCH PROJECT

MEASURES AND TECHNOLOGIES FOR A LOW-CARBON ZAMBIAN ENERGY SYSTEM

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Zambia Report Series

This three-part report series offers an in-depth exploration of Zambia's energy system, focusing on its current status, the pathways for transitioning to a low-carbon future, and the broader economic role of electricity within the country. The report, ***Status Quo on Consumption and Energy System in Zambia***, lays the groundwork by analysing Zambia's existing energy consumption patterns, production capacities, and the challenges associated with its heavy reliance on biomass and hydropower. Building on these insights, this report, ***Measures and Technologies for a Low-Carbon Zambian Energy System***, is the second in the series. It explores the essential technologies and strategies that Zambia can adopt to reduce its carbon footprint, with a focus on renewable energy, energy efficiency, and carbon sequestration. Finally, the third report, ***Overview of the Electric Energy Economy in Zambia***, provides a detailed evaluation of the electricity sector's macroeconomic contributions, the regulatory framework, and the investment landscape, offering a forward-looking perspective on how Zambia can leverage its electricity resources to drive sustainable economic growth. Together, these reports provide a comprehensive roadmap for understanding and addressing Zambia's energy challenges and opportunities in the context of national development and global climate goals.

Contents

List of Tables

List of Figures

Units of Measurement

gCO²eq	Gram of carbon dioxide equivalent
GW	Gigawatt
GWh	Gigawatt hour
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt hour
L	Litre
m	Metre
m^2	Square metre
m^3	Cubic metre
m ASL	Metres above sea level
MW	Megawatt
MWh	Megawatt hour
TJ	Terajoule
TWh	Terawatt hour
USD	United States Dollars
Yr	Year

Abbreviations

7NDP	Seventh National Development Plan
ARTB	African Review of Business and Technology
AU	African Union
BGFZ	Beyond-The-Grid-Fund Zambia
CCG	Climate Compatible Growth programme
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CFL	Compact Fluorescent Lamp
CHP	Combined heat and power
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CSP	Concentrated Solar Power
DAC	Direct air capture
DME	Dimethyl ether
DSM	Demand Side Management (ZESCO department)
EE	Energy efficiency
EESAP	Energy Efficiency Strategy and Action Plan
EMRCL	Energy Market and Regulatory Consultants
EV	Electric Vehicle
FIP	Forest Investment Plan
GETFIT	Global Energy Transfer Feed-in Tariffs
GHAZ	Green Hydrogen Association of Zambia
GHG	Greenhouse gas
GGI	Green Grids Initiative
GGIA	Green Grids Initiative Africa Working Group
GoPRO-Zambia	CCG Funded Project: Green Growth Prospects in Zambia
HFO	Heavy Fuel Oil
IEA	International Energy Agency
IMF	International Monetary Fund
ITMO	Internationally Transferable Mitigation Outcome
LEAP	Leapfrogging to E-mobility Acceleration Partnership
LFO	Light Fuel Oil
MoE	Ministry of Energy
MoNDP	Ministry of National Development Planning
MoU	Memorandum of Understanding
MSW	Municipal solid waste
MW	Megawatt
NAMA	Nationally Appropriate Mitigation Action
NDC	Nationally Determined Contribution
PMRC	Policy Monitoring and Research Centre
PV	Photovoltaic
PwC	PricewaterhouseCoopers
RE	Renewable energy
REA	Rural Electrification Authority
REDD+	Reduce Emissions from Deforestation and Forest Degradation
REFIT	Renewable Energy Feed-in-Tariff
RES	Reference Energy System
RESAP	Renewable Energy Strategy and Action Plan
RTIFF	Regional Transmission Infrastructure Financing Facility
SADC	Southern African Development Community
SAPP	Southern African Power Pool
SFM	Sustainable forest management
TPES	Total Primary Energy Supply
UNEP	United Nations Environment Programme
USD	United States of America dollars
VCM	Voluntary carbon market
ZEMIA	Zambian Electric Mobility Innovation Alliance
ZESCO	Zambia Electricity Supply Corporation Limited

Executive Summary

The report delves into the essential technologies and strategies that Zambia can adopt to transition towards a sustainable, low-carbon energy future. It is the second in a series of three reports and explores the intersection of technology, policy, and investment, providing a roadmap for reducing emissions while maintaining economic growth and improving energy security.

Zambia is positioned to implement three broad categories of low-carbon technologies. First, carbon reduction technologies focus on improving energy efficiency across industries, households, and public infrastructure. Energy-efficient lighting, smart grids, and industrial audits form part of a broader national strategy to reduce electricity wastage. Government initiatives encouraging the adoption of compact fluorescent lamps and energy-efficient appliances are beginning to make inroads, particularly in urban areas, where energy use is more concentrated.

Second, carbon-free technologies represent a pivotal area for Zambia's energy future, with renewable energy sources, particularly solar and biomass, identified as key contributors to a cleaner energy mix. Although Zambia has one of the highest solar potentials in Africa, with an estimated grid-connectable capacity of 2,300 MW based on the current network configuration, the actual potential could exceed this value, with prospects of enhanced regional integration into the Southern African Power Pool (SAPP) market. Currently, the installed solar capacity remains at a mere 89 MW. Programmes like the Renewable Energy Feed-in Tariff (REFiT) and the Global Energy Transfer Feed-in Tariffs (GETFiT) have been designed to boost private investment in renewables, but there is considerable room for growth in wind and biomass technologies, which remain largely undeveloped.

Lastly, carbon removal technologies, such as carbon capture and storage (CCS) and reforestation, provide Zambia with opportunities to directly mitigate greenhouse gas emissions. Zambia's vast forested areas, which act as carbon sinks, play a crucial role in the country's climate mitigation strategy. The development of carbon credit markets, which monetise carbon sequestration through forestry initiatives, is being promoted as a key component of Zambia's low-carbon strategy.

Zambia's Nationally Determined Contribution (NDC) under the Paris Agreement commits the country to reducing its greenhouse gas emissions by 25% by 2030, with an enhanced target of 47% reduction contingent upon international support. To meet these targets, Zambia is focusing on expanding renewable energy capacity, particularly in rural areas, improving forest management, and promoting sustainable agricultural practices.

The report acknowledges the significant challenges that lie ahead. Financing remains a major barrier, with limited access to capital for large-scale renewable projects and carbon removal initiatives. Additionally, the technical capacity to implement and maintain new technologies is still developing, requiring targeted training and knowledge transfer initiatives. With the right mix of policy incentives, technological investments, and international collaboration, Zambia could potentially position itself as a leader in low-carbon development within the region, while simultaneously achieving its climate goals and improving energy security.

1 INTRODUCTION

In the face of the global challenge of climate change, Zambia stands at a pivotal juncture, recognising the urgent need to transition towards a low-carbon economy while continuing to develop its economy. The adoption of cutting-edge low-carbon technologies is not only an environmental imperative but a strategic pathway for Zambia's economic transformation and sustainable growth (MoE, 2022a; Nyoni et al., 2021).

This report explores the critical role of these technologies in mitigating the adverse impacts of carbon emissions, with a specific focus on their significance within the unique challenges and opportunities that define Zambia's context. It has been prepared within the GoPRO- Zambia research project. This project is funded by the Climate Flexible Research Fund 2022 of the Climate Compatible Growth (CCG) programme, a UKAid-funded programme. The project's main objective is to identify green growth opportunities in Zambia and analyse their macroeconomic implications. To this end, we intend to investigate the decarbonisation potential using a power system capacity and transmission expansion model, along with an input-output model for macroeconomic analysis.

This report is part of the first steps of the GoPRO-Zambia research project, and forms a coherent body of research together with two other reports. First, a report presenting an overview of the energy sector in Zambia, including energy consumption and the three energy sub-sectors as defined by the Energy Regulation Board: petroleum, electricity, and renewable energy sub-sectors. The focus is on the structure and functioning of the sub-sectors and the performance of consumption and the sub-sectors in recent years, presenting a snapshot of their present state and insights from the recent past (Chitandula et al., 2024). Second, a report that gives an overview of the energy sector in Zambia focusing on the interactions between the electricity sector and the wider economy (Maliye et al., 2024). In particular, it summarises the Zambian energy regulatory framework, explores the macroeconomic contributions of the electricity sector, and highlights the importance of adequate investment in electricity infrastructure.

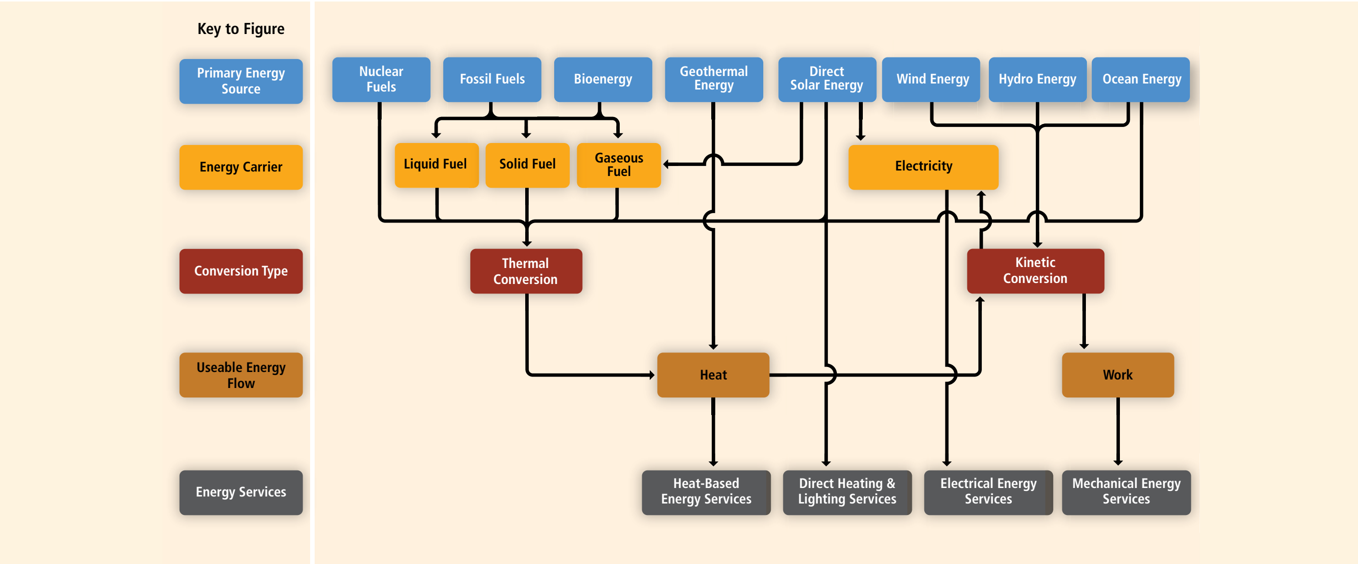
This report is organised as follows. The remainder of this introductory section provides the Zambian context and introduces supply and demand opportunities for the development of an energy transition strategy. Section 2 classifies low-carbon technologies, and Section 3 places them in the Zambian context. Section 4 describes the Nationally Determined Contribution (NDC) for Zambia, as committed in the Paris Agreement. Section 5 describes the broader energy transition by looking at strategies already in place in Zambia. Finally, Section 6 complements Section 5 by exploring the research done around energy transition strategies and low-carbon technologies in Zambia.

