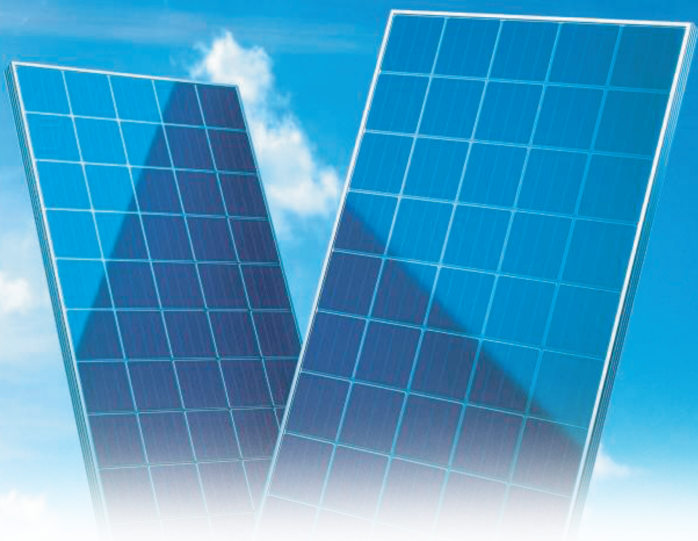
100%RE
multi-actor
partnerships



A POLICY ROADMAP FOR 100% RENEWABLE ENERGY FOR ALL BY 2050 FOR UGANDA

December 2023

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ACKNOWLEDGEMENT

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All Photos and info-graphics were freely accesed from: *https://www.google.com/search?sca_esv=601388725&rlz=1C-1GCEU_enUG1089UG1092&hl=en&q=Renewable+energy+transition&tbm=isch&source=lnms&sa=X&ved=2ahUKEw-jd9dngxfiDAxWdX0EAHXXeDJ0Q0pQJegQIDRAB&biw=1280&bih=593&dpr=1.5#imgrc=28dYGrgNCXozqM*

THE 100% REMAP PROJECT

The scale of the transformation ahead calls for collaboration and collective action. Inclusive alliances must be built that include people from all sectors, regions, and walks of life. New approaches must be implemented that facilitate innovative ideas to move us forward towards a renewable energy future. New business models must be developed that take the fast moving and shifting business conditions into account. We need a positive vision for our future, one that empowers change-makers and builds capacities across all sectors. By focusing on the opportunities related to 100% RE, rather than focusing on the fear related to the looming climate crisis, we can unlock the transformative power of renewables.

This work is part of the "Multi-Actor Partnership (MAP) for Implementing Nationally Determined Contributions (NDCs) with 100% Renewable Energy for All in the Global South (100% RE MAP)" project being implemented by WWF-UCO, Ecological Christian Organisation (ECO), the World Future Council, the World-Wide Fund for Nature Germany (WWF Germany), and Brot für die Welt. The 100% RE MAP project aims to facilitate positive changes and advance the transformation necessary to ensure economic and social development in line with the Paris Agreement's climate target of 1.5 °C. By strengthening MAPs, we enable inclusive decision-making and unlock disruptive innovations for scalability. It is through partnerships that we can overcome short-term political interests, which can upend years of work when political power transfers take place. The project ensures strategic buy-in from opinion leaders, academia, civil society, government and think tanks, and is being implemented simultaneously in Nepal, Uganda and Vietnam. A policy roadmap for 100% renewable energy explores different transition pathways by investigating policies, investments and capacities, and provides policy recommendations for a transition agender of "100% RE for all" target for Uganda by 2050.

PROJECT'S CONSORTIUM

The **WWF Uganda Country Office** main objective is to implement low carbon development pathways and increase resilience of the country's forest landscapes, wildlife populations and freshwater ecosystems to support biodiversity protection and socioeconomic, sustainable development.

WWF Germany is an independent, non-profit, non-partisan foundation, and part of the WWF network, which operates in over 100 countries and consists of national organizations and program offices.

Brot für die Welt is the globally active development and relief agency of the Protestant Churches in Germany. In more than 90 countries all across the globe, we empower the poor and marginalized and closely and continuously cooperate with local, often church-related partner organizations. Through lobbying, public relations and education we seek to influence political decisions in favour of the poor and to raise awareness for the necessity of a sustainable way of life.

The **World Future Council** is a foundation based in Hamburg, Germany. Against the background of ever-increasing global problems that affect all areas of human life, a global group of experts have set up the World Future Council as a politically neutral and independent body. It brings the interests of future generations to the centre of policy making and addresses challenges to our common future and provides decision makers with effective policy solutions.

Federal Ministry for Economic Cooperation and Development

The project was supported by the German Federal Ministry for Economic Cooperation and Development (BMZ)

ACRONYMS

CREEC	Centre for Research in Energy and Energy Conservation
CSOs	Civil Society Organisations
EACREEE	East African Centre of Excellence for Renewable Energy and Efficiency
ECP	Electricity Connections Policy
EDT	Electricity Disputes Tribunal
EE	Energy Efficient
EEAU	Energy Efficiency Association of Uganda
ERA	Electricity Regulatory Authority
ESCOs	Energy Service Companies
ESI	Electricity Supply Industry
EU	European Union
FAO	Food and Agriculture Organization
GGGI	Global Green Growth Institute
GHGs	Green House Gases
GIZ	German Development Agency
GoU	Government of Uganda
IEA	International Energy Agency
IR	Inception Report
KWh	Kilo Watt Hour
LPG	Liquefied Petroleum Gas
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries (MAAIF)
MAP	Multi-Actor Partnership
MDAs	Ministries, Departments and Agencies
MEMD	Ministry of Energy and Mineral Development
MOH	Ministry of Health
MoWE	Ministry of Water and Environment
MTIC	Ministry of Trade, Industry and Cooperatives
MW	Mega Watt
NAP	National Adaptation Plan
NDC	National Determined Contribution
NDP	National Development Plan
NES	National Electrification Strategy
NREP	National Renewable Energy Platform
PAOP	Power Africa Off-grid Project
PAYG	Pay Go
PPP	Public Private Partnership
PSFU	Private Sector Foundation Uganda

RE	Renewable Energy
RESP	Rural Electrification Strategy and Plan
SDG	Sustainable Development Goals
SE4ALL	Sustainable Energy for All
SMEs	Small and Medium Enterprises
SNV	Netherlands Development Organisation
TOR	Terms of Reference
UECCC	Uganda Energy Credit Capitalization Company (UECCC)
UGGDS	Uganda Green Growth Development Strategy
UIA	Uganda Investment Authority
UIRI	Uganda Industrial Research Institute
UMA	Uganda Manufacturers Association
UNBS	Uganda National Bureau of Standards (UNBS)
UNCDF	United Nations Capital Development Fund
UNDP	United Nations Development Programme (UNDP)
UNREEEA	Uganda National Renewable Energy and Energy Efficiency Alliance
USAID	United States Agency for International Development
USEA	Uganda Solar Energy Association
USSIA	Uganda Small Scale Industries Association
WWF	World Wide Fund for Nature
WWF UCO	World Wide Fund for Nature Uganda Country Office

FOREWORD

In this era of combating climate change with global transitioning to a low carbon economy, decarbonising energy is considered an essential element of the global efforts to reduce greenhouse-gas (GHG) emissions and limit global warming to below 1.5 °C. As Uganda joins the world to move towards a low-carbon economy, it must also recognise the need to cope with the changing climate, which has already significantly impacted its ecosystems. Climate change is threatening human and animal health, food and water security, infrastructure, and economic stability, to name a few. As the science tells us, climate change does not only impact countries that contribute the most to global warming: Uganda already experiences negative impacts despite contributing less than 0.1% to the global GHG emissions. This impact could result in annual costs of USD 3.2 – 5.9 billion if no action is taken, according to 2022 Uganda's Nationally Determined Contribution (NDC) report released by the Ministry of Water and Environment (MWE).

Renewable energy (RE) has become a critical component, as both a mitigation and adaptation measure in transforming Uganda´s energy systems. Renewables-based adaptation solutions promote mitigation and reinforce adaptation efforts across many sectors. According to a 2019 IRENA report, renewables and energy efficiency, boosted by substantial electrification, can provide over 90% of the necessary reductions in energy related carbon emissions. From an adaptation perspective, renewable energy such as solar, biogas and wind plants, functions as green infrastructure, lowering utility costs, enhancing ecosystem services, creating green jobs and increasing resilience to the exacerbated disasters caused by climate change.

We know that increasing the share of renewables to 100% by 2050 is possible, and a review of the best practices across different sectors and the recently completed technical scenario study (**Uganda's Energy Transition: Towards 100% Renewable Energy by 2050)** by WWF in partnership with Brot für die Welt and World Future Council show how it can be done. This **POLICY ROADMAP FOR 100% RENEWABLE ENERGY FOR ALL BY 2050 FOR UGANDA** report provides an important perspective on the opportunities and challenges that lie before us. The report specifies solutions and actions needed today to accelerate a transition to 100% RE by 2050. It shows that progress in the power sector has been slow with less than 2% in the total energy mix, but to reach broader sustainability objectives, more action is needed in the transport, cooking, industry and agriculture sectors. Continuous innovation is required, both to modernise traditional energy uses and to enhance the innovation and deployment of new technologies.

Special thanks to all those who contributed to preparing this report, especially, the 100% RE Multi-Actor Partnership (MAP) platform members, WWF Germany, Brot für die Welt, World Future Council, Heden Engineering Solution Ltd and the German Federal Ministry for Economic Cooperation and Development (BMZ) who funded the entire project. I hope that this report delivers a catalyst for high motivation matched with decisive action on the ground to advance an inclusive, fair and economically, socially and environmentally beneficial energy transformation in Uganda.

Ivan Tumuhimbise
Country Director, WWF Uganda

EXECUTIVE SUMMARY

Uganda, a landlocked country, has experienced significant population growth, from 12.6 million in 1980 to 45.8 million in 2023, with a projection to reach 100 million in 2050. Yet, the country's modern energy consumption per capita has remained low, around 30 times lower than the average in advanced economies, regardless of its GDP annual growth being 6% in the last two decades (IEA 2023). Electricity access is only 2% of the national total energy mix at an installed capacity of 1,347MW, despite a huge untapped Renewable Energy (RE) potential of about 11,400MW from hydropower, biomass, solar, geothermal and wind resources. Nonetheless, the country is committed to sustainable energy practices, evident in its participation in global frameworks like the Paris Agreement where Uganda committed to reduce its GHG emissions by 24.7% by 2030 as a contribution in limiting global warming to below 1.5 °C, through its Nationally Determined Contributions (NDC). However, this will only be achieved by implementing policies and measures across different sectors including energy, agriculture, forestry, and other land use (AFOLU), peatland, waste, and industrial processes and product use (IPPU). To achieve this, a complete decarbonization and shift to 100% RE in all emission sectors is necessary.

This policy roadmap was developed to envision energy alternatives, their effects in the coming years and how the existing energy related policies and scenarios can be effectively implemented to achieve a sustainable energy future. In this study, a comprehensive 100% RE policy roadmap has been developed based on RE transition pathways for priority sectors such as energy, transport, household, industry and agriculture (Möller et al., 2023). This has been done in consultation with over 30 stakeholders from the public and private sectors, including government officials, representatives from industries, civil society organisations (CSOs), and review of existing policy frameworks and government plans.

Renewable Energy Transition Pathways

The 100% RE policy roadmap explores different transition pathways and scenarios developed by Reiner Lemoine Institut (RLI) using the Open Energy Modelling Framework (oemof) (Möller et al., 2023). The roadmap extends beyond technical scenario modeling, incorporating a commitment to actionable steps and policy measures across various sectors, from energy production to consumption patterns. It establishes clear targets, timelines, benchmarks, and opportunities, providing a solid foundation for monitoring progress and ensuring accountability in Uganda's energy landscape. In this study, investments and capacities required to fulfil the energy demands for each of the three developed pathways for 2030, 2040 and 2050 using the created energy system model were investigated. Transition pathways include:

- **the business-as-usual (BAU)** which considers national plans such as the Uganda vision 2040 with future developments of nuclear, peat energy and biofuel extensions, without restricting unsustainable biomass use;
- **a high RE pathway (HighRE80)** with an RE share of 80% with sustainable biomass limits, and biofuel extensions;
- **a full RE pathway (FullRE100)** with 100% RE with sustainable biomass limits.

These pathways were developed considering the need for all Ugandans to access modern energy services, but also the need to ensure that energy demand is met by sustainable and renewable resources as opposed to non-renewable energy sources.

Key findings from the energy transition pathway development

The pathways for the target years (2030, 2040 and 2050) showed substantial growth in Uganda's energy demand and a complete restricting of power production and storage capacities, cooking devices, industrial heat devices, and transport fleet. Results show that for cost effective and sustainable transition, Uganda will need 74 GW of installed capacity and 404 GWh PV storage battery for HighRE80, 130 GW of installed capacity and 525 GWh PV storage battery for FullRE100, as opposed to 24GW installed capacity in the BAU, all by 2050 (Figure 0-1). This implies that over 90% of total energy demand will come from solar PV and battery storage capacities if Uganda is to take FullRE100 pathway. Hence, Uganda will need installed power capacities for HighRE80 and FullRE100 pathways higher than BAU by over 300% and 500%, respectively.

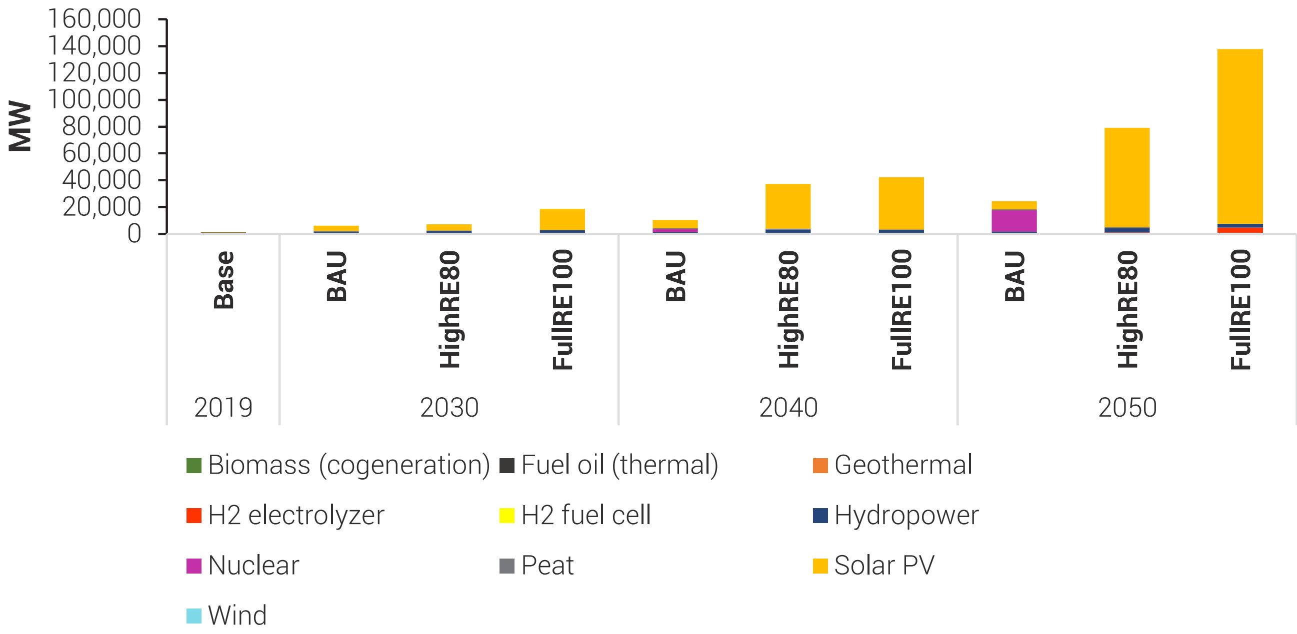


Figure 0-1: Installed power production capacities in the different pathways

The transition to a high or full renewable energy system requires substantial upfront investment costs, ranging from 245 to 393 billion USD, in contrast to the 132 billion USD in the BAU scenario (Figure 0-2). Nevertheless, these investments offer substantial long-term benefits, including potential annual cost savings of up to 80% due to reduced fuel costs. These savings may further increase in response to rising fuel prices. Government plans to meet the rising demand with nuclear power are less cost-competitive compared to renewable energy-based extension plans. By 2050, transitioning to a fully renewable energy system (FullRE100) is projected to result in a 60% reduction in the LCOE compared to the business-as-usual (BAU) plans. A high renewable energy system (HighRE80) could yield even greater savings, with a 72% LCOE reduction.

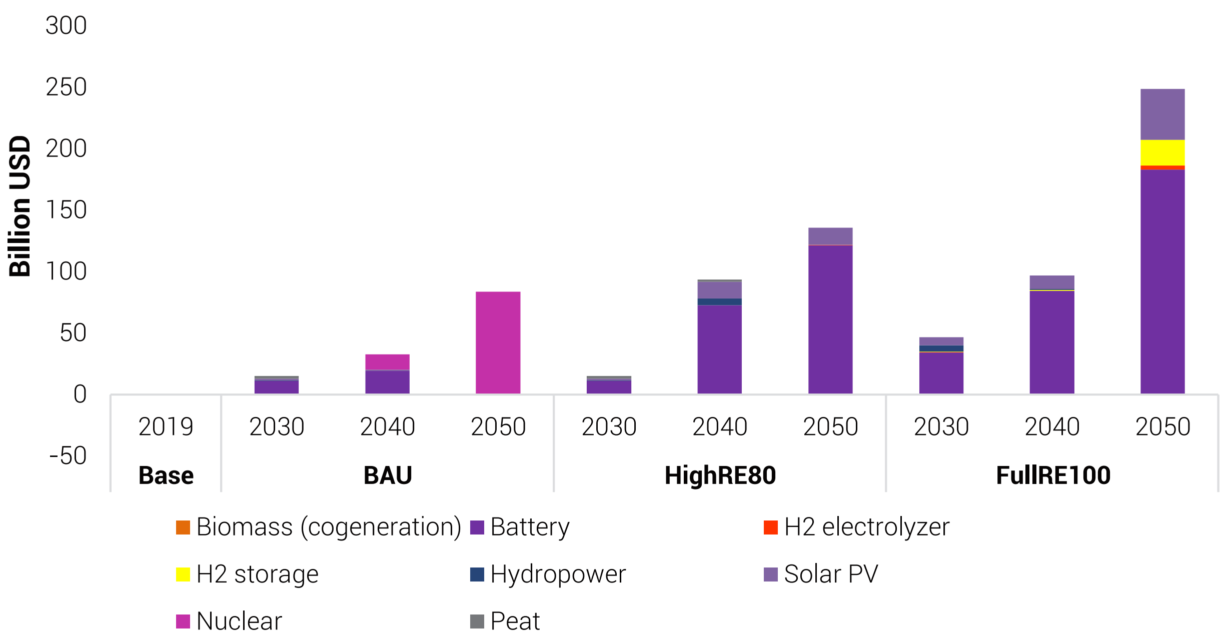


Figure 0-2: Upfront investment costs for the defined pathways and target years

Choosing a BAU pathway for energy expansion will lead to a 24% increase in annual emissions by 2050 compared to the 2019 energy system. In contrast, opting for a high or full renewable energy pathway has the potential to reduce emissions from 60% to 100% by 2050 (Figure 0-3).