1.1. Background

Zambia, akin to many nations, has grappled with the consequences of the industrialisation era, witnessing a significant surge in carbon dioxide emissions that contribute to the global challenge of climate change. As the nation pursues its development goals, the adoption of low-carbon technologies emerges as an opportunity to continue its development while keeping carbon emissions low.

Hence, the pursuit of a low-carbon energy future aligns with Zambia's commitment to sustainable

Figure 1: Illustrative paths of energy from source to service. All connected lines indicate possible energy pathways (Source: Moomaw, et al., 2023).



development. Moreover, the nation faces challenges such as energy security concerns and the need for economic diversification, making the adoption of low-carbon technologies a strategic and transformative solution (MoE, 2022b; Nyoni et al., 2021).

The paths of energy from source to service are summarised in **Figure 1**, identifying the different options by which energy services can be met and the energy transformations required (Moomaw, et al., 2023). Four energy services are identified: heat-based, direct heating and lighting, electrical, and mechanical. These can be met from the following primary energy sources: nuclear fuels, fossil fuels, bioenergy, geothermal, direct solar, wind, hydro, and ocean energy. The possible paths to provide the energy services by the primary energy sources are shown in the figure with arrows. For instance, hydro energy can be used to obtain electricity by kinetic conversion, which provides electrical energy services.

The context shown in Figure 1 is not specific to Zambia, but global. Nonetheless, it applies to it after some considerations are made. First, Zambia is a land-locked country, and hence ocean energy is not a valid energy source for Zambia. Second, since there are no nuclear power stations in Zambia (IEA, 2022), and given their long construction times, a delay in the ability to harness nuclear energy should be considered.

The 'Climate Compatible Growth Starter Data Kit: Zambia' (CCG, 2023) provides a Reference Energy System (RES) for Zambia. A RES is a detailed diagram of all technical activities required to supply various forms of energy to end-use activities. In this sense, it further disaggregates Figure 1, as it shows in greater detail how the primary energy sources or commodities are obtained, the specific energy services provided, and the uses of certain primary energy sources or commodities in specific energy services and sectors.

The following primary energy sources or commodities are identified in the starter data kit (CCG, 2023): biomass, coal, Light Fuel Oil (LFO), Natural Gas, Heavy Fuel Oil (HFO), solar potential, hydro potential, wind potential, uranium potential, and geothermal potential. Observe that these primary energy sources or commodities can be aggregated in the high-level categories shown in Figure 1.

The RES also identifies four consumption sectors, namely transport, industry, residential, and commerce and public services. Beyond the greater detail in each of the consumption sectors, the classification of the energy services in Figure 1 and the Starter Data Kit (CCG, 2023) is different. While Figure 1 focuses on the type of energy obtained (heat, electrical, mechanical, etc), whereas the Starter Data Kit focuses on the uses of that energy (transport by car, residential heating, industry electricity demand, etc).

1.2. Supply and Demand Context

It is imperative for Zambia to develop a comprehensive and integrated energy transition strategy that considers both the supply and demand sides. This strategy must be tailored to the country's unique characteristics and challenges, emphasising the engagement of stakeholders from both the public and private sectors. Successful implementation hinges on collaboration and alignment with the most current reports, policies, and initiatives in Zambia related to energy transition and low-carbon technologies (Nyoni, 2022).

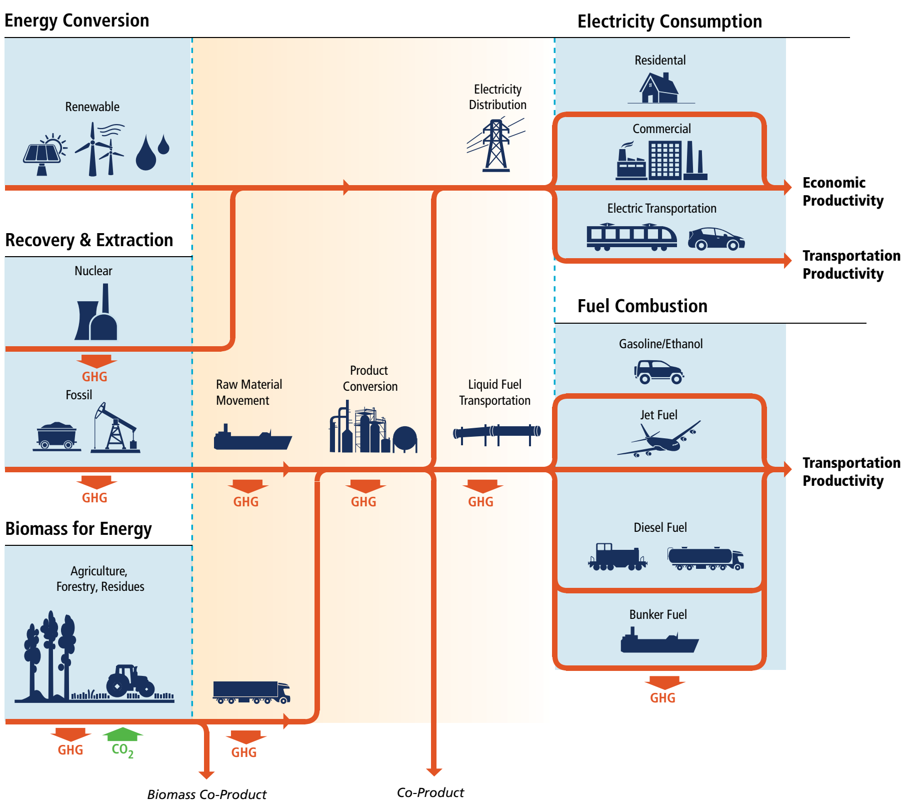
Central to the success of Zambia's integrated energy transition strategy is the collaboration of stakeholders and the development of sustainable financing mechanisms for the implementation of the energy transition strategy (Downs *et al.*, 2020; Nyokabi et al., 2023).

First, engaging with various stakeholders, from both the public and private sectors, ensures a holistic approach that addresses diverse perspectives and leverages collective expertise (Downs et al., 2020). Otherwise, it might be difficult to capture all points of view, and interesting opportunities might be overlooked.

Second, developing sustainable financing mechanisms is crucial for the implementation of the energy transition strategy. Exploring partnerships with international organisations and private investors as well as leveraging innovative financial instruments will be essential to secure the necessary financial resources for large-scale deployment (Nyokabi et al., 2023).

There are examples in Zambia where inadequate financing mechanisms resulted in

Figure 2: Illustrative system for energy production and use, illustrating the role of renewable energy along with other production options (Source: Moomaw et al., 2023). GHG = Greenhouse gas.



undesired consequences in the long term. For instance, non-cost-reflective electricity tariffs led ZESCO, the dominant vertically integrated utility in the Zambian electricity sector, to encounter financial difficulties (EMRC, 2021). Similarly, the International Monetary Fund highlighted that the petroleum pricing mechanism used by the government resulted in implicit fuel subsidies, which led to large bills for the government and instability in the energy sector (IMF, 2015).

The linkages between supply and demand and the role of renewable energy and other production options are shown in **Figure 2** (Moomaw et al., 2023). It also specifies whether each option is a greenhouse gas (GHG) source (shown in orange) and/or sink (shown in green).

The supply side is classified in three subgroups: energy conversion (renewable energy), recovery and extraction (nuclear and fossil fuels), and biomass for energy (agricultural, forestry, residues). The demand side is classified in two subgroups: electricity consumption (residential, commercial, and electric transportation) and fuel combustion (gasoline/ethanol, jet fuel, diesel fuel, bunker fuel). In this sense, it is a summary of the RES presented in the Starter Data Kit for Zambia (CCG, 2023), described above where some energy sources are aggregated (e.g., fossil fuels, renewables) and some energy uses are not present (e.g., heating or EV).

The remainder of this section summarises different options found in the literature that could be explored to develop an energy transition strategy. We classify them as supply-side (Section 1.2.1) or demand-side (Section 1.2.2) options.

1.2.1. Supply Side

- **Hydropower:** Leveraging Zambia's significant hydropower potential by expanding and optimising hydropower facilities for a cleaner energy mix (Downs et al., 2020).
- **Solar Power:** Harnessing solar energy in regions with high solar potential for decentralised power solutions (Stritzke and Jain, 2021).
- **Bioenergy:** Utilising biomass and biogas technologies for electricity generation, heating, and cooking in rural areas (Kaoma et al., 2017).
- **Wind Power:** Implementing wind farms in suitable locations to contribute to the electricity grid (Chibwe, 2020).
- **Energy Storage:** Deploying storage technologies to manage and balance the intermittent nature of renewable sources (Zebra et al., 2021).
- **Grid Modernisation:** Upgrading grid infrastructure with smart technologies to improve efficiency and reliability and to accommodate a higher share of renewables (Butt et al., 2021; Bazilian et al., 2011).

1.2.2 Demand Side

- **Energy Efficiency:** Promoting energy-efficient appliances, enforcing building codes, and optimising industrial processes for increased (or constant) productivity while reducing overall energy consumption (Brown, 2015).
- **Transportation:** Encouraging electric vehicles (EVs) and their infrastructure, investing in public transportation, and adopting cleaner production techniques in the industrial sector (IEA, 2023b).
- **Awareness and Education:** Raising public awareness about energy conservation and the benefits of low-carbon technologies (Kaoma-Sikaneta, 2020).
- **Policy and Regulatory Frameworks:** Establishing renewable energy targets, implementing carbon pricing mechanisms, and enforcing regulations to drive investments in clean energy (Fay, 2013; Qudrat-Ullah, 2022).

> “It is imperative for Zambia to develop a comprehensive and integrated energy transition strategy that considers both the supply and demand sides”

2 LOW-CARBON MEASURES AND TECHNOLOGIES IN THE ZAMBIAN CONTEXT

2.1 Classification of Low-Carbon Measures and Technology

In the quest for a resilient and sustainable energy future, Zambia stands out by aligning with global endeavours while customising solutions to suit its distinctive context. The Zambian context, characterised by diverse geographical landscapes and an economy reliant on agriculture, calls for tailored approaches in adopting low-carbon technologies. The country's rich potential in renewable resources, including abundant sunlight and water resources, uniquely positions Zambia to harness solar and hydropower technologies (African Development Bank, n.d.). Additionally, the commitment to rural development increases the prospects for decentralised energy solutions as a cost-effective and sustainable option to achieve rural development in Zambia.

In this section, we categorise low-carbon technologies into five key areas, forming a crucial framework that addresses the specific needs and challenges of Zambia. These categories provide insight into the current state of the technology in Zambia.

2.1.1 Carbon Reduction Technology

In recent years, carbon reduction technology has gained traction in Zambia, aiming to strategically boost energy efficiency, especially in power-intensive sectors (MoE, 2019). This aligns with national ambitions for both economic and environmental sustainability, driving active efforts to optimise energy use and shrink carbon footprints (MoE, 2022b). In this report, carbon reduction technology refers to new technologies or technological developments that reduce carbon emissions when compared to current practice. In the Zambian context, this includes efficiency improvements and smart grid technologies.

Energy efficiency plays a crucial role in minimising Zambia's carbon footprint. Various strategies can enhance the efficiency of the power system and contribute to environmental sustainability. One key approach involves the promotion of energy-efficient appliances. This can be achieved through initiatives such as labelling schemes, tax incentives, and awareness campaigns, encouraging households to use appliances that consume less energy, thereby reducing overall energy consumption (MoE, 2022).

Moreover, industrial energy efficiency is also important. By encouraging industries to adopt energy-efficient technologies and processes, significant reductions in their carbon footprint can be achieved. This approach not only benefits individual industries but also contributes to the overall goal of creating a more energy-efficient and environmentally responsible power system in Zambia (Mehmood, 2023).

Additionally, the implementation of smart grid technologies in Zambia is essential. Investing in advanced metering and demand-side management through smart grids can optimise the distribution of energy and minimise losses in the system. This technological advancement enhances the overall efficiency of the power infrastructure, ensuring a more sustainable and eco-friendly energy distribution network (Zulu, 2021).

2.1.2 Carbon-Free Technology

Zambia is looking to expand its use of carbon-free technology from solar, wind, and biomass. The installed capacity for solar is currently 89 MW, and the potential for solar power is at 2,300 MW (Sparkman, 2023). Currently, no power is being generated from wind, but the Ministry of Energy states that the potential for wind power capacity is 3 GW. While no power is currently produced from biomass, about 90% of people in rural areas use it for cooking. The potential for biomass power generation is estimated at 1.1 GW (MoE, 2022b).

Recognising this significant potential in solar, wind, and biomass, Zambia is committed to diversifying its energy mix. Initiatives like the Renewable Energy Feed-in-Tariff (REFIT) highlight this commitment. The REFIT programme offers a fixed tariff rate for electricity generated from renewable sources, including solar energy. The programme aims to boost investment in renewable energy projects by providing a guaranteed price for electricity generated from these sources. Ultimately, this approach is expected to encourage and increase investment in carbon-free technologies, such as solar power (MoE, 2019; MoE, 2022b).

2.1.3 Carbon Removal Technology

Zambia, with its vast forests and abundant natural resources, is actively exploring various carbon removal technologies to combat climate change and contribute to a greener future. The government is considering the possibility of utilising carbon credits as a means to finance such projects. Carbon credits, which are a type of market-based instrument that allow companies, governments, and other organisations to address their GHG emissions by funding, can be sold to businesses that are obligated to reduce their emissions. The funds generated from these sales can then be directed towards initiatives focused on removing carbon (Freedman et al., 1996; Balmford et al., 2023).

> “The Zambian context, characterised by diverse geographical landscapes and an economy reliant on agriculture, calls for tailored approaches in adopting low-carbon technologies”

Despite the government's dedication to carbon removal technologies, certain challenges persist. These include the high costs associated with deploying such technologies, substantial energy requirements, and the significant amount of land needed for certain carbon removal methods. Nevertheless, the government sees carbon removal technologies as essential components of its strategy for mitigating climate change. This is exemplified by the recent development of the Part I of the Carbon Market Framework for Zambia (MoGEE, 2023a).

Carbon removal opportunities also arise from public–private partnerships. Dubai-based Blue Carbon entered into a Memorandum of Understanding (MoU) with the Ministry of Green Economy and Environment to execute carbon removal projects in the forest sector under Article 6 of the 2015 Paris Agreement (Carbon Capture Technology Expo, 2023).

Although the implementation of carbon removal technologies in Zambia is still in its initial phases, the potential impact of these technologies on the country's efforts to mitigate climate change is significant.

2.1.4 Carbon Management Measures

One of the carbon management techniques being implemented in Zambia involves the strategic planting of trees. Forests are integral to Zambia's natural capital, providing essential benefits to rural and urban communities, contributing to the national economy, and offering global ecological value. With an estimated land area of 75.3 million hectares, the remaining forest cover ranges from 39 million to 53 million hectares. However, the country faces significant deforestation challenges, with rates varying from 113,000 to 850,000 hectares per year. Zambia ranks second in per capita deforestation in Africa and fifth globally (UNEP, 2015).

The primary drivers of deforestation include charcoal production, agricultural expansion, human settlement growth, and illegal timber exploitation. Trees act as carbon sinks, absorbing carbon dioxide, and the reduction in forest cover signals a decline in this crucial function.

To counteract this trend, a key carbon management approach involves planting more trees. This cost-effective strategy has the potential to significantly reduce the carbon footprint. Notably, in Zambia, the Maamba power station, utilising coal for power generation, actively contributes to this technique. In 2018, they planted over 72,000 tree saplings (Maamba Power Station, 2018). This initiative aims to mitigate carbon dioxide emissions in the surrounding area, demonstrating a proactive commitment to sustainable carbon management practices.

2.1.5 Resource Conservation and Recycling Technologies

In pursuit of sustainable practices, Zambia emphasises the importance of resource conservation and recycling technologies. This involves promoting efficient resource use, reducing the need for new production, and minimising associated carbon emissions (MoE, 2022a). This aligns with Zambia's broader goals of environmental stewardship and responsible resource management (Republic of Zambia, 2021).

> “Zambia is actively promoting resource conservation and recycling technologies through a multi-pronged approach involving policy and investment”

Zambia is actively promoting resource conservation and recycling technologies through a multi-pronged approach involving policy and investment. Examples of this are:

- **The National Policy on Environment:** This overarching policy framework emphasises the importance of sustainable resource management and encourages the adoption of cleaner technologies (Ministry of Tourism, Environment and Natural Resources, 2007).
- **Renewable Energy Feed-in Tariff (REFIT):** This programme incentivises investments in renewable energy projects, including solar and wind power, to reduce reliance on fossil fuels and conserve resources (MoE, 2017).

2.2 Features and Functions of Low-Carbon Technology

2.2.1 Carbon Reduction Focus

Low-carbon technology in Zambia maintains a sharp focus on carbon reduction, actively working towards minimising energy consumption and emissions. This strategic emphasis is crucial for achieving sustainable development goals while mitigating the impacts of climate change (MoE, 2022a).

2.2.2 Environmental Harmony

In the realm of low-carbon technology, environmental harmony refers to achieving a state of equilibrium and mutual benefit between technological advancements and the natural world. It involves the development and utilisation of technologies designed to have minimal environmental impact while simultaneously supporting and enhancing ecosystem health (Edinburgh Sensors, 2021). One key aspect of environmental harmony is the focus on minimising emissions and pollution.

Low-carbon technologies inherently produce significantly fewer GHGs and pollutants compared to traditional methods. This reduction plays a crucial role in addressing climate change, enhancing air and water quality, and safeguarding biodiversity. These technologies often leverage renewable energy sources such as solar, wind, geothermal, and hydropower, thereby reducing reliance on fossil fuels—a major contributor to climate change and environmental degradation (UNEP, 2016b).

In the context of Zambia, the introduction of the Renewable Energy Feed-in Tariff (REFIT) is anticipated to stimulate increased investment in the renewable energy sector. This incentivisation will contribute to a further reduction in the use of fossil fuels, promoting environmental sustainability. Additionally, the establishment of the Rural Electrification Authority (REA) in Zambia is noteworthy. The REA's primary function is to connect rural areas to the electricity grid or mini-grids, many of which are powered by solar energy (REA, 2024). The expanded access to electricity in rural areas is expected to encourage the adoption of cleaner cooking methods, potentially leading to a substantial reduction in deforestation (Clean Cooking Alliance, 2022).

Finally, another measure being implemented in Zambia is the preservation of trees. They serve as carbon sinks and become instrumental in managing and mitigating the overall carbon footprint. This holistic approach aligns with the goal of fostering environmental harmony through the integration of low-carbon technologies and sustainable practices (Tanner and Johnston, 2017).

2.2.3 Sustainability Emphasis

In Zambia, the emphasis on sustainability within the context of low-carbon technology goes beyond a narrow focus on carbon reduction. It encompasses a multidimensional approach that assesses the potential long-term benefits across various aspects of the country's development. This sustainability emphasis considers economic, social, environmental, and institutional dimensions. In evaluating low-carbon technologies, questions arise regarding their ability to create jobs, stimulate local businesses, contribute to economic growth (especially in rural areas), improve the well-being of Zambians, empower communities, promote gender equality, and address broader environmental issues such as deforestation and water scarcity (UNEP, 2016a).

Several examples highlight sustainability in action, such as solar irrigation systems fostering agricultural resilience and the introduction of EVs contributing to emission reduction while creating economic opportunities. Given Zambia's vulnerability to climate change and its unique development challenges, prioritising sustainability in low-carbon technology becomes pivotal. This approach ensures that the transition to a low-carbon economy is not only environmentally responsible but also economically and socially beneficial, contributing to a resilient and prosperous future for all citizens (United Nations, 2021).

> "Given Zambia's vulnerability to climate change and its unique development challenges, prioritising sustainability in low-carbon technology becomes pivotal"

2.2.4 Energy Efficiency

Efficiency is a cornerstone of low-carbon technology in Zambia. By producing significant benefits with reduced energy use, these technologies contribute to economic prosperity, energy security, and a healthier environment. The pursuit of efficiency is intertwined with the broader goal of achieving a resilient and low-carbon energy future for Zambia (MoE, 2022a).

Deforestation in Africa

PHOTO: ISTOCKPHOTO

> "In the quest for a resilient and sustainable energy future, Zambia stands out by aligning with global endeavours while customising solutions to suit its distinctive context"

3 LOW-CARBON TECHNOLOGIES IN ZAMBIA: A COMPREHENSIVE PERSPECTIVE

This section delves into the multifaceted landscape of low-carbon technologies in Zambia, accentuating the nation's commitment to energy efficiency, carbon-free technologies, and future considerations for carbon removal.

3.1. Carbon Reduction Technology: Energy Efficiency

Zambia has embraced a comprehensive array of energy-efficient technologies across its residential, commercial, industrial, and transportation sectors. The government's commitment to fostering energy efficiency is evident through a well-crafted and multifaceted framework (MoE, 2022a).

3.1.1 Financial Incentives

At the core of Zambia's strategy is the implementation of dynamic financial incentives designed to catalyse investments in energy efficiency. These incentives, strategically formulated by the Zambian government, play a pivotal role in driving businesses and households towards the widespread adoption of energy-efficient measures. The incentives, designed to address power shortages in Zambia and promote energy efficiency are structured as a combination of supply and demand-side interventions.

In response to the power shortages experienced in 2015, the Government of the Republic of Zambia initiated a series of energy efficiency measures (MoE, 2022a). On the demand side, ZESCO's Demand Side Management (DSM) department played a pivotal role in implementing specific interventions. These included a Compact Fluorescent Lamp (CFL) programme, focusing on energy-efficient lighting, a programme for the installation of 'solar geysers' to enhance hot water production through solar energy, and a programme offering free energy audits aimed at improving the power factor (MoE, 2022a).

The CFL programme, for instance, aimed to encourage efficient energy use and reportedly saved an estimated 45 MW of capacity through the distribution of 1 million energy-saving CFLs. Recognising its success, this initiative was integrated into ZESCO's DSM department as an ongoing internal function, with over 2 million CFLs procured by 30 June 2015 for further distribution (MoE, 2022a).

Looking forward, the government is continuing its commitment to energy sector growth by implementing measures outlined in the 2024 budget (Musokotwane, 2023). These measures are designed to increase electricity generation capacity, which currently stands at 3,790 MW as of August 2023 (PWC, 2023). The proposed incentives include extending the period during which a business can claim a refund on Value Added Tax incurred on eligible goods for hydroelectricity generation. The extension, from the current 4 years to 7 years, provides the time required for investments to materialise effectively (PWC, 2023). Additionally, the government aims to further support investment in geothermal energy activities by removing customs duty on machinery, equipment, and other goods designed for such purposes.