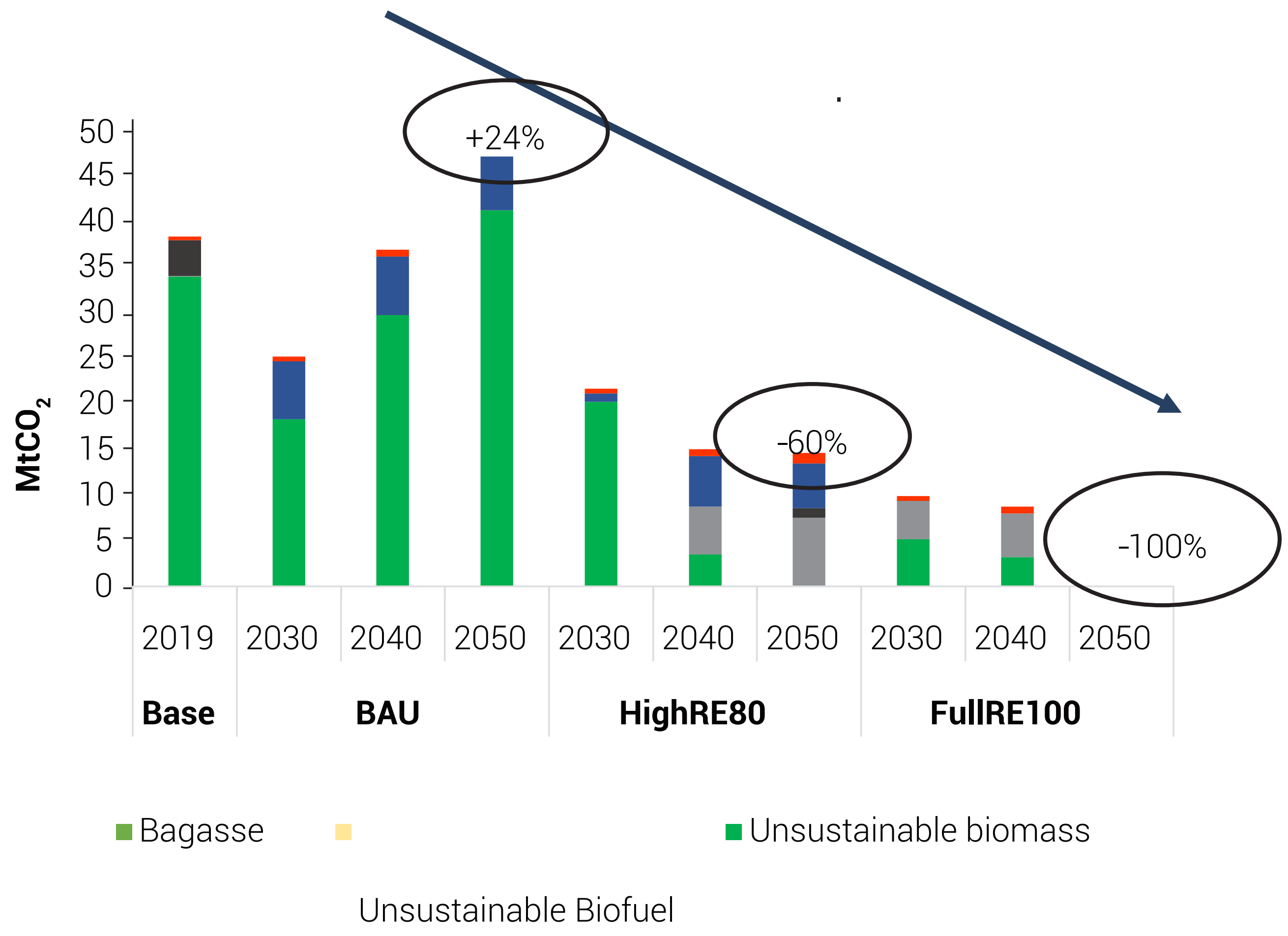


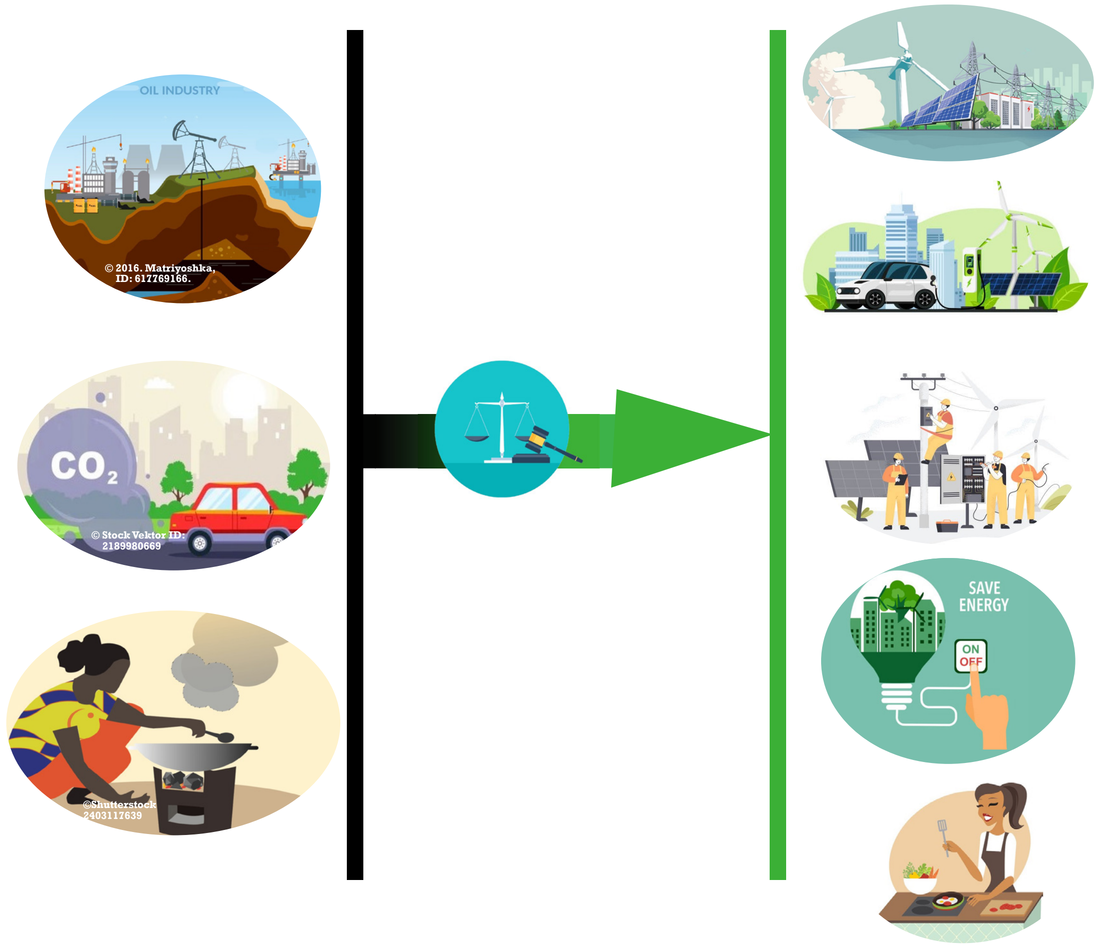
Figure 0-3: Direct CO2 equivalent emissions for defined pathways

Woody biomass annual usage is restricted to 30.975 million tons in 2030, 20.65 million tons in 2040, and 10.325 million tons in 2050 for HighRE80 and FullRE100 pathways, as compared to the 48 million tons/year in 2019 base year. All other biomass use is limited according to the sustainable biomass limits as described in the RE technical scenario report (RLI, 2023).

Successively decreasing usage limits for fuel oil and LPG are set in FullRE100. Finally, all fossil fuel resources and technologies are fully phased out by 2050 and replaced with renewable energy-based alternatives including photovoltaics, combined heat and power plants, battery storages, hydrogen storages, electric vehicles, electric cookers, hydrogen aircrafts, and improved stoves using sustainable biomass.

Policy Recommendations

The policy roadmap puts forwards policy recommendations across various sectors, detailing actionable strategies for a successful transition to 100% renewable energy by 2050:



Energy Supply Recommendations

- Establishing a robust policy and regulatory environment for renewable energy and energy efficiency.
- Strengthening transmission and distribution infrastructure, with a focus on reducing power losses
- Strategic investments in renewable energy, utilizing patient and affordable financing mechanisms.

Energy Demand Recommendations

- Accelerating the adoption of clean cooking technologies through incentivized strategies.
- Promoting biofuels, green hydrogen, and electric mobility in the transport sector.
- Facilitating local manufacturing of renewable energy and energy efficiency technologies.

Cross-Cutting Recommendations

- Fostering cross-sectoral planning to enhance interlinkages and coordination.
- Promoting knowledge management through research, awareness campaigns, and skills development.
- Ensuring robust monitoring and evaluation mechanisms to track progress and address challenges.

1 BACKGROUND

Uganda is a landlocked country occupying a total land area of 241,555 square metres with a population that has grown from 12.6 million people in 1980 to over 45 million people in 2022 (The National Population Council, 2022). It is projected that the population will reach 57 million, 72 million and 100 million in 2030, 2040 and 2050, respectively (Uganda Bureau of Statistics (UBOS), 2020 and Danish Trade Union Development Agency (DTDA), 2022). Agriculture is an important part of Uganda's economy and over 71.8% of the land area is under cultivation. Subsistence farming covers the largest portion as compared to commercial cultivation (FAO, 2016).

Uganda is energy rich in terms of renewable energy resources which include hydropower, biomass, solar, geothermal and wind, as well as high potential for non-renewable energy such as oil and gas. Despite this abundance, the nation's energy potential has not been fully harnessed to meet the growing demands of its population and economy. To address this gap and foster energy sustainability, Uganda has taken significant steps to create a conducive regulatory environment. These efforts are designed to incentivize diversification in the country's energy generation mix, encouraging the exploration and utilization of renewable energy sources. The urgency of sustainable energy practices is further underscored by the nation's commitment to mitigating climate change impacts since it subscribes to the Paris agreement and other global frameworks.

In an effort to achieve a sustainable energy future, Uganda has embarked on a transformative journey guided by a strategic 100% RE policy roadmap. It represents a comprehensive and forward-thinking approach and serves as blueprint, developed through the convergence of expert insights and stakeholder input. Over 30 stakeholders, representing diverse sectors ranging from government bodies and private enterprises to research institutions, have contributed to this RE policy roadmap's development, which is in line with the Energy transition plan for Uganda (ETP). The ETP (IEA, 2023) is a strategic roadmap for the development and modernisation of Uganda's energy sector. It charts a pathway to achieve universal access to modern energy and power the country's economic transformation in a sustainable and secure.

Central to this roadmap are detailed scenarios, each depicting a distinct energy pathway that Uganda could follow. The Business-as-Usual (BAU) trajectory, characterized by existing practices and planned policies, is contrasted with the High-Renewable-Energy (HighRE80) and Full-Renewable-Energy (FullRE100) pathways (Möller et al., 2023). These scenarios have not materialized in isolation; rather, they have been modeled, utilizing the

Open Energy Modelling Framework (oemof) and insights from experts in the field. The modeling process, led by Reiner Lemoine Institute (RLI), has provided valuable forecasts and data-driven projections, shaping the RE policy roadmap's recommendations and milestones.

This policy roadmap signifies more than a technical document; it is a commitment to tangible action. It outlines clear, actionable steps and policy measures, tailored for different sectors of the economy. From energy production to consumption patterns, from infrastructural enhancements to policy frameworks, each facet of Uganda's energy landscape has been scrutinized, offering a holistic view. The roadmap outlines measurable targets, establishing timelines, benchmarks, and opportunities. These quantifiable metrics provide a concrete foundation for tracking progress and ensuring accountability.

The urgency of transitioning to renewable energy cannot be overstated. Climate change impacts, such as droughts and floods, have already made their mark on Uganda, impacting both the economy and the populace. Through embracing renewable energy wholeheartedly, Uganda not only mitigates its carbon footprint but also enhances its resilience against future climate-related challenges. Moreover, this shift ensures energy security, reducing dependency on imported fossil fuels and stabilizing energy prices, thereby fostering economic stability.

This roadmap is not just a vision for a distant future. But a call to action for the present. Its policies and recommendations are designed to be implemented today and in the near future, fostering an environment where innovation, investment, and sustainable practices can flourish. The roadmap empowers Uganda to lead by example, showcasing to the world the transformative potential of renewable energy. Uganda stands at the threshold of a historic energy transition, and this roadmap lights the way forward, showing a path toward a brighter, sustainable future for all its citizens.

2 SITUATIONAL ANALYSIS

2.1 Demographic and Socio-economic situation in Uganda

Uganda has a population of 45.8 million as of 2021 according to World bank, of which 74.4% are rural inhabitants, even though the urbanization process has been increasing in recent decades. Kampala and other cities have shown rapid growth that has been changing the role of large cities in the country's economy. Uganda's urbanization growth rate is estimated at 19%, higher than the world's average urban population growth rate (5.4%), one of the highest urban population growth rates in the world (5.4%). Projections anticipate that urbanization at the current pace would result in an urban population of more than 20 million by 2040, and 32 million by 2050.

2.2 Energy Supply

According to the Uganda Energy Statistical Abstract 2019, the primary energy supply for Uganda in 2019 was comprised of: 9.1% petroleum (1,941 ktoe), 1.5% hydropower (326ktoe), 89.4% Biomass (19,064 ktoe), Figure 2-1.