These incentives collectively form a comprehensive strategy to attract and facilitate investment in power generation, with the proposed measures demonstrating a proactive approach to ensuring the sustained and effective implementation of these initiatives. The success of these incentives would likely be evaluated based on their impact on increasing electricity generation capacity, fostering investment, and contributing to the overall goals of energy efficiency and sustainability in Zambia.

Furthermore, Zambia's government has implemented a range of incentives to promote engagement in renewable energy and low-carbon sectors. These incentives, outlined in the 2023 national budget and driven by the Ministry of Finance, aim to encourage various stakeholders. One notable incentive is the Global Energy Transfer Feed-in Tariffs (GETFIT), which is supported by the German Government and has empowered local players in renewable energy. Through GETFIT, six Solar Photovoltaic projects with a total capacity of 120 MW were awarded, including two 20 MW projects led by the Copperbelt Energy Corporation. This marks a significant step towards a low-carbon economy (World Bank, 2019a; Africa Energy, 2019).

The government's commitment to promoting sustainable energy extends to tax incentives, as highlighted in the 2023 national budget announcements (Mate, 2022). Notable measures include the exemption of interest income on green bonds from Withholding Tax, which aims to strengthen the green bond market. The Copperbelt Energy Corporation's issuance of a green bond, along with tax reliefs on gas cylinders and EVs, demonstrates the alignment of financial policies with the goals of a sustainable energy landscape.

> “Zambia has embraced a comprehensive array of energy-efficient technologies across its residential, commercial, industrial, and transportation sectors”

In addition to fiscal incentives, Zambia is also providing regulatory support and pursuing carbon credits to further its commitment to creating a green economy. The country has developed guidelines and listing rules for green bond issuers and investors, and has signed the Green Compact Agreement with the UK government to foster innovation in renewable energy (Mitimingi, 2023). Furthermore, the Ministry of Green Economy and Environment is spearheading the forthcoming climate change bill, which will establish the climate change fund and carbon market in Zambia. These initiatives showcase the government's comprehensive and forward-looking approach to environmental sustainability.

3.1.2 Specific Measures

Zambia's dedication to energy efficiency is not confined to abstract principles but is clearly evident through specific measures aimed at transforming the nation's infrastructure. The promotion of energy-efficient buildings and appliances stands as a testament to this commitment. The government, through stringent standards imposed on new constructions, ensures that the foundations of sustainability are embedded in the very structures that shape the nation. Simultaneously, financial incentives extended to private developers further stimulate the adoption of cutting-edge energy-efficient technologies. This dual approach creates an environment conducive to innovation, fostering a seamless integration of sustainable practices into the fabric of Zambia's infrastructure development (MoE, 2022a; Energy Regulation Board, 2022).

The Renewable Energy Strategy and Action Plan outlined by the Ministry of Energy in Zambia incorporates a multifaceted approach to stimulate the growth of the renewable energy (RE) sector. Structurally, the proposed measures are designed to create an enabling environment through policy and regulatory frameworks. This involves streamlining licensing procedures, implementing economic policy instruments, and enforcing RE standards (MoE, 2022b).

The Ministry of Energy, along with relevant government bodies, administers these changes to attract RE investments and increase the sector's contribution to the energy mix. Another facet involves developing innovative financing mechanisms to support both supply- and demand-side RE investments (MoE, 2022b). Collaborating with financial institutions and international entities, the Ministry aims to improve the viability of RE projects and enhance overall financial sustainability.

Furthermore, the plan advocates for power sector reforms, emphasising fair network access for Independent Power Producers and the establishment of an Independent System Operator (MoE, 2022b). The Energy Regulation Board is crucial in administering clear rules to minimise regulatory uncertainty. Success is gauged by increased non-discriminatory access and improved financial and technical performance.

Lastly, the strategy underscores the promotion of productive use of renewable energy, linking modern energy services to economic activities. Enhanced coordination and information-sharing among implementing agencies are vital for successful administration. Evaluation focuses on increased economic activities in rural areas, particularly in agriculture, and the broader impact on social development aspects like healthcare, education, and clean water supply. Together, these measures represent a comprehensive effort led by the Ministry of Energy to foster sustainable growth and widespread adoption of renewable energy practices in Zambia (MoE, 2022b).

Zambia's commitment to energy efficiency is supported by a comprehensive legislative framework. Articles 255 through 257 of the Zambian constitution mandate the implementation of mechanisms for waste reduction, environmental management, and sustainable development. This demonstrates a commitment to environmental standards that benefit citizens (Katati and Lange, 2023). The Environmental Management Act No. 12 of

Rubbish tip in Zambia

PHOTO: ISTOCKPHOTO

“Zambia's government has implemented a range of incentives to promote engagement in renewable energy and low-carbon sectors”

> “The Beyond-The-Grid-Fund Zambia has successfully connected 194,000 households as of 31 December 2022, with over 50% of them being rural customers”

Mini-grid for Ngwerere, on the outskirts of Lusaka

PHOTO: BEYOND THE GRID FUND FOR AFRICA

2011 further strengthens this commitment by requiring every person to safeguard and enhance the environment, making it the principal law for protecting the environment from harm caused by human activities (Katati and Lange, 2023). The Energy Regulations Act No. 23 of 2003 complements these constitutional measures by regulating energy use and promoting alternative energy sources such as solar, wind, and geothermal, as well as energy efficiency and conservation (Katati and Lange, 2023).

However, some initiatives have faced challenges. The Scaling Solar Program, launched in 2015 as a collaboration between Zambia's Industrial Development Corporation and foreign private investors under the World Bank, aimed to install 600 MW of solar power with ZESCO as the sole recipient. However, due to financial constraints at ZESCO, the programme was suspended (Elsner et al., 2021). Similarly, the GETFIT programme has been criticised for excluding local players due to high financial requirements, creating a barrier for smaller companies and experts (Elsner et al., 2021).

On a positive note, the Beyond-The-Grid-Fund Zambia (BGFZ) has emerged as a successful response to the challenges faced by the Rural Electrification Project. The BGFZ, which provides grants to small-scale energy companies for off-grid solutions, has successfully connected 194,000 households as of 31 December 2022, with over 50% of them being rural customers. This marks a significant achievement in expanding energy access (Elsner et al., 2021). This success highlights the importance of adaptable strategies in achieving sustainable energy goals.

The emphasis on specific measures not only signifies a commitment to immediate change but also lays the groundwork for a sustainable and energy-efficient future

3.2. Carbon-Free Technology: Electric Vehicles (EVs) and Green Hydrogen

This subsection scrutinises Zambia's embrace of carbon-free technologies, specifically EVs and green hydrogen, shedding light on the roles played by key organisations: the Zambian Electric Mobility Innovation Alliance (ZEMIA) and the Green Hydrogen Association of Zambia (GHAZ).

3.2.1 EV Policy and Regulatory Framework

ZEMIA, a non-profit organisation established in 2021, is a leading advocate for electric mobility in Zambia. ZEMIA works with various stakeholders, including the government, private sector, civil society, and academia, to promote policies and initiatives that support the development and adoption of EVs in the country. As one of the seven partner organisations across Africa and Latin America that received the Leapfrogging to E-mobility Acceleration Partnership (LEAP) Fund grant in 2023, a programme under the Drive Electric Campaign, ZEMIA has been actively involved in advancing electric mobility (ZEMIA, 2023a; ZEMIA, 2023b).

One of the projects supported by the LEAP Fund is ZambiaEmobilize, launched in November 2023. ZambiaEmobilize serves as a pivotal initiative in the nation's commitment to accelerating the transition to clean transportation. This project focuses on accelerating the adoption of E-mobility in public transportation. With a research duration from September 2023 to July 2025, the project aims to understand the challenges and possibilities for effective implementation. The project has two main work packages: a research and development focus for public buses and a roadmap development for electrifying buses. These components highlight the comprehensive approach taken by ZEMIA through ZambiaEmobilize to expedite the electrification of public transportation in selected urban areas (ZEMIA, 2023a; ZEMIA, 2023b; Nyoni et al., 2023).

3.2.2 Green Hydrogen Landscape

The Green Hydrogen Association of Zambia (GHAZ) is a non-governmental, non-profit organisation committed to advancing the development and utilisation of green hydrogen technology within Zambia. Established in 2022 and fully registered in 2024, it focuses on awareness, policy development, and practical applications. Beyond its role in grid balancing, green hydrogen could find applications in sustainable transport, clean cooking, and agriculture for fertiliser production. GHAZ envisions green hydrogen as a central player in Zambia's overarching energy transition strategy (GHAZ, 2023).

However, the development of green hydrogen faces several challenges, such as high production costs, lack of infrastructure, regulatory barriers, and technical issues. These obstacles may influence green hydrogen's role in Zambia's overarching energy transition strategy. To overcome these challenges, GHAZ advocates for a supportive policy environment, increased investments, capacity building, and international cooperation.

Zambia possesses favourable conditions for harnessing green hydrogen, including abundant renewable energy resources, especially solar and hydro. Although landlocked, Zambia's strategic location in Southern Africa allows for potential integration into regional transportation networks and partnerships, facilitating the export of green hydrogen to neighbouring countries with port access, and from there to global markets. Despite these advantages, effective harnessing of hydrogen in Zambia requires addressing specific circumstances such as human capital, resource constraints, and knowledge gaps. Being at the forefront of this emerging industry, GHAZ relies on its extensive network of local and international partners and draws inspiration from successful models in South Africa and Namibia.

The establishment of a green hydrogen sector in Zambia necessitates significant investments in public awareness campaigns. GHAZ recognises the importance of educating the public about the benefits of green hydrogen, not only in terms of grid balancing but also in transforming sustainable transport, clean cooking, and fertiliser production for agriculture. Additionally, GHAZ aims to emphasise the broader advantages, including improvements in the fertiliser industry, human capacity development, and employment opportunities.

By actively involving the public and stakeholders, GHAZ aims for green hydrogen to contribute to a sustainable and eco-friendly future. The challenges and circumstances mentioned underscore the complexities associated with green hydrogen development in Zambia, emphasising the need for a concerted effort and collaborative strategies to overcome these obstacles.

PHOTO: © WEFOREST AND © ZEI

> "Through their partnership with WeForest, Just One Tree is helping to regenerate and restore the forests in the Luanshya district, Copperbelt (Zambia)"

3.3. Carbon Removal Technology

This subsection explores Zambia's forward-looking considerations and pilot initiatives regarding carbon removal technologies, particularly direct air capture (DAC) and bioenergy with carbon capture and storage (BECCS) (IEA, 2023a; Royal Society, 2022).

3.3.1 Carbon Credit Financing

In Zambia's strategic use of carbon credits to combat climate change, it is essential to delve into the nuanced aspects of project structuring for sustainable, long-term carbon storage. The government's appreciation of carbon credits goes beyond their financial value, recognising them as a tangible representation of Zambia's commitment to sustainability. Aligned with the Paris Agreement, especially under Articles 6.2 and 6.4, international market mechanisms are introduced to facilitate green investments, contributing to the achievement of the Nationally Determined Contribution (NDC) and global climate goals (MoGEE, 2023a).

Within this framework, Zambia's involvement in carbon credit financing marks a departure from traditional approaches. Projects carried out under Article 6, termed Internationally Transferable Mitigation Outcomes (ITMOs), provide a mechanism for the transfer of carbon credits with diverse applications. These include NDC compliance by acquiring parties, such as the country receiving the ITMO transfer, through the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) compliance by international airlines, and via contribution to net zero or carbon-neutral goals in the voluntary carbon market (VCM) (MoGEE, 2023a).

Project structuring is pivotal for success within this context, and Zambia, under Article 6, has the opportunity to collaborate with other nations, international organisations, and private sector entities. Embracing cooperative approaches, especially with countries facing lower marginal abatement costs, positions Zambia as a "Transferring Party". This collaboration involves providing results-based co-funding for emissions-reducing mitigation activities that demonstrate sustainable development co-benefits and foster transformative impacts. Such an approach empowers Zambia's private sector to structure investments in emissions reductions that might otherwise face implementation challenges (MoGEE, 2023a).

Ensuring long-term accountability in carbon storage, these cooperative transactions promote transparency and a commitment to sustainable development co-benefits. The overall impact of these collaborations not only assists Zambia in achieving ambitious NDC targets, including a substantial reduction of GHG emissions, but also supports an increase in ambition for all parties involved in terms of setting higher targets for renewable energy adoption, technological innovation, and sustainability practices.

Zambia's commitment extends beyond financial gains, emphasising the interconnectedness of environmental stewardship and economic pragmatism. This showcases the nation's dedication to combating climate change while fostering sustainable and transformative practices in collaboration with the global community (MoGEE, 2023a).

Zambia's approach is characterised by a keen awareness of potential challenges associated with carbon credit financing. Issues such as market fluctuations, regulatory complexities, and project implementation hurdles are acknowledged and actively addressed. By developing proactive solutions, such as risk mitigation strategies and adaptive governance frameworks, Zambia positions itself as a resilient actor in the global carbon reduction landscape (PROSPERO, 2023).

Zambia's carbon credit initiatives, covered in the forthcoming climate change bill, involve the identification and implementation of projects that contribute to GHG emissions reduction or removal. These projects may span various sectors such as renewable energy, reforestation, and sustainable land-use practices (Farmers Review Africa, 2022). A crucial aspect is the adherence to approved methodologies established by recognised standards bodies like the Clean Development Mechanism (CDM) (Millock, 2013), which provide a framework for quantifying emissions reductions or removals, ensuring consistency and reliability in the carbon credit projects.

Ensuring long-term accountability in carbon storage is a critical consideration (Sullivan, 2023). To address the challenge of permanence, projects may implement strategies such as long-term land-use agreements and continuous monitoring. These measures aim to guarantee that the carbon sequestration achieved through these projects remains stable over an extended period, preventing unintended releases of stored carbon back into the atmosphere.

Moreover, afforestation projects involve creating new forests in areas that were not previously forested, while reforestation projects involve replanting trees in deforested areas. In these tree-planting initiatives, additionality is essential to demonstrate that the planted trees represent a genuine increase in carbon sequestration beyond what would have occurred naturally or through business-as-usual practices. Additionality is a key criterion to ensure that the carbon credits generated truly contribute to mitigating climate change (Sullivan, 2023). The success of these projects is contingent on rigorous monitoring, maintenance, and protection of the planted trees to ensure long-term carbon storage and avoid consecutive decades of deforestation.

Through its commitment to carbon credit financing, Zambia aspires not only to meet its domestic carbon reduction targets but also to contribute significantly to global climate change mitigation. The proactive stance adopted by the Zambian government aligns with international efforts to create a sustainable and resilient future. This global leadership role enhances Zambia's standing in climate change negotiations and establishes the nation as a responsible and influential participant in the broader environmental discourse.

4 NATIONALLY DETERMINED CONTRIBUTION (NDC) FOR ZAMBIA

This section delves into Zambia's commitment to the Paris Agreement, detailing its Nationally Determined Contribution (NDC), mitigation actions, and adaptation components.

4.1. Background on Zambia's NDC

Zambia's initial Nationally Determined Contribution (NDC), submitted on 9 December 2016, reflects a comprehensive approach to climate change, encompassing both mitigation and adaptation components. The NDC outlines a conditional pledge to reduce GHG emissions by 25% (20,000 Gg CO2 eq.) by 2030 against a base year of 2010 under the Business As Usual (BAU) scenario with limited international support or by 47% (38,000 Gg CO2 eq.) with substantial international support (Republic of Zambia, 2021).

In this context, limited international support refers to the domestic resources that the country can allocate towards climate-related activities, including the existing international resources (Business as Usual resources) that the country was receiving as of 2015, estimated at USD 15 billion. On the other hand, substantial international support denotes a more significant level of assistance sought from the international community, encompassing both bilateral and multilateral support, to effectively implement its climate mitigation and adaptation measures. This level of support was estimated to be USD 35 billion (Republic of Zambia, 2021).

4.2. Mitigation Actions

The NDC focuses on three key mitigation programmes:

4.2.1 Sustainable Forest Management

Zambia's commitment to sustainable forest management (SFM) is intricately woven into its broader climate response strategy, aiming to mitigate climate change by preserving and enhancing the carbon sequestration capacity of its forests. The sustainable forest management initiatives align with the nation's rich biodiversity and forest ecosystems. However, the implementation and intricacies of this commitment involve a multifaceted approach, considering the broader context of climate change impacts on the country.

The SFM programme plays a pivotal role in achieving both mitigation and adaptation goals. Deforestation and forest degradation are identified as significant contributors to carbon emissions, and Zambia's Nationally Determined Contribution (NDC) commits the country to substantial reductions. This commitment involves reducing carbon dioxide-equivalent emissions by 25% by 2030 compared to the 2010 base year levels, with a potential higher reduction of 47% if substantial international support is available (Republic of Zambia, 2021).

To achieve these ambitious goals, the Forest Investment Plan (FIP) has been developed, strategically focusing on the conservation of high-value forest areas and promoting resilient landscapes, sustainable agriculture, and energy. The FIP, with a preliminary funding target of USD 404.67 million over 5 years, seeks to address deforestation and forest degradation. It also emphasises the creation of an enabling environment for implementing the plan successfully. The implementation of FIP involves mobilising funds from various sources, including public and private entities and multilateral and bilateral institutions. Zambia aims to attract international funding from entities such as the World Bank, the African Development Bank, and the

Green Climate Fund. However, challenges related to institutional capacity have been identified, with the need for enhanced capacity to absorb international funding. Weak financial management and internal controls have contributed to a slow uptake of resources, necessitating urgent capacity-building efforts, including support for government institutions and training for accountants and auditors (World Bank, 2019b).

Zambia's SFM programme, guided by international initiatives such as REDD+, NAMAs, and the Technology Needs Assessment, showcases a comprehensive strategy to address climate change. FIP, if successfully implemented, has the potential to significantly contribute to mitigating carbon emissions and enhancing the resilience of Zambia's forests. Challenges related to institutional capacity highlight the need for concerted efforts to ensure the effective utilisation of international funding for SFM and climate change mitigation (World Bank, 2019b).

To achieve SFM goals, strategies include reforestation, afforestation, and preventing deforestation. Notable projects, like the Zambia National Strategy to Reduce Emissions from Deforestation and Forest Degradation (REDD+), focus on combating deforestation caused by sectors like agriculture, water, wildlife, energy, mining, and land use in three identified focal landscapes: Zambezi watershed, Kafue watershed, and Luangwa watershed. The strategy allows commercial use and logging but strictly regulates practices to ensure the long-term health of the forest. Selective logging, preferring only certain trees to be harvested, minimises ecosystem disruption. Timber concession areas have enforced and monitored management plans with full community participation, and the production of wood fuel (charcoal and firewood) is also regulated (Matakala, Kokwe, and Statz, 2015).

> “Zambia's Nationally Determined Contribution outlines a conditional pledge to reduce GHG emissions by 25% by 2030 with limited international support or by 47% with substantial international support”

4.2.2 Sustainable Agriculture

Zambia's sustainable agriculture programme underscores efforts to reduce emissions associated with agricultural practices, recognising the interdependence of nature and people. The commitment to achieving low-carbon and climate-resilient development is reflected in strategic approaches to agriculture, wildlife, and water systems (Republic of Zambia, 2021).

To enhance resilience in productive systems, Zambia has adopted various climate-smart practices, including those to improve agricultural productivity and resilience, early warning and preparedness for climate hazards, and mapping and monitoring of vulnerable areas, water resources, and ecosystems. Additionally, the country focuses on restoring and conserving natural habitats, promoting sustainable wildlife management, ecotourism, and human-wildlife coexistence, supporting renewable energy sources, energy efficiency, and conservation (MoNDP, 2016; Kalantary, 2010).

To facilitate these actions, Zambia has implemented key policies and programmes in recent years, and it continues to do so at present. These include the Zambia National Policy on Climate Change (MoNDP, 2016), the Revised and Updated Nationally Determined Contribution (Republic of Zambia, 2021), and the National Adaptation Plan for Zambia (MoGEE, 2023b).

To facilitate these actions, Zambia has implemented key policies and programmes, including the Zambia National Policy on Climate Change 2016, the National Adaptation Plan for Zambia 2020, the Revised and Updated Nationally Determined Contribution 2021, and the Climate Promise (MoNDP, 2016; USAID, 2013; Kalantary, 2010).

The Seventh National Development Plan (7NDP) outlines government projects aimed at promoting the adoption of environmentally friendly and climate-smart agricultural practices. These practices include conservation farming, crop diversification, crop rotation, and reducing the use of chemical fertilisers. Farming, a significant contributor to climate change due to GHG emissions, particularly methane and nitrous oxide, is targeted for reduction through climate-smart agriculture techniques like conservation agriculture. Conservation agriculture involves minimal soil disturbance, cover cropping, and crop residue retention, promoting carbon sequestration, soil health improvement, and water conservation (PMRC, 2020).

4.2.3 Renewable Energy and Energy Efficiency

The renewable energy and energy efficiency programme represents a cornerstone in Zambia's mitigation strategy. By transitioning to cleaner energy sources and improving energy efficiency, the country addresses the root causes of emissions, contributing to a low-carbon future (MoE, 2019; MoE, 2022a; MoE, 2022b). The role of renewable energies within the portfolio of zero- or low-carbon mitigation options is highlighted in **Figure 3**.