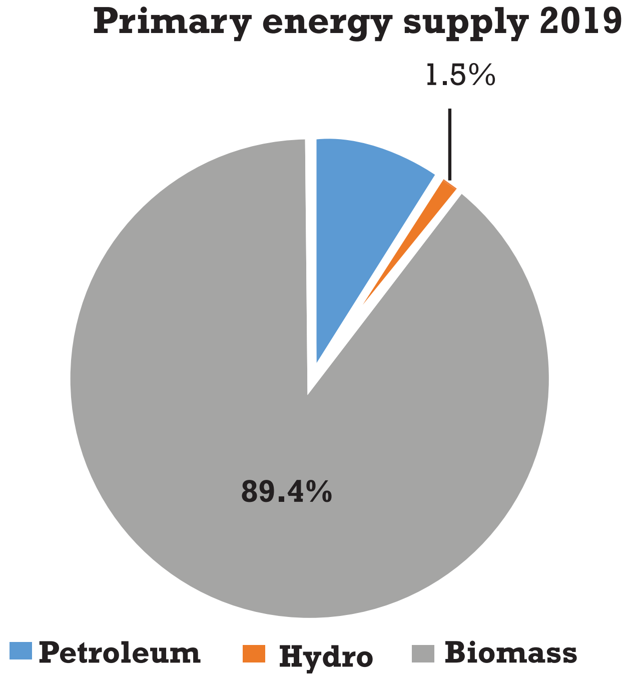


Figure 2-1: Uganda primary energy supply 2019 (Source: MEMD Statistical Abstract 2019)

The total installed generation capacity in 2019 was 1,257.673 MW (MEMD, 2019). Hydropower, cogeneration, thermal and solar contributed 1007.95 MW, 96.2 MW, 102.723 MW, and 50 MW respectively. The generation mix comprises hydropower (80%), cogeneration (8%), thermal (8%) and solar (4%), Figure 2-2

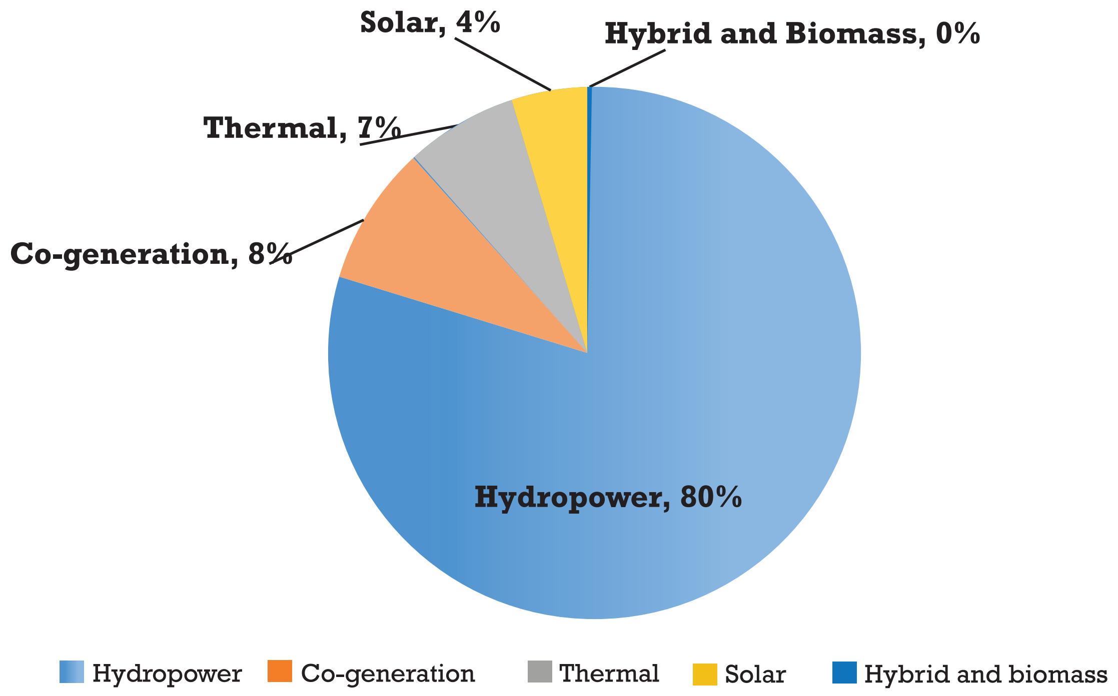


Figure 2-2: Installation electricity generation capacity in 2019 (MEMD 2019 Statistical Abstract)

According to IEA data, total energy supply in Uganda in 2021 was about 22 million tons of oil equivalent (Mtoe) (925 PJ), up from 17.6 Mtoe (737 PJ) in 2015. Approximately 90% of the energy supply in 2021 was bioenergy, mainly wood and charcoal, slightly down from 94% in 2000. Imported oil products represented almost 9% and electricity almost 2%.

2.3 Energy demand

In 2019, Uganda's total energy consumption was reported at 15.24.5Mtoe (MEMD, 2019). Energy demand is expected to increase over the years at an average of 3% due to population growth, rate of urbanization, lifestyle changes, growth of industries, mechanization efforts in agricultural production and value addition, advancements in the electric vehicle mobility and increased improvements in other technologies (UBOS, 2020). This increase in demand calls for an increased investment in sustainable and resilient renewable energy supply as well as increased investment in energy efficiency at both generation and utilization.

The total grid electricity (UMEME) sales in 2019 are indicated in the Table 2-1

Table 2-1: UMEME Sales in 2019

Category	Energy sales (GWh)
Domestic	666.43
Commercial	365.08
Medium Industrial	500.07
Large Industries	889.79
Extra Large Industries	759.32
Streetlights	1.29
Total	3,163.04

Households accounted for about 61% of final energy consumption, industry 22%, transportation 7% and public services 9% (Table 2-2). In 2021, total final consumption (TFC) was around 0.37 toe per capita, up from 0.31 toe in 2000.

Table 2-2: Total energy and electricity consumption per sector

Sector	Energy demand	Electricity Demand
Household	50.85%	21.78%
Commercial & public service	29.68%	11.18%
Industrial	1.13%	67.04%
Transport	2.28%	0.00%
Agriculture, forestry & fishing	0.1%	0.00%

Source:(MEMD statistical abstract 2021)

2.3.1 Household Sector

Firewood and charcoal were the most commonly used sources of energy for mainly cooking while other sources used included LPG, kerosene and electricity. The use of traditional biomass for cooking is still prevalent in most households, with 73% using firewood and 21% using charcoal, contributing significantly to environmental degradation, health issues, and high household expenditure (UBOS, 2021).

Charcoal is used by 13% of the population living mainly in urban and peri urban settings with over 10% of the total charcoal sold in urban centers being discharged as wasted charcoal dust (E.Mainimo, et al, 2022). LPG and kerosene are used by a very small percentage of households (below 0.5% each) while about 0.8% use a mix of cooking fuels from microenterprises (E.Mainimo, et al, 2022). Additionally, access to modern lighting in households is limited, with only 56% of households using electricity for lighting.

2.3.2 Agricultural sector

According to UNBS, Uganda's agricultural sector employs about 70% of the country's working population. During the financial year 2021/2022 agriculture accounted for 24.1% of Uganda's GDP and 33% of export earnings, as reported by Ministry of Finance, Planning and Economic development.

The total energy demand for the agriculture sector in 2020 was recorded at 181.33 ktoe (0.1%) [UBOS. 2022]. There is an increasing trend towards investments in sustainable agricultural practices and the development of agribusinesses, such as the use of solar-powered irrigation systems and biogas production in the country.
Access to energy and to other energy- intensive products, services, and facilities can increase farmer incomes and boost agricultural productivity (IEA and the World Bank, 2015).

Climate smart agricultural practices and agribusiness development like the aforementioned renewable energy applications are increasingly being used in the agricultural sector in Uganda to improve access to energy, increase productivity and reduce reliance on fossil fuels, subsequently increasing the disposable income available for purchases.

2.3.3 Industrial Sector

Uganda's industry sector can be divided into several subsectors, including Iron and Steel, Chemical (including petrochemical), Non-metallic minerals, Transport equipment, and Food (beverages and tobacco). These sub sectors have varying energy requirements depending on the nature of their operations.

According to data from Uganda's Ministry of Energy and Mineral Development (MEMD) in 2020, the industry sector consumed total energy of 2.044 ktoe (1.13%). Much of the electricity utilized by the industry is from the grid, with a very small percentage powering industries from off-grid sources.

The energy consumed by the industry sector is used for various purposes, including heating, cooling, running motors, lighting, and other industrial processes. The non-metallic minerals subsector, the food and beverage subsector each consumed 35% of the energy, while the basic metal and iron and steel subsector consumed 24%, the transport equipment subsector consumed 4%, and the chemical subsector consumed only 2% of the energy (Figure 2-3).

Despite efforts to promote renewable energy in Uganda, the industrial, commercial/ institutions and households are still heavily dependent on biomass using inefficient technologies. This highlights the need for further investments in energy efficient biomass technologies to reduce reliance on fossil fuels and improve energy security.

2.3.4 Commercial & Social institutions

Commercial and social institutions in Uganda, encompassing hospitals, schools, hotels, and offices, significantly contribute to the nation's energy consumption. In 2020, this sector consumed 5,365.15 ktoe, representing 29.68% of Uganda's total energy consumption. Specifically, these institutions utilized 11.18% of the electricity generated in the country and accounted for 8% of the biomass consumption. Despite these figures, the adoption of renewable energy sources, like solar and sustainable biomass, remains low, prompting recent governmental initiatives and installations of solar systems in some institutions to address this challenge.

2.3.5 Cooking demand

Of the 94% Ugandan households that primarily depend on biomass, 73% use firewood while 21% use charcoal for cooking, 1.4% electricity, 0.6% kerosene, and other sources including LPG, bio-fuels account for 3.9% (UBOS, 2021) Uganda's over-reliance on traditional biomass is an indicator of a country trapped in a tragedy of environmental degradation and its resultant impacts related to health, gender and household expenditure (GIZ, 2014). Uganda suffers a degradation loss of USD 2.3 billion, of which 25% is wood fuels (National Planning Authority, 2020, p. 145). According to the National Environment Management Authority (NEMA), 2.6% of Uganda's forests are cut down annually for firewood, charcoal, agriculture, and to make way for population growth. If this trend persists, Uganda will lose all its forest cover in less than 25 years (NEMA, 2020).

2.3.6 Lighting demand

According to the Uganda National Household Survey (UNHS, 2020) conducted in 2019-2020 by Uganda Bureau of Statistics it shows that 56% households in Uganda used Electricity for lighting, which included 27% of the households used the solar Kit, 19% used grid electricity and 11% used solar home system, 14% use Canister wick lamps (tadooba) while 2% used paraffin lanterns. For a comparison of lighting in the rural and urban areas, Half of the households in urban areas used grid electricity for lighting (51%) compared to only five percent of households in rural areas. In rural areas, three in every ten households (31%) used 'solar kit' for lighting compared to 16% in urban areas. A notable percent of the households in rural areas also used Dry cell/ batteries (18%) for lighting. A sizable section of the population in the rural areas still uses biomass (firewood/cow dung/grass) for lighting.

2.3.7 Transport sector

In Uganda, the transport sector is predominantly road-based, with a high motorization rate and 1.4 to 2 million registered vehicles, including motorcycles, as of 2019. The total energy demand for the sector in 2020 was 1,264.17 ktoe, comprising 2.28% of the country's total energy consumption. Fossil fuels, particularly petroleum products like oil, petrol, and diesel, are the primary energy sources, accounting for 68% of the sector's consumption and 11% of the country's final energy consumption.