4.3. Adaptation Actions

Zambia's NDC emphasises adaptation actions across various sectors:

4.3.1 Strategic Productive Systems

Adaptation actions in agriculture, wildlife, and water aim to build resilience in these productive systems, acknowledging the interconnectedness of natural systems and human well-being in Zambia's response to climate change impacts

> “Farming, a significant contributor to climate change due to GHG emissions, particularly methane and nitrous oxide, is targeted for reduction through climate-smart agriculture techniques like conservation agriculture”

Holistic Planned Grazing

PHOTO: © GRASSROOTS TRUST

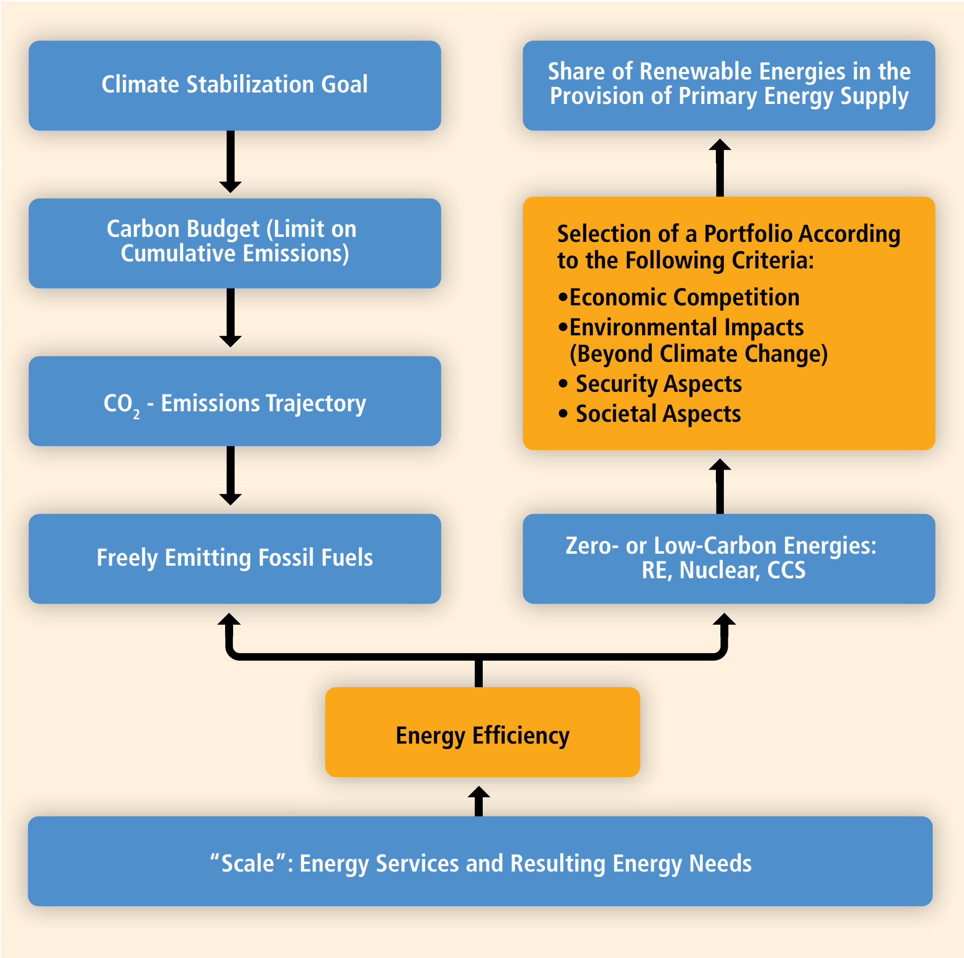
(Republic of Zambia, 2021). Several policies and strategies are being implemented to enhance resilience in these sectors:

Agriculture:

Climate-smart agriculture (CSA) technologies and practices are integral to addressing climate change challenges and fostering economic growth in the agriculture sector. Practices are deemed climate-smart if they enhance food security and contribute to adaptation and/or mitigation. Notable practices in Zambia include:

1. **Diversification of Crops:** Farmers are encouraged to diversify their crop selections, planting a variety of crops resilient to different climate conditions. This approach reduces the risk of crop failure amid changing weather patterns.
2. **Climate-Smart Farming Practices:** The adoption of climate-smart agricultural techniques is promoted, encompassing conservation agriculture, crop rotations, agroforestry, and precision farming. These practices aim to enhance productivity while minimising environmental impact (CIAT and World Bank, 2017).

Figure 3: The role of renewable energies within the portfolio of zero- or low-carbon mitigation options (qualitative description) (Source: Moomaw, et al., 2023). CCS = Carbon Capture and Storage



Wildlife:

In the wildlife sector, policies and projects focus on:

1. **Habitat Restoration and Protection:** Implementing policies and projects that concentrate on restoring and protecting natural habitats for wildlife. This involves preserving biodiversity-rich areas, reforesting, or rehabilitating degraded ecosystems, and restocking depleted national parks. Additionally, it emphasises improving planning and management of wildlife estates (MoGEE, 2023b).
2. **Community Engagement:** Involving local communities in wildlife conservation efforts, ensuring that their needs are considered, and providing incentives for sustainable coexistence with wildlife.

4.3.2 Strategic Infrastructure and Health Systems

Infrastructure and health systems form critical components of Zambia's adaptation strategy. By developing robust infrastructure and healthcare systems, the country aims to withstand and respond effectively to climate-related challenges (Republic of Zambia, 2021). The adaptation measures include establishing integrated land-use planning, incorporating climate considerations into national health and environmental health policies, and strengthening decentralised climate information services that are essential strategies for fostering sustainability in natural resource management, infrastructure development, and public health in the face of climate change.

4.3.3 Capacity Building, Research, Technology Transfer, and Finance
Enhancing capacity building, research, technology transfer, and finance for adaptation is integral to Zambia's NDC. These components ensure the country's ability to implement and continually improve adaptive measures, fostering a climate-resilient future (Republic of Zambia, 2021).

4.4. Strengthening the NDC

Zambia's commitment to enhancing its NDC involves broadening the scope of sectors under mitigation, including transport, liquid waste, and coal (production, transportation, and consumption). Additionally, elaborating the adaptation component with indicators will enable the country to track progress systematically, reinforcing its dedication to achieving climate resilience in both human and physical systems. The recognition of the need for substantial resources underscores Zambia's proactive approach to implementing effective climate action, and to track progress of implementation of both mitigation and adaptation (Republic of Zambia, 2021).

The Zambezi river, border between Zambia and Zimbabwe

PHOTO: ISTOCKPHOTO

> “Adaptation actions in agriculture, wildlife, and water aim to build resilience in productive systems, acknowledging the interconnectedness of natural systems and human well-being in Zambia's response to climate change impacts”

5 THE ZAMBIAN ENERGY TRANSITION

This section provides a comprehensive exploration of Zambia's broader energy transition, incorporating the Energy Efficiency Strategy and Action Plan (EESAP) (MoE, 2022a), and the Renewable Energy Strategy and Action Plan (RESAP) (MoE, 2022b).

5.1. Energy Efficiency

EESAP outlines energy efficiency across measured sectors and proactive initiatives to reduce energy losses. The efficient use of energy is crucial for Zambia's development and economic independence. EESAP, aligned with the National Energy Policy 2019 (MoE, 2019), plays a pivotal role. Envisioned as the first step towards creating a firmly established energy efficiency market in Zambia by 2030, the EESAP sets measurable time-bound targets. Its strategic objectives are designed to expand the deployment of energy-efficient technologies and practices, emphasising a 2% annual decrease in Total Primary Energy Supply (TPES) until 2030, over a period of 12 years, with 2018 as a base year. Currently, Zambia's energy resources include electricity (hydropower), petroleum, coal, biomass, and renewable energy. Petroleum is the only energy source that is wholly imported, while electricity trade exists between Zambia and Mozambique, Zimbabwe, and the Southern African Power Pool (SAPP). The primary energy imports in Zambia were 61,008 TJ in 2020, which made around 13% of the total energy supply in the country (479,772 TJ) (IRENA, 2023a). This proactive approach of decreasing the TPES and promoting energy efficiency aligns with Zambia's commitment to optimal energy-resource use and becoming a net exporter of energy (MoE, 2022a).

5.2. Renewable Energy Technologies

Zambia has developed a roadmap, RESAP, for accelerating the adoption and diffusion of renewable energy (RE) technologies, which targets specific capacity goals and wider energy access. With specific targets for grid-connected RE electricity, off-grid renewables, biofuels, and biogas, Zambia aims to diversify its energy mix and increase energy access. The RESAP's grid-connected targets (**Table 1**) include hydro, solar, wind, and geothermal capacities, with a clear focus on improving rural electrification through solar PV mini-grids and solar home systems. The biofuels and biogas targets further demonstrate Zambia's commitment to sustainable energy solutions (MoE, 2022b).

5.2.1 Grid-connected RE electricity targets

Table 1: *Grid-connected RE capacity targets for Zambia (MW)*

Technology	Short term (2020–2023)	Medium term (2023–2026)	Long term (2027–2030)	Total
Hydro	1,200	183		1,383
Solar			500	500
Wind		130		130
Geothermal		2.2		2.2
Total	1,200	315	500	2,015

5.2.2 Off-grid targets

Zambia aims to connect 1.4 million people to mini-grids and 7.3 million to solar home systems by 2030, addressing rural electrification needs (MoE, 2022b).

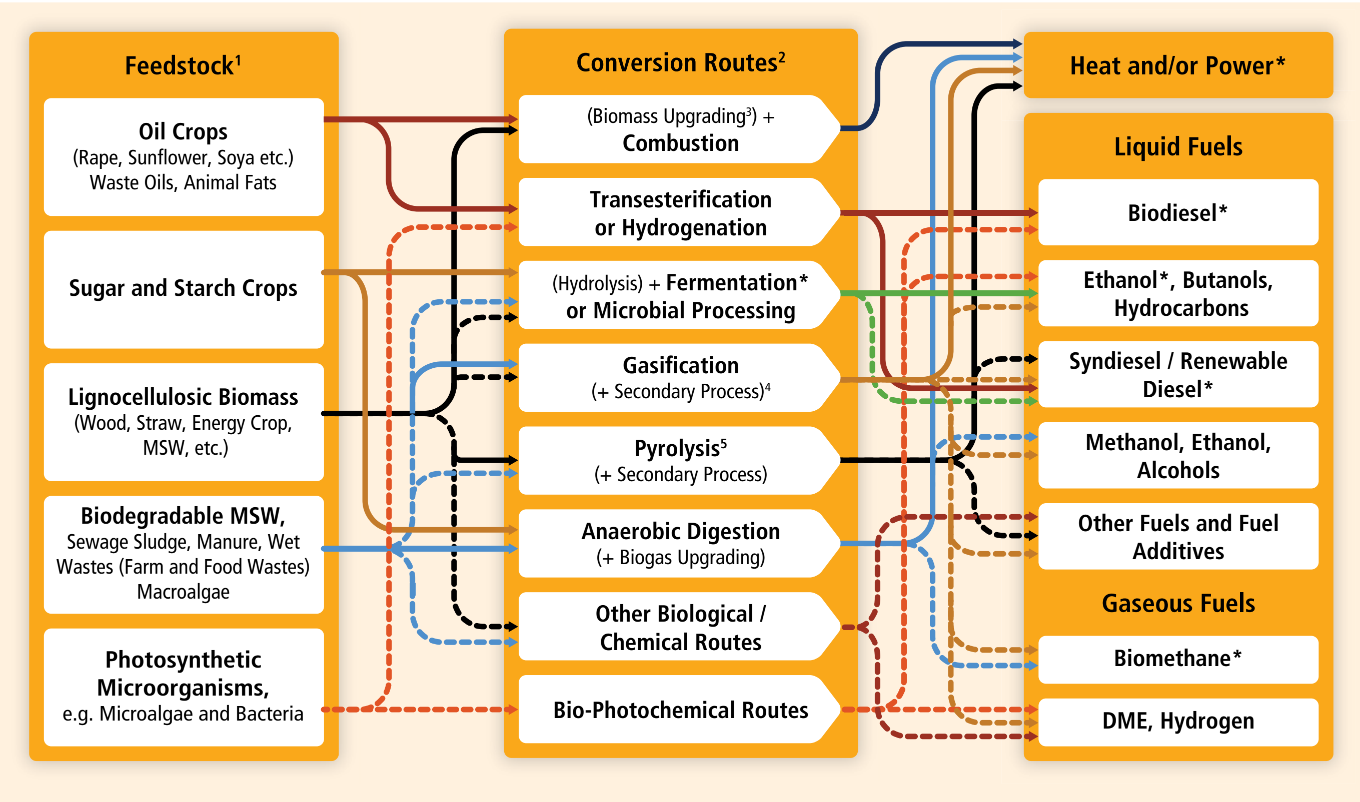
5.2.3 Biofuels targets

Fuel blending is considered an efficient method to displace petroleum with alternative fuels. The government is promoting the use of biofuels in the transport sector. Consequently, it envisions blending petrol and diesel with bioethanol and biodiesel, with projected 5% biodiesel and 10% bioethanol blending ratios in diesel and petrol engines by 2026, as aligned with biofuel mandates (MoE, 2022b).