Road transport dominates, utilizing 93% of fossil fuels, while rail, domestic navigation, and aviation consume the remainder. Although the transport sector used minimal electricity in 2020, there's a growing trend toward electric vehicles (EVs), with the government establishing Kiira Motors Corporation in 2014 to promote technological advancements and local manufacturing. However, the development of e-mobility faces challenges like high upfront costs, policy gaps, and infrastructure limitations. The government is collaborating with private operators and international partners to transition to greater EV usage, emphasizing the benefits of electric transport in reducing air pollution and associated health risks. Despite progress being slow, efforts are underway to overcome obstacles and advance e-mobility in Uganda.

Despite being a country with abundant biofuel resources, such as sugarcane and maize, there isn't much use of biofuels or its derived products in the transport sector.

2.4 Existing Legal, Policy and Institutional Frameworks

2.4.1 Legal, Policy and Institutional Frameworks at National Level

"In line with Uganda's commitment to a sustainable energy future, a comprehensive legal, policy, and institutional framework serves as the backbone for transitioning to cleaner energy sources, encompassing various policies and initiatives contributing to Uganda's renewable energy transformation, as discussed below.".

1. The 1995 Constitution of Uganda (As amended) includes the right to a clean environment (Article 245a), emphasizing sustainable development and responsible natural resource utilization.

2. Uganda Vision 2040 seeks to achieve 80% electricity access by 2040, prioritizing renewable sources like hydropower, solar, wind,and geothermal for low-carbon development and enhanced energy efficiency.

3. Uganda's National Development Plan III prioritizes reliable energy for economic growth, poverty reduction, and societal transformation, targeting 200 off-grid mini-grids and promoting renewable energy solutions by 2025.

4. The 2022 amendment to the Electricity Act requires the ERA to set standardized feed-in tariffs for renewable energy systems, applicable to capacities up to 50MW or as determined by the Authority, aiming to enhance investment profitability, ensure a stable market, and facilitate project financing.

5. The National Electrification Strategy (NES) seeks universal electricity access, addressing financing challenges through a Public Private Partnership (PPP) model for grid extension and emphasizing cost efficiency, community involvement, and dedicated financial instruments for different electrification approaches.

6. The Electricity Connections Policy (ECP) in Uganda targets 60% electricity access by 2027, increasing annual connections to 300,000, adding 500MW to the main grid, and providing free connections wWithin 90 meters of low-voltage poles, aligning with the Rural Electrification Strategy, Vision 2040, and aiming for 67% grid and 33% off-grid access.

7. The Biomass Energy Strategy (BEST) 2013 engages diverse stakeholders in a participatory approach to develop rational and implementable methods for Uganda's biomass energy sector management.

8. The Uganda Irrigation Policy 2017 highlights the role of renewable energy in enabling sustainable irrigation, especially in remote areas, advocating for solar, wind, and hydropower solutions.

9. Uganda's revised NDC prioritizes mitigation through measures like renewable energy, energy efficiency, and increased electricity access, while also focusing on a National Adaptation Plan for robust adaptation planning and finance (MoWE, 2022).

10. The National Climate Change Policy in Uganda seeks a coordinated approach for climate-resilient and low-carbon development, emphasizing interventions in the energy sector, such as promoting renewable energy, efficient energy use, and sustainable energy access (MoWE, 2015).

11. National Environment Management Policy for Uganda, 2014, aims for sustainable development, emphasizing optimal resource utilization and setting energy sector objectives, including promoting sustainable energy use, efficiency, private sector involvement, exploration of sustainable energy, bio-fuels, wind power, co-generation, and implementing energy legislation (MoWE, 2014).

12. The Uganda Green Growth Development Strategy focuses on renewable energy investments, technology improvements for biomass and solar power, geothermal energy, and environmental safeguards for sustainable energy generation (NPA, 2017).

13. "The Climate Change Act of Uganda, 2021 establishes compliance mechanisms, emissions trading, and measures for greenhouse gas reductions, incorporating provisions for climate change financing and incentives to implement response measures for adaptation and mitigation (MoWE, 2021)".

14. The "Uganda Energy Transition Plan (ETP)" is a strategic roadmap for the development and modernisation of Uganda's energy sector. It charts an ambitious, yet feasible pathway to achieve universal access to modern energy and power the country's economic transformation in a sustainable and secure way. It also highlights key steps to further the energy sector's decarbonisation beyond 2050 and estimates at what point the energy sector is poised to reach net zero. The objectives include: i) Provide universal access to electricity and cleaner cooking by 2030; ii) Modernise and diversify Uganda's energy mix and promote its efficient use across all sectors to support industrial growth, poverty reduction and socioeconomic transformation; iii) Ensure secure and affordable energy supply; iv) Mitigate energy emissions in line with Uganda's conditional climate commitments, which imply a 20% reduction compared to baseline emissions in 2030; v) Position Uganda as an energy hub for the East African region.

15. The "Energy Policy for Uganda 2023" is an updated version of the "Energy Policy for Uganda 2002", whose goal was "To meet the energy needs of Uganda's population for social and economic development in an environmentally sustainable manner" and has been a guiding document for the past 20 years. The Energy Policy for Uganda 2023 is aligned with the National Development Plan (NDP) III through the Sustainable Energy Programme, which reaffirms that 'the availability of sustainable (reliable, affordable and clean) energy services is critical for economic growth, poverty reduction, as well as the social and cultural transformation of society'.

2.4.2 Global and regional frameworks

The transition to renewable energy is essential for reducing greenhouse gas emissions and addressing climate change, and international organizations, agreements, and initiatives play a crucial role in guiding countries, including Uganda, in developing renewable energy sources and improving access to clean energy; some of these include:

1. The Sustainable Development Goals (SDGs), established by the United Nations in 2015, target poverty eradication, environmental protection, and universal prosperity, with renewable energy serving as a vital catalyst in achieving goals such as affordable and clean energy (SDG 7), sustainable cities and communities (SDG 11), and climate action (SDG 13), contributing to emission reduction, climate change mitigation, energy security, access, economic growth, and job creation.

2. The United Nations Framework Convention on Climate Change (UNFCCC), an international treaty focused on mitigating climate change by reducinggreenhouse gas emissions, birthed the Paris Agreement in 2015, urging global efforts to limit the temperature increase to well below 2°C and aiming for 1.5°C, while also promoting the increased use of renewable energy resources.

3. Sustainable Energy for All (SEforALL) is a global initiative striving for universal access to modern energy services, aiming to double the share of renewable energy and improve energy efficiency rates by 2030, collaborating with governments, the private sector, and civil society to achieve these ambitious goals.

4. Africa 2063, which is a continental development framework by the African Union since 2013, envisions an integrated and prosperous Africa with renewable energy as a key pillar, essential for energy access, security, greenhouse gas reduction, and sustainable economic growth (Africa Union, 2014).

5. "East African Community Vision 2050, adopted by member states, aims for economic growth and regional integration, emphasizing renewable energy expansion to achieve energy access, security, reduce fossil fuel dependence, and promote sustainable growth (EAC, 2019)."

2.5 Barriers to Renewable Energy Technology Adoption in Uganda

In the past decade, there has been an increase in the adoption of renewable energy technologies. However, there are still barriers hindering the scale up of renewable technologies in Uganda. Quantitative data collection was used to obtain the barriers indicated below.

i. Insufficient awareness and education regarding RE technologies

Although knowledge of renewable energy technologies exists, there is still lack of comprehensive information about their benefits and limitations. People are unaware of where to find genuine technologies, preventing them from making well-informed purchasing decisions.

ii. Limited access to affordable and patient financing

A major obstacle to adopting renewable energy technologies in Uganda is the scarce availability of affordable financing options for businesses. Particularly in rural areas, low affordability hampers adoption due to high initial costs. Credit facilities are scarce, and hire-purchase arrangements are underdeveloped.

iii. Knowledge gap on factors driving renewable energy demand

The absence of empirical information hampers the implementation of strategies and policies aimed at reducing unsustainable energy usage, especially in sectors like households.

iv. Inadequate policy support for small scale RE projects

There is inadequate policy support for small scale RE projects due to the lack of favorable feed in tariffs for such projects. The Electricity Regulatory Authority (ERA) should offer competing tariffs for small renewable energy projects to attract investors.

v. Lack of policy and institutional coordination

Inadequate coordination among government agencies and stakeholders results in inconsistent and incoherent data within the overall policy framework. This lack of harmony impedes the growth and development of renewable energy technologies in Uganda.

vi. Proliferation of substandard RE technologies in the market

Uganda has some substandard products entering the market adversely impacting the renewable energy market. Addressing this issue requires education about quality standards and enforcement.

vii. Inadequate after-sales support

A critical barrier to renewable energy adoption lies in the limited availability of after-sales services, especially in rural areas. Sparse distribution of service centers with appropriate capacity increases transaction costs and leads to frequent system malfunctions, tarnishing the reputation of renewable energy technologies.

viii. Scarcity of technical expertise in renewable energy (RE) design, installation, operation, and maintenance

The shortage of skilled personnel and technical expertise in renewable energy technologies poses a significant barrier to adoption. The lack of expertise hampers proper installation, operation, and maintenance, limiting the widespread adoption of renewable energy technologies in Uganda.

3 RENEWABLE ENERGY TRANSITION PATHWAYS

This chapter presents three distinct pathways for energy transition that were modeled by RLI, each offering a unique perspective on Uganda's energy future in 2030, 2040 and 2050. These pathways represent the existing governmental energy plans ("business-as-usual"), as well as ambitious RE transition plans to high and full renewable energy solutions.

Business-as-Usual (BAU) Scenario

This pathway maintains the status quo by considering the government's plans for nuclear, peat, and biofuel extensions, without restricting unsustainable biomass use. Nuclear energy capacities are assumed to go on- grid in 2040 with 2.6 GW and 15.6 GW in 2050 (Nhede, 2023). Peat energy is assumed to be developed with a capacity of 400 MW by 2030 and 800 MW by 2040 (Electricity Regulatory Authority (ERA), 2022). Biofuel production is assumed to be extended, growing up to 2 million m3 in 2030, 3 million m3 in 2040, and 4 million m3 in 2050. The use of biomass is not restricted in this pathway. Besides these specifications, the energy system is optimized for minimum annual cost to meet the annual energy demand.

High Renewable Energy (HighRE80) Pathway

The "High Renewable Energy" (High RE, 80) pathway targets an 80% renewable energy share while enforcing fully sustainable biomass usage by 2050. Investments in nuclear, peat energy, and new fuel oil power plants are not restricted and cannot be achieved by the current policy framework. All other biomass use is limited according to the sustainable biomass limits in all scenario years. Woody biomass usage is restricted to 30.975 million tons in 2030, 20.65 million tons in 2040, and 10.325 million tons in 2050.

Full Renewable Energy (FullRE100) Pathway

The Full RE100 pathway aims to reach a fully renewable-based energy system and only allow sustainable biomass usage given the defined limits by 2050. This pathway is not favored by the existing policies; investments in nuclear, peat energy, and new fuel oil power plants are not allowed in this pathway. Woody biomass usage is restricted to 30.975 million tons in 2030, 20.65 million tons in 2040, and 10.325 million tons in 2050. All other biomass use is limited according to the sustainable biomass limits as described in the technical modeling report. Further, successively decreasing usage limits for fuel

oil and LPG are set in this pathway. Finally, all fossil fuel resources and technologies are fully phased out by 2050 and replaced with renewable energy-based alternatives including photovoltaics, combined heat and power plants, battery storages, hydrogen storages, electric vehicles, electric cookers, hydrogen aircrafts, and improved stoves using sustainable biomass.

3.1 Installed Capacities and System Costs

This subsection shows the results of the three pathways (BAU, HighRE80, FullRE100) for the target years 2030, 2040 and 2050 from the optimization, compared to the baseline scenario (scheduled to the year 2019 for demand and 2021 for installed capacity). The optimization results provided the optimal additional capacities required to fulfill the electricity, transport, cooking, and industrial heat demand, as well as the optimal dispatch for each technology in the energy system.

Figure 3-1 and Figure 3-2 show the total installed capacities (existing plus optimized) of the electricity production units and the storage for each pathway and target year, respectively. In BAU capacity extensions are comparably low, with nuclear taking the main share of installed capacity and generated electricity in 2050. In HighRE80, electricity supply is realized via PV panels, battery storage, hydropower, geothermal energy, and biomass cogeneration systems. In FullRE100, PV capacity combined with batteries and (from 2050 on) H2 storages and H2 electrolysers are massively expanded. Electricity production is complemented with hydropower and combined heat and power (CHP) plants. Figure 3-3 shows the corresponding electricity generation of all pathways where most of the electricity, close to 90%, is expected to come from solar PV by 2050 for the HighRE80 and FullRE100 pathways.

Figure 3-4 shows the Levelised Cost of Energy (LCOE) for the defined pathways across various target years. In 2030, a promising trend with consistently low LCOE values for all pathways, indicating an initial period of cost-efficiency was observed. However, in the later target years where demand growth rates were considered, distinct patterns emerged. In 2040, the BAU pathway becomes more expensive than the renewable pathways, because of developments in nuclear and peat power plants. By 2050, the landscape further evolves. Due to large developments in nuclear, the BAU scenario is 255% more expensive than the HighRE80 pathway.

The FullRE100 pathway becomes 41% more expensive than the HighRE80 pathway in 2050. This is because being fully renewable necessitates larger capacities and storage solutions to meet demands during periods of high demand but low electricity production. This requirement leads to the oversizing of capacities, contributing to the higher LCOE in 2050 for this pathway. In contrast, the HighRE80 pathway consistently demonstrates cost-effectiveness, offering a compelling energy supply system throughout the examined years.