5.2.4 Biogas Targets

With a conservative target of 62,000 households by 2030, Zambia aims to harness biogas for cooking energy, promoting sustainability in rural areas (MoE, 2022b). **Figure 4** shows the commercial and developing bioenergy technology routes.

Figure 4: *Schematic view of the variety of commercial (solid lines) and developing bioenergy routes (dotted lines) from biomass feedstocks through thermochemical, chemical, biochemical, and biological conversion routes to heat, power, CHP (combined heat and power), and liquid or gaseous fuels. Commercial products are marked with an asterisk (Source: Moomaw, et al., 2023). DME = Dimethyl ether; MSW = Municipal solid waste* [1, 2, 3, 4, 5]



[1] Parts of each feedstock could be used in other routes.

[2] Each route can also make coproducts.

[3] Biomass upgrading includes densification processes (such as palletization, pyrolysis, torrefaction, etc.).

[4] Anaerobic digestion processes to various gases which can be upgraded to biomethane, essentially methane, the major component of natural gas.

[5] Could be other thermal processing routes such as hydrothermal, liquefaction, etc. Other chemical routes include aqueous phase reforming.

> “The efficient use of energy is crucial for Zambia's development and economic independence”

5.3. Innovative Hybrid Energy Systems

The adoption of a diversified energy mix, including floating photovoltaics (FPV) and onshore wind turbines, will enhance Zambia's resilience against climate change. Scholarly analysis by Nyoni et al. (2021) has evaluated the technical parameters of FPV, national electricity grid, hourly generation profiles, and potential for variable renewable energy generation and existing reservoir-based hydropower plants. The study shows how a diversified energy mix could lead to reduced network losses and increased energy generation capacity, which would contribute to a resilient and sustainable energy transition.

5.4. Digitalisation and Cybersecurity Concerns

This section underscores the critical role of secure digital networks, specifically within electric mobility infrastructure and power system dispatch and operation for distribution and transmission network providers like ZESCO. Emphasising the intersection of digitalisation and cybersecurity becomes paramount in ensuring a resilient and secure energy transition. Acknowledging the significance of robust cybersecurity measures is instrumental in upholding the reliability and safety of these digital networks (Phiri et al., 2022a; Phiri et al., 2022b).

5.4.1 The Nexus of Digitalisation and Cybersecurity

In the evolving landscape of Zambia's energy transition, the integration of digital technologies plays a pivotal role. This integration is particularly evident in electric mobility infrastructure and the operations of entities like ZESCO, which is responsible for the distribution and transmission of power. The reliance on digital networks is integral to the efficiency, monitoring, and management of these systems (Phiri et al., 2022a; Phiri et al., 2022b).

5.4.2 Importance of Secure Digital Networks

Secure digital networks are the backbone of a reliable and resilient energy transition. In the context of electric mobility infrastructure, these networks facilitate efficient charging infrastructure operations, real-time data monitoring, and the seamless integration of EVs into the transportation system. For power system dispatch and operation, secure digital networks are crucial for ensuring the stability and optimal performance of the distribution and transmission network (IEA, 2023c).

5.4.3 Ensuring Cybersecurity for Resilience

Electric Mobility Infrastructure:

- **Secure Charging Infrastructure:** As electric mobility gains momentum in Zambia, the establishment of secure charging infrastructure is imperative. This involves implementing robust cybersecurity measures to protect against potential threats, ensuring the uninterrupted functionality of charging stations and the safety of users (Phiri et al., 2022b).

Power System Dispatch and Operation:

- **Resilient Transmission Networks:** In the realm of power system dispatch and operation, the resilience of transmission networks is paramount. Cybersecurity measures are essential to safeguard against cyber threats that could compromise the stability of these networks. Regular assessments and updates to security protocols are critical to staying ahead of evolving cybersecurity challenges (Phiri et al., 2022a).

5.4.4 Measures for Cybersecurity in the Zambian Energy Transition

Electric Mobility Infrastructure:

- **Encryption and Authentication:** Implementing advanced encryption and authentication protocols for EV communication ensures secure data transmission and protects against unauthorised access (Phiri et al., 2022b).
- **Regular Security Audits:** Conducting routine security audits of charging infrastructure helps identify vulnerabilities and allows for the timely implementation of security patches and updates (Phiri et al., 2022b).

Power System Dispatch and Operation:

- **Intrusion Detection Systems:** Deploying robust intrusion detection systems within the power system's digital infrastructure helps identify and respond to potential cyber threats promptly (Phiri et al., 2022a).
- **Employee Training Programmes:** Educating personnel on cybersecurity best practices is crucial. This includes creating awareness about phishing attacks, password management, and the importance of reporting any suspicious activities (Miranda, 2018).

5.4.5 Integration with Low-Carbon Technologies

The convergence of secure digital networks with low-carbon technologies is a fundamental aspect of the envisioned Zambian energy transition. By integrating these elements, the nation can not only achieve its carbon reduction goals but also create a sustainable and resilient energy infrastructure.

5.5. Sector-Coupled Approach and Demand-Side Management

This section advocates for a sector-coupled approach and underscores the paramount importance of effective demand-side management in achieving optimal utilisation of energy resources. This helps create a sustainable, resilient, and low-carbon energy future for Zambia. In the context of Zambia's energy transition, comprehensive integration across diverse sectors is emphasised. Simultaneously, effective demand-side management is highlighted as a critical strategy for optimising energy-resource use, reducing wastage, and ensuring the sustainability of the energy ecosystem.

5.5.1 Sector-Specific Demand Characteristics in Zambia

Mining Sector:

- **Demand Characteristics:** The mining sector in Zambia often requires a substantial amount of energy for extraction and processing activities (Mumba, 2023).
- **Low-Carbon Technologies:** Implementing energy-efficient mining technologies and exploring renewable energy sources for power-intensive operations can contribute to carbon reduction (Imasiku and Thomas, 2020). Several programmes and initiatives have already kicked off in this sector. To address mining-related environmental degradation, the Zambian government established the Environmental Protection Fund (EPF), aiming to enforce compliance with approved Environmental Impact Assessments and safeguard against financial liabilities associated with mine area restoration and closure (Wambwa et al., 2023). Moreover, the “Strengthening Zambian Mining Governance in The Nexus of Environment, Human Rights, and Climate” (ZAMNEX) programme runs from October 2022 to September 2026 (Swedish Environmental Protection Agency, 2023). This aims to streamline the licensing and permit processes for large-scale mining and to enhance awareness, knowledge generation, and strategic planning on climate change issues associated with mining.

Nyati milling plant near Lusaka in Zambia

PHOTO: ISTOCKPHOTO

> “Currently, Zambia’s energy resources include electricity (hydropower), petroleum, coal, biomass, and renewable energy”

Residential Sector:

- **Demand Characteristics:** Residential areas have varying energy demands, primarily for lighting, heating, and appliances (Bhattacharyya and Timilsina, 2010).
- **Low-Carbon Technologies:** Promoting energy-efficient appliances and solar water heaters and incentivising residential solar installations can enhance sustainability (MoE, 2022a).

Commercial Sector:

- **Demand Characteristics:** Commercial establishments, such as offices and retail spaces, require energy for heating, ventilation, and air conditioning (HVAC) systems, lighting, and other electronic equipment (Westphalen and Koszalinski, 1999; Watson et al., 2006).
- **Low-Carbon Technologies:** Adopting smart building technologies, energy-efficient lighting, and incentivising green building designs can reduce carbon footprint (King and Perry, 2017).

Industrial Sector:

- **Demand Characteristics:** Industries demand energy for manufacturing processes, machinery, and equipment (Andrei et al., 2022).

- **Low-Carbon Technologies:** Implementing energy-efficient industrial processes, utilising waste heat recovery systems, and integrating renewable energy sources into industrial operations can contribute to carbon reduction (de Pee et al., 2018).

Agricultural Sector:

- **Demand Characteristics:** Agriculture relies on energy for irrigation, machinery, and processing.
- **Low-Carbon Technologies:** Implementing precision farming techniques and solar-powered irrigation systems, and promoting sustainable agriculture practices can align with low-carbon goals. This can be done by encouraging farmers to practise sustainable farming, which would improve their productivity and incomes while adopting environmentally friendly practices and avoiding food security threats (Nkomoki et al., 2018). Moreover, the government will support the agricultural sector to achieve 15% energy savings and savings for the water utilities (MoE, 2022a). This is implemented by means of developing a local certification body on energy auditing, capacity building for local experts and energy professionals, as well as raising public awareness on renewable energy, energy efficiency, and behavioural change.

Transport Sector:

- **Demand Characteristics: The** transport sector encompasses road and air transport, with heavy-duty vehicles requiring substantial energy (Khalili et al., 2019).

> “Effective demand-side management is highlighted as a critical strategy for optimising energy-resource use, reducing wastage, and ensuring the sustainability of the energy ecosystem”

- **Low-Carbon Technologies:** Introducing electric or hybrid heavy-duty vehicles, investing in public transportation infrastructure, and exploring sustainable aviation fuels can significantly reduce emissions in the transport sector (IEA, 2023b).

5.5.2 Measures for Effective Demand-Side Management

Cross-Sectoral Collaboration:

- **Integrated Planning:** Collaborative planning across sectors ensures a holistic approach to energy management, allowing for more effective demand-side management.

Advanced Technologies:

- **Smart Grids:** Implementing smart grids facilitates real-time monitoring and control of energy consumption, enabling more precise demand-side management.

Policy Interventions:

- **Incentive Programmes:** Government incentives for adopting energy-efficient technologies and practices encourage businesses and individuals to contribute to demand-side management efforts.

Education and Awareness:

- Public Engagement: Raising awareness about the importance of energy conservation and providing information on adopting energy-efficient practices fosters a culture of responsible energy use.

5.5.3 Integration with Low-Carbon Technologies

The amalgamation of effective demand-side management with low-carbon technologies is pivotal for the Zambian energy transition. It not only ensures optimal use of resources but also aligns with the nation's commitment to reducing carbon emissions and building a sustainable energy future (Nyoni, 2022; Nyoni et al., 2021).

6 LOW-CARBON TECHNOLOGIES AND MEASURES WITH RESEARCH AND DEVELOPMENT

This section provides an overview of the Zambian Energy Transition (ZET) Study, including system studies, the integration of low-water consumption technologies, and global perspectives aligning with the 2063 Agenda for Africa.

6.1. Zambian Energy Transition (ZET) Study

The ZET study serves as a foundational pillar for Zambia's strategic energy planning. Leveraging simulation models like OSeMOSYS (Howells et al., 2011), and the International Renewable Energy Agency's (IRENA) FlexTool (IRENA, 2018), the study scrutinises various scenarios (business as usual, integrated resource plan, and Net Zero) spanning from 2022 to 2063. The simulation meticulously evaluates capacity expansion, emissions reduction, and system flexibility to facilitate informed decision-making.