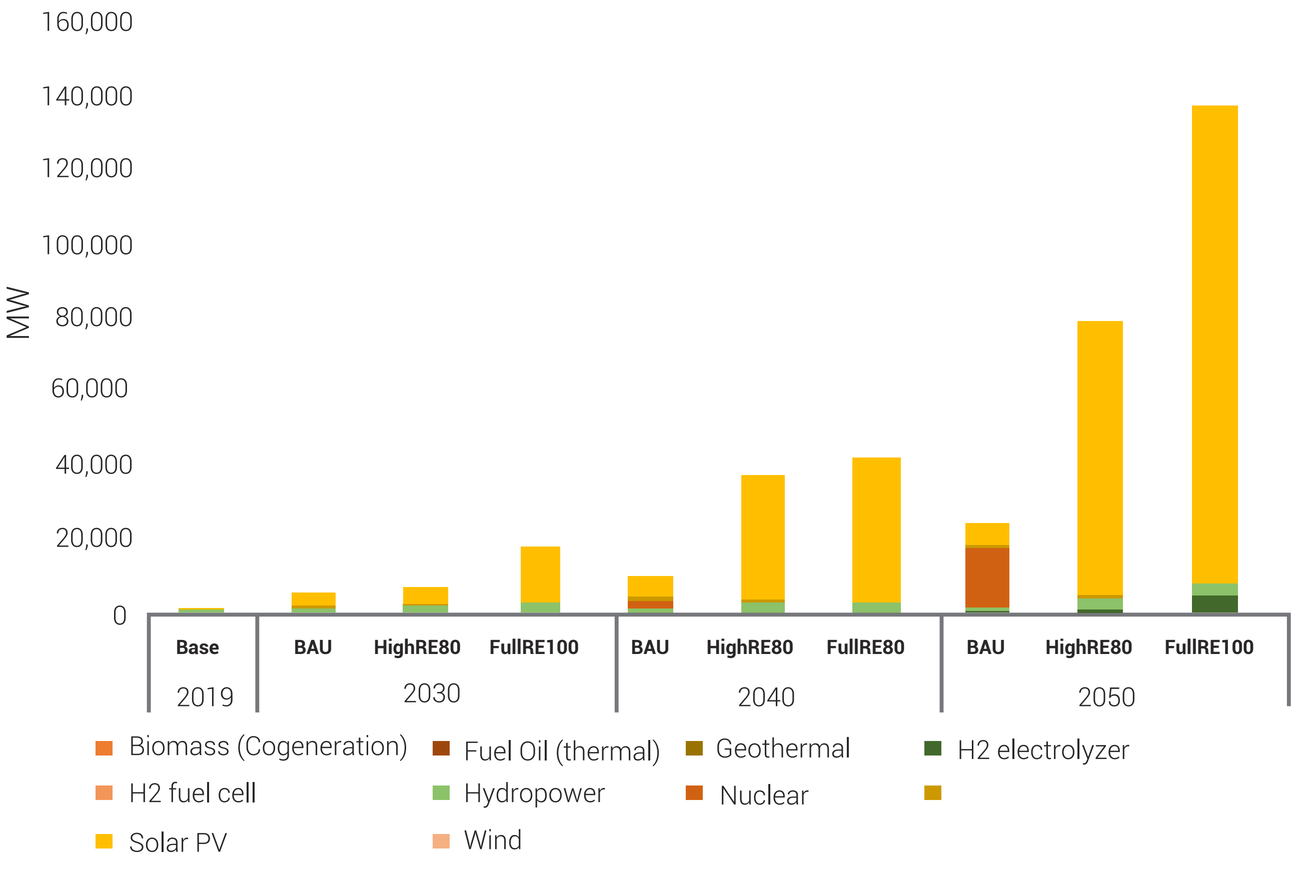


Figure 3-1: Installed power production capacities in the different pathways

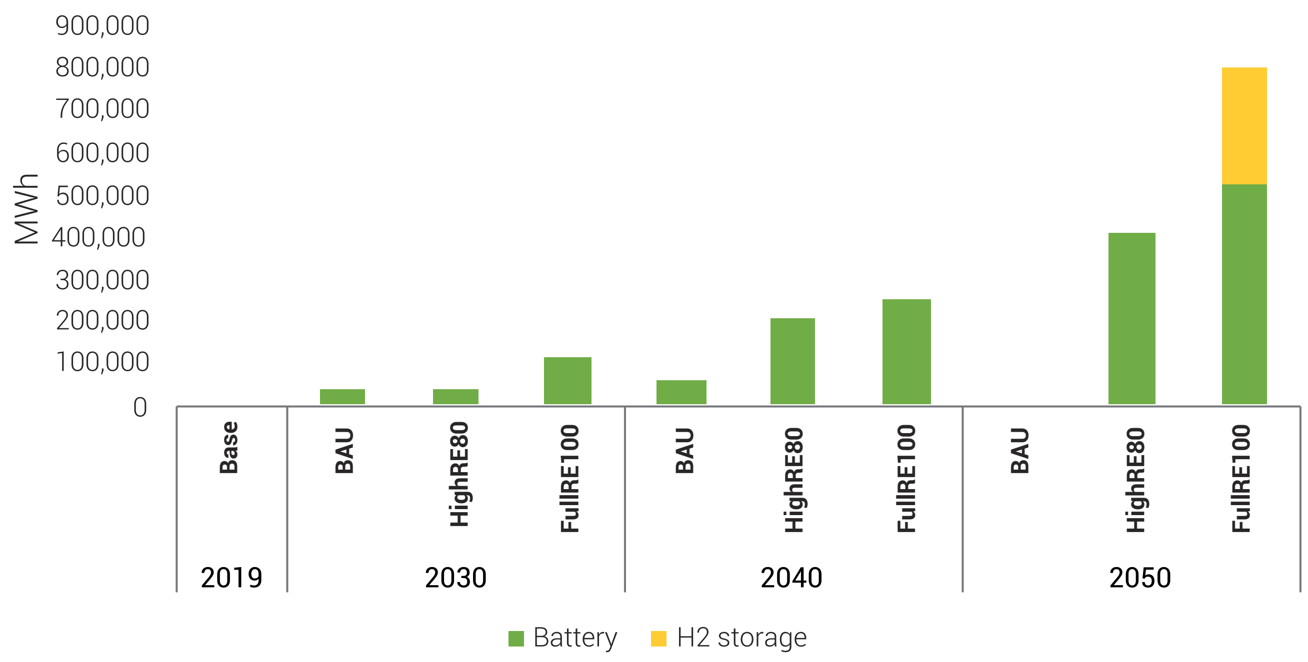


Figure 3-2: Installed storages in the different scenarios

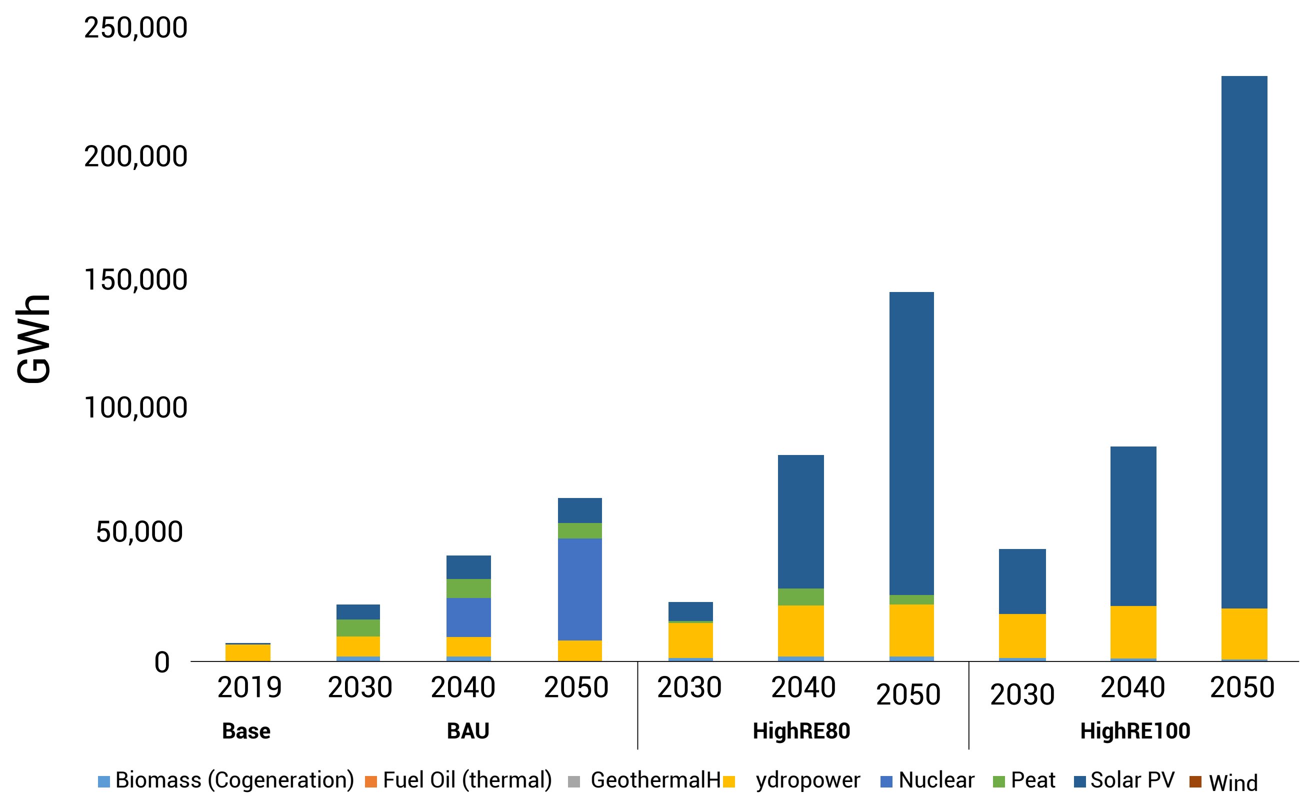


Figure 3-3: Electricity generation for each pathway and target year

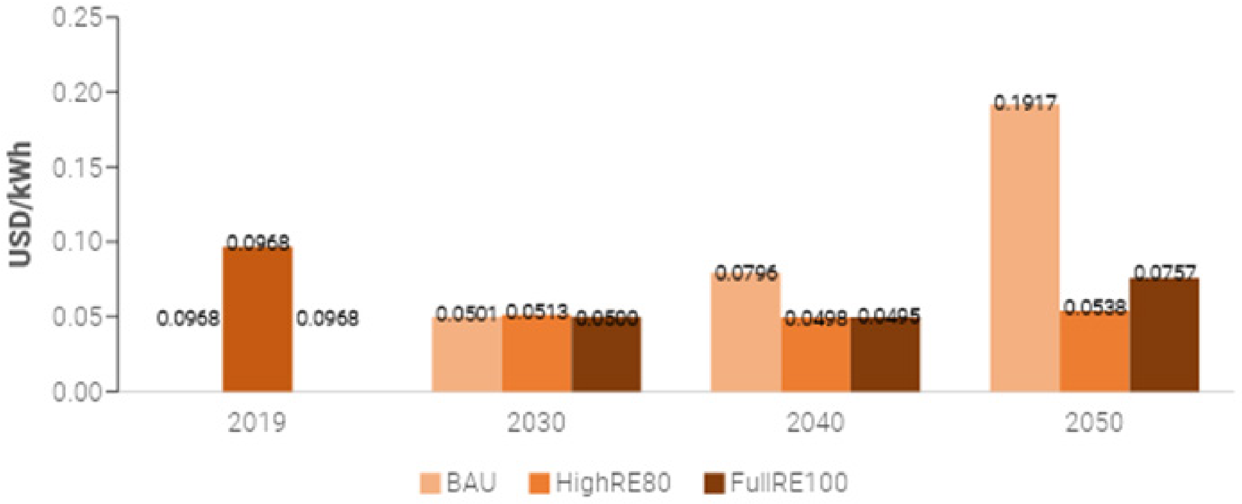


Figure 3-4: LCOE for the defined pathways and target years

3.2 Industrial Heat Devices

Figure 3-5 provides an insightful overview of the industrial heat sector's evolution within the specific pathways and target years. After examining the pathways for the target years 2030 and 2040, a consistent selection of capacities for key components such as biogas heating, biomass cogeneration, and wood boilers was noticed. These pathways exhibit similarity in their approach to meet industrial heat requirements during these years. However, the divergence becomes evident in 2050 when there is a significant increase in heat demand. In the HighRE80 pathway, a dynamic strategy was employed to address this increased demand. Here, a combination of industrial boilers and H2 boilers was selected to effectively cover the additional heat demand.

Conversely, the FullRE100 scenario adheres to a stringent sustainability approach. With a strict prohibition on unsustainable biomass usage and a commitment to exclusively utilize renewable resources, this pathway opts for reduced wood boiler capacities. To meet the additional heat demand in 2050, the FullRE100 scenario relies on H2 boilers, aligning with its sustainability principles.

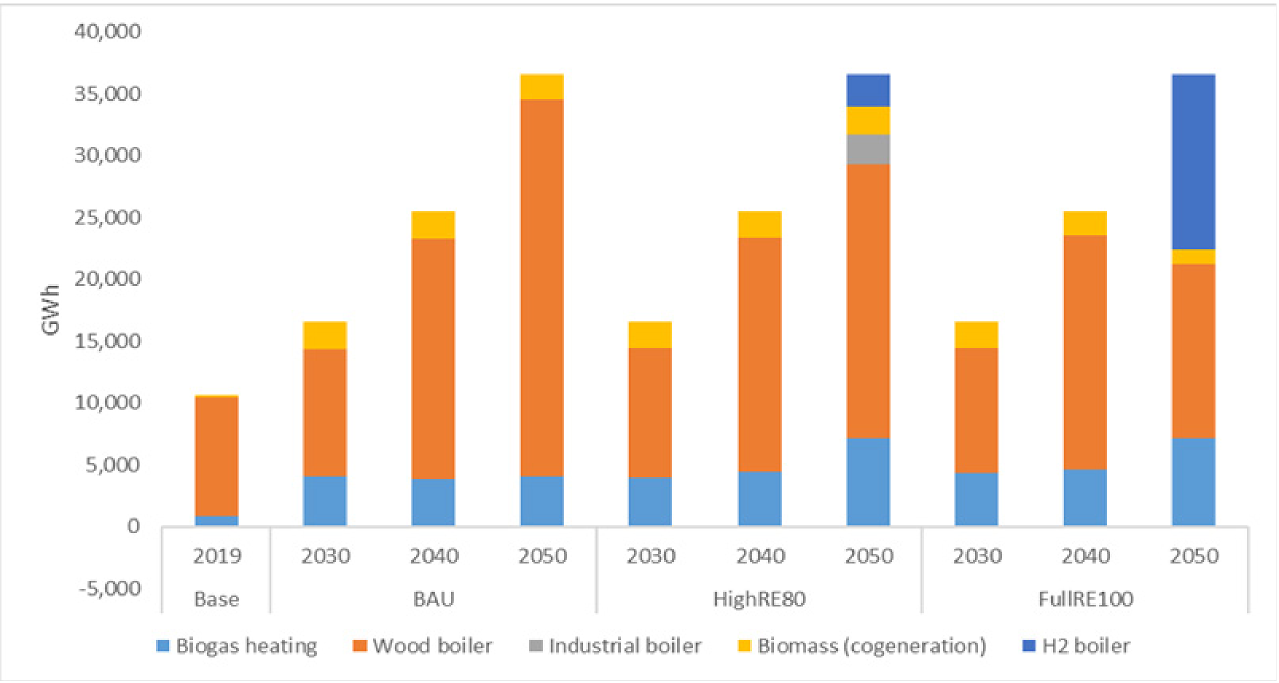


Figure 3-5: Energy consumption by Industrial heat supply devices in the defined pathways and target years

3.3 Cooking Devices

Figure 3-6 shows the development of the cooking sector in the specific pathways and target years. Across all pathways, a consistent trend emerges – the replacement of unimproved cooking stoves with improved cooking stoves and electric stoves. This transition serves two primary objectives: cost reduction and improved efficiency of cooking appliances.

In the BAU scenario, biomass cooking remains dominant, particularly with improved stoves, supplemented by modest proportions of LPG and electric stoves. LPG stoves serve as transitional solutions in 2030 and 2040 for both the HighRE80 and FullRE100 pathways. By 2050, the HighRE80 scenario relies only on LPG and electric stoves. In the FullRE100 scenario, however, only electric stoves are chosen due to the sustainability limitations on unsustainable biomass usage and restrictions of LPG usage.

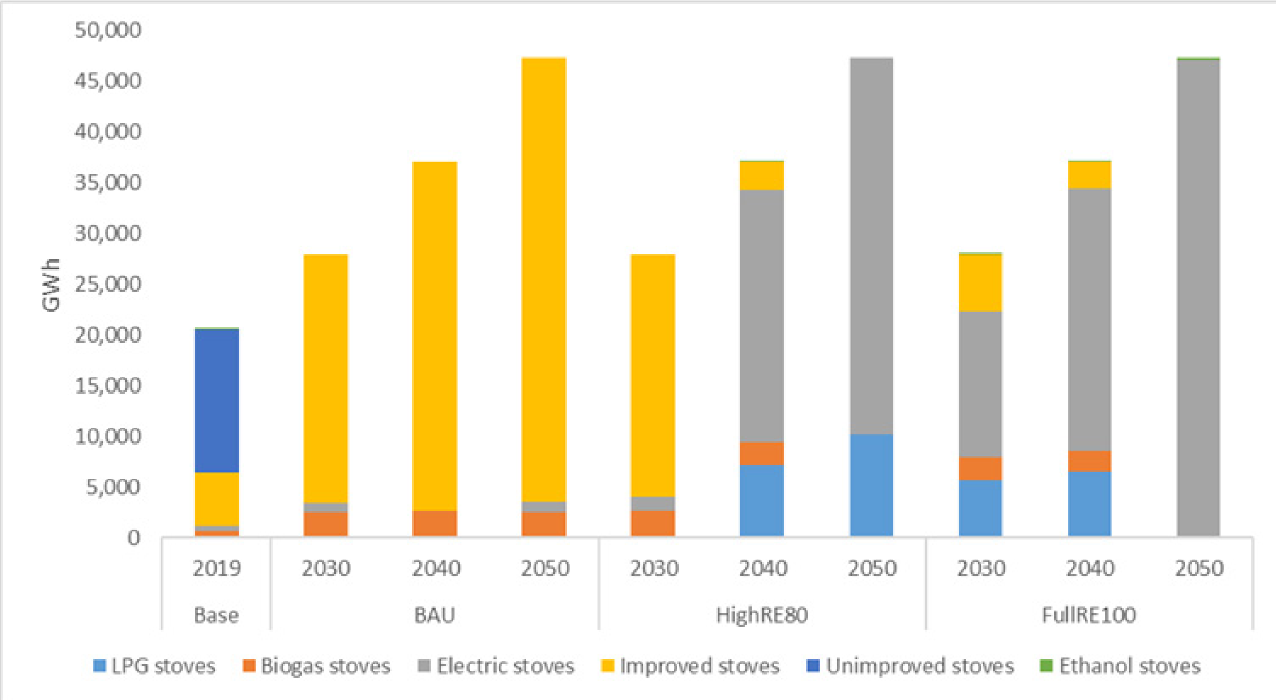


Figure 3-6: Energy Consumption by cooking devices in the defined pathways and target years

3.4 Transport Fleet

Figure 3-7 shows the distinct trends exhibited by the transport fleet for the defined pathways and target years. All pathways transition from combustion engine vehicles to electric vehicles in 2030 due to high fuel oil prices. While biofuel vehicles are deployed until 2040 in BAU, and until 2030 in HighRE due to their relatively low cost, they are also introduced in the FullRE100 2050 scenario to cost-efficiently meet the full renewable energy goals. In the BAU and FullRE100 pathways, there is a shift from kerosene aircrafts to green H2 aircrafts in 2050, attributed to high kerosene prices and the availability of low-cost green H2 resulting from excess, reliable nuclear energy (BAU) or the 100% renewable goal (FullRE100), respectively. However, the HighRE80 pathway continues to use kerosene, as green H2 production prices remain relatively high due to less reliable electricity sources.

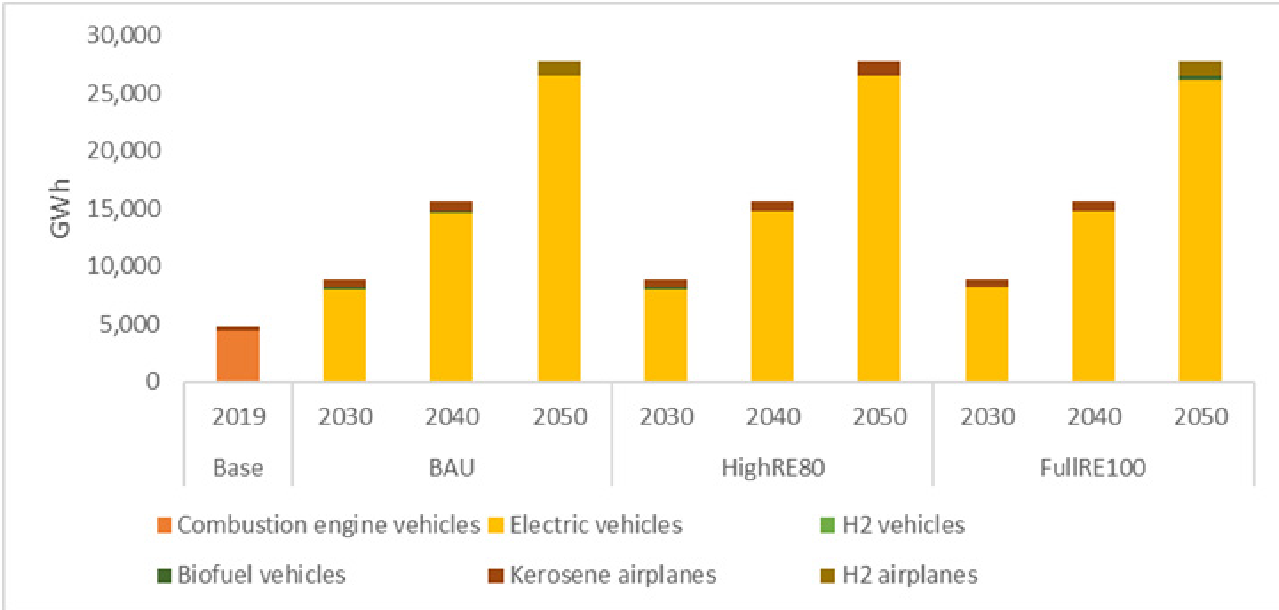


Figure 3-7: Energy consumption of transport fleet in the defined pathways and target years

3.5 Renewable Share of Overall Energy System

After considering large parts of current biomass usage as unsustainable and thus non-renewable, the renewable share of the total energy system in 2019 is 36%. In BAU, the renewable share rises until 2030, largely attributed to the affordability of PV panels and a relative reduction of biomass consumption due to the adoption of improved stoves. However, the BAU scenario witnesses a decline in renewables shares by 2040 and 2050 (Figure 3-8), primarily due to the introduction of nuclear energy and the ongoing unrestricted use of unsustainable biomass. HighRE80 and FuLLRE100 increase their renewable share according to the defined trajectory. This increase is achieved through the deployment of large PV and storage capacities, as well as using electricity and green H2 to replace unsustainable biomass use and fossil fuels in the transport, heat, and cooking sector.

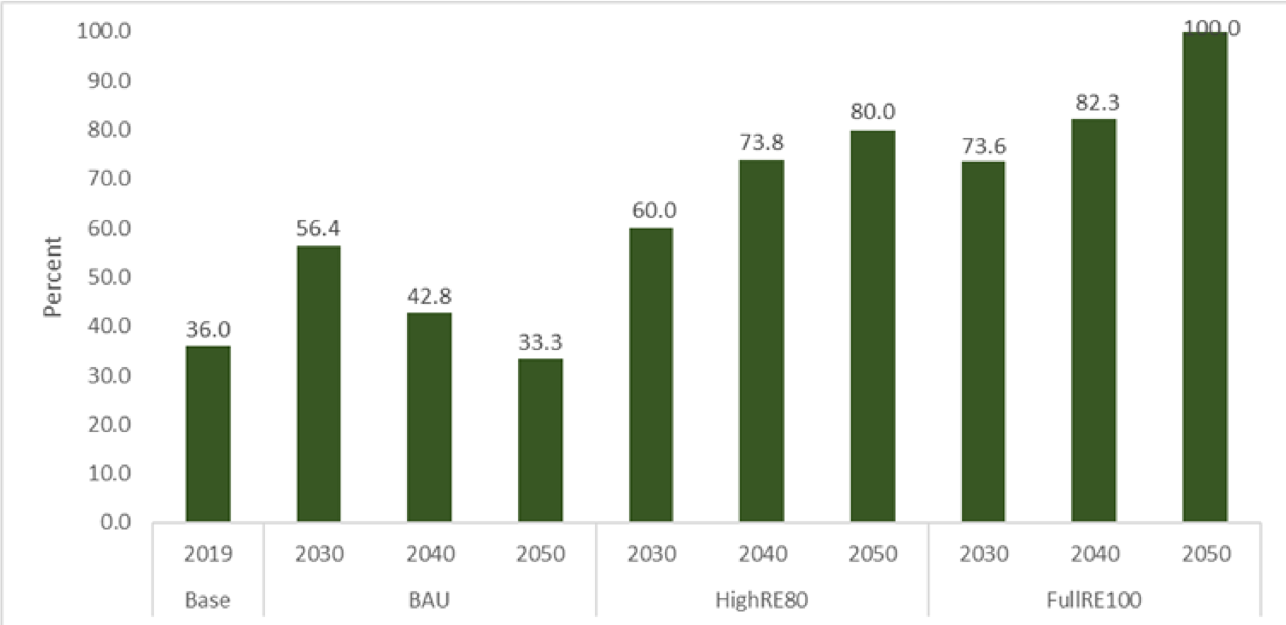


Figure 3-8: Renewable share of energy generation for the defined pathways and target years

3.6 Investment Costs of the Renewable Energy Scenario

Figure 3-9 shows the additional upfront investment costs required for each target year of each defined pathway. In 2030, the BAU and HighRE80 scenarios demand upfront investments of around 16 billion USD, while the FullRE100 scenario requires 47 billion USD due to larger PV and storage infrastructure. In 2040, the upfront investment costs are substantially lower for the BAU scenario at 33 billion USD compared to 94-97 billion USD for the renewable pathways. A 100% renewable transition by 2050 necessitates an extra 249 billion USD, while an 80% transition requires 136 billion USD. The BAU case calls for 84 billion USD in additional investments. The transition to a high or full renewable energy system requires total upfront investment costs over the target years, ranging from 245 to 393 billion USD, in contrast to 132 billion USD in the BAU scenario. Despite the high upfront investment requirements for a renewable transition, they still make sense from a cost perspective due to reduced fuel costs. This can be seen in the LCOE comparison in Figure 3-4, where potential cost savings of up to 80% can be achieved.

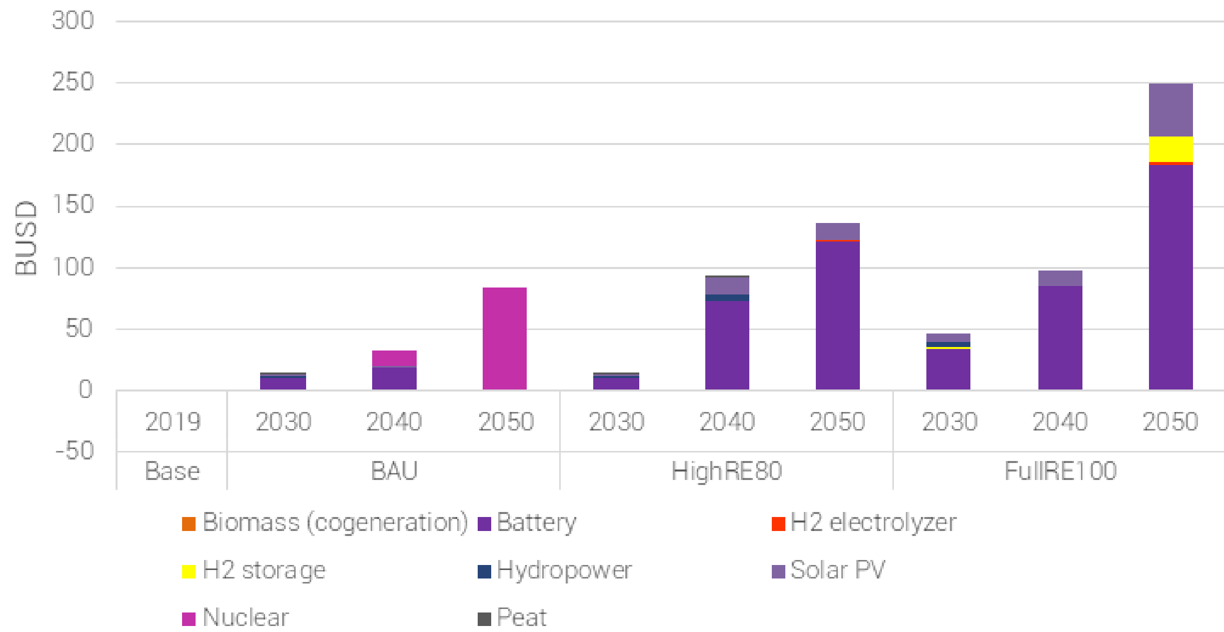


Figure 3-9: Upfront investment costs for the defined pathways and target years

3.7 Sensitivity Analysis

To evaluate the robustness of the oemof model results and explore key parameter sensitivities, a sensitivity analysis was conducted. Specifically, the focus was on two critical parameters: the equivalent annual costs associated with PV and battery storage. From 2030 onwards, a noteworthy 46.4% reduction in PV equivalent annual costs, based on insights from the African Energy Outlook 2022 (IEA, 2023a) was assumed. However, it was important to acknowledge the dynamic nature of technology costs, and as such, scenarios where the equivalent annual costs for PV and battery storage range from 50% below the predicted prices to 100% above the predicted prices were considered. By conducting the sensitivity analysis, the aim was to gain an understanding of how changes in these costs impact the energy system model. The interest was assessing the effects on key variables such as newly invested capacities or LCOE.

The target year 2050 was selected to demonstrate the effects of changing PV and battery costs across defined pathways on installed power capacities (Figure 3-10), installed storages (Figure 3-11) and LCOE (Table 3-1). In the BAU 2050 scenario, the energy system remains