OSeMOSYS generates results that intricately outline the expansion of generation assets required to meet projected demand from 2022 to 2063. This involves an in-depth analysis of the energy mix, assessing the performance of hydro, thermal, and renewable energy projects. The study further identifies the adequacy of existing assets and proposes cost-effective additions to the energy mix. Subsequently, FlexTool comes into play, assessing the system's flexibility based on the capacity expansion plans outlined by OSeMOSYS. This comprehensive approach ensures a holistic understanding of the potential challenges and benefits associated with different scenarios (Nyoni, 2022).

6.2. Global Perspectives and Aligning with 2063 Agenda

Examining global perspectives is crucial for aligning Zambia's energy transition with the broader goals outlined in the 2063 Agenda for Africa (AU, 2023). By considering successful strategies and best practices from other countries, Zambia can adopt innovative approaches tailored to its unique context, while keeping the 2063 Agenda for Africa under consideration. This alignment not only enhances the effectiveness of Zambia's energy policies but also ensures that they contribute to the continent-wide objectives of sustainable development, economic growth, and environmental stewardship. With approximately 80% of the global population lacking access to electricity residing in sub-Saharan Africa, the inadequacies of the current fossil fuel-based energy system in meeting the continent's power needs are evident. Urgent action is imperative (IEA, 2022).

6.2.1. Renewables as a Compelling Solution

Renewables emerge as a compelling solution to address Africa's energy challenges. Their rapid deployability, versatility, and affordability position them as the most viable technology. A recent analysis by IRENA underscores the positive impact of adopting renewable power in Africa, resulting in USD 19 billion in fossil fuel cost savings within the electricity sector since 2000 (IRENA, 2023b).

Africa possesses abundant renewable energy resources, surpassing the projected demand for electricity in 2040. However, the distribution of these resources across the continent is uneven, necessitating the development of appropriate infrastructure. The establishment of such infrastructure is vital to harness and distribute renewable energy efficiently, ensuring sustainable, affordable access to energy across Africa (IRENA, 2023a).

The Green Grids Initiative Africa (GGIA) Working Group was established under the African Union Commission in 2021 (GGI, 2024). Its primary objective is to provide complementary support for the accelerated development of regional transmission projects. The GGIA focuses on developing resilient transmission grids that facilitate the scale-up of renewable energy generation across Africa, thereby supporting the goal of achieving universal access to reliable, modern energy services. Work on the grid infrastructure is already underway. The Southern African Power Pool (SAPP), in partnership with the Southern African Development Community (SADC) announced a USD 1.3 billion Regional Transmission Infrastructure Financing Facility (RTIFF), focused on improving strategic interconnection and cross-border energy transmission in the Southern Africa region (ARBT. 2024).

6.3. Global Energy Landscape and Transition to Clean Energy Economy

The global energy landscape is marked by various challenges and opportunities that significantly influence Zambia's energy transition. While some immediate pressures from the global energy crisis have eased, uncertainties in energy markets, geopolitics, and the global economy persist, posing risks of further disruption.

6.3.1 Current Challenges and Complexities

Several factors contribute to the unsettled nature of the global energy landscape. Fossil fuel prices, while down from their 2022 peaks, remain tense and volatile. Continued geopolitical conflicts, such as the prolonged fighting in Ukraine and the risk of protracted conflict in the Middle East, add to the complexities. The macro-economic mood is downbeat, characterised by stubborn inflation, higher borrowing costs, and elevated debt levels (IEA, 2023d).

Furthermore, the impact of climate change is evident in the global average surface temperature, which has already risen to approximately 1.2 °C above pre-industrial levels. This warming has led to heatwaves and extreme weather events. GHG emissions continue to rise, contributing to air pollution linked to over 6 million premature deaths annually. Positive trends in improving access to electricity and clean cooking have slowed or reversed in some countries (IEA, 2023d).

6.3.2 Transition to Clean Energy Economy

Against this complex backdrop, there is hope in the emergence of a new clean energy economy, prominently led by solar PV and EVs. The investment in clean energy has risen significantly, driven not only by the push to reduce emissions but also by strong economic incentives, energy security considerations, and industrial strategies aiming to create clean energy jobs.

Key indicators of this transition include the notable increase in EV sales and the record-setting addition of over 500 GW of renewables generation capacity in 2023. The daily spending on solar deployment exceeding USD 1 billion underscores the commitment to clean energy. The manufacturing capacity for key components such as solar PV modules and EV batteries is expanding rapidly, indicating a robust momentum towards sustainability (IEA, 2023e). However, the transition to renewable energy technologies also highlights the critical need for access to essential raw materials. Current announced critical mineral mining projects fall short of meeting the demand projected by the 2050 Net Zero Scenario (NZE Scenario) for 2030 (IEA, 2023e). Bridging this gap necessitates a multifaceted approach, focusing on increased investment, enhanced recycling efforts, technological innovation, and changes in consumption behaviours to ensure a sustainable supply chain for these vital materials.

These materials are crucial for the production of solar panels, batteries, and other renewable energy technologies. Ensuring a stable supply of these materials is vital for sustaining growth in the clean energy sector.

6.4. IEA's Net Zero Roadmap

The International Energy Agency (IEA), in its updated Net Zero Roadmap, acknowledges the challenges in limiting global warming to 1.5 °C but maintains that a viable pathway remains open. The report emphasises the difficulties while underscoring the importance of continued efforts to transition to cleaner energy sources (IEA, 2023e).

6.5. Importance of Technological Innovation in Achieving Carbon Neutrality

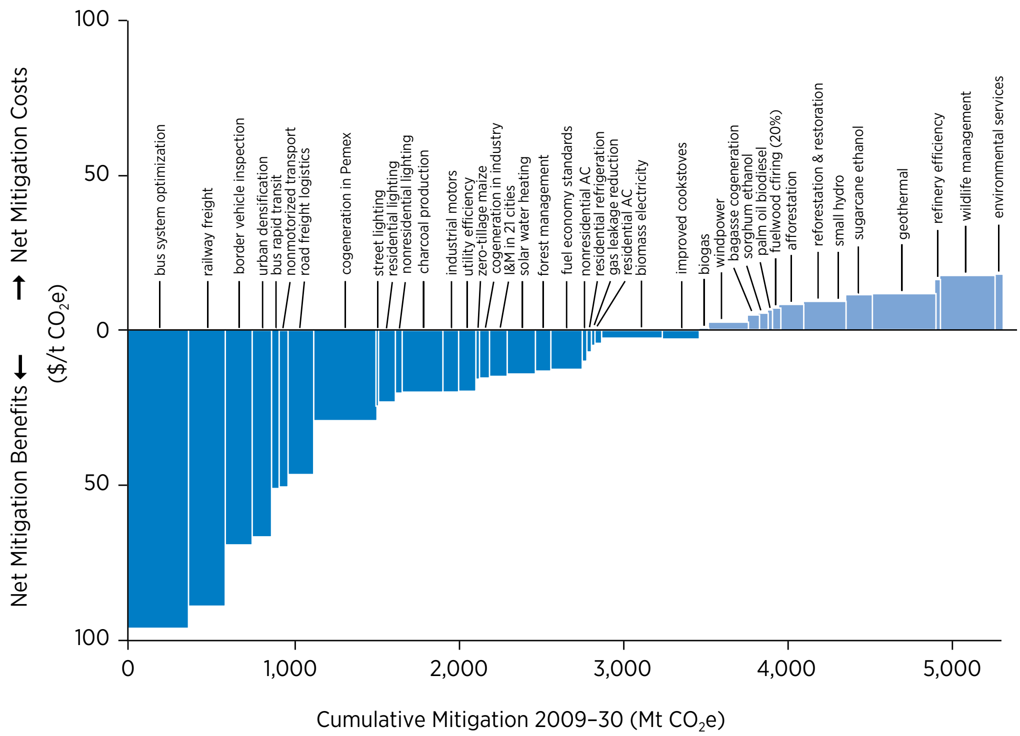
The quest for carbon neutrality necessitates a deep transition in modes of production, marked by technological innovation. The historical evolution of technologies, as witnessed in the case of solar PV and wind power, demonstrates the transformative power of strategic investments. Cheaper energy today is a testament to the success of once-debated subsidies (World Bank, 2023).

6.5.1 Marginal Abatement Cost Curves and Strategic Decision-Making

To further understand the dynamics of carbon abatement potential, marginal abatement cost curves (**Figure 5**) illustrate the costs associated with interventions to reduce GHG emissions. This approach considers the costs and benefits of various actions, helping prioritise those with the lowest abatement costs and the potential for net economic gain.

The creation of marginal abatement cost curves involves ranking various emission reduction options based on their costs and potentials. While such an approach is suitable for marginal emission reductions, achieving carbon neutrality requires a broader strategy. The challenge shifts from identifying low-cost opportunities to avoiding all emissions at the lowest possible cost.

Figure 5: Exemplary Marginal Abatement Cost Curve for Mexico (Source: World Bank, 2023)



> “With approximately 80% of the global population lacking access to electricity residing in sub-Saharan Africa, the inadequacies of the current fossil fuel-based energy system in meeting the continent's power needs are evident. Urgent action is imperative”

6.5.2 Road Transport as a Case Study

Road transport exemplifies the need for a radical change rather than marginal improvements. While it may be cost-effective to marginally improve petrol cars, achieving complete decarbonisation necessitates a holistic approach. This includes embracing public transport, non-motorised transport, and the electrification of cars and trucks (World Bank, 2023).

For instance, around 80% of new car registrations in Oslo in 2022 are electric vehicles (EVs), and this increases to around 88% when accounting for Plug-in hybrid electric vehicles (World Economic Forum, 2023). This shift was driven by strong government incentives, extensive charging infrastructure, and public awareness campaigns, thus making significant progress towards reducing its carbon footprint. In contrast, Zambia faces different challenges. The country has seen rapid urbanisation and an increase in the number of vehicles on the road, leading to severe congestion and air pollution. The high cost of EVs and limited charging infrastructure hinder widespread adoption of electric vehicles. This encouraged initiatives like the Lusaka Decongestion Project, which aims to enhance traffic flow and reduce emissions by constructing new roads and flyovers (World Bank, 2021).

Nonetheless, the high adoption of EVs remains in its nascent stages due to economic and infrastructural barriers. By examining these case studies, it becomes clear that achieving complete decarbonisation in road transport requires a comprehensive strategy tailored to the specific context of each country. This includes a mix of policy interventions, infrastructure development, and public engagement to drive the transition towards sustainable, low-carbon transport systems.

6.5.3 Identifying Key Technologies for the Future

In navigating the complex landscape of technological choices, identifying key technologies for the future is paramount. Beyond solar PV and EVs, other technologies, including zero-carbon cement, carbon capture and sequestration, zero-carbon steel, green hydrogen fertilisers, and more, demand attention.

6.6. Balancing Support and Avoiding Technological Determinism

The challenge lies in striking a balance between supporting the development of key technologies and avoiding over-determination. While complete neutrality in technology choices is unrealistic, preventing undue influence from lobbies on preferred technologies poses a challenge for governments. This delicate balance is crucial for fostering innovation without succumbing to external pressures.

As Zambia aligns its energy transition with global perspectives and endeavours to achieve the objectives outlined in the 2063 Agenda for Africa, the intricate interplay of technological innovation, policy decisions, and global dynamics must be considered. The journey towards a sustainable, low-carbon future demands strategic planning, collaborative efforts, and a commitment to navigating the complexities of the evolving energy landscape.

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Climate Compatible Growth

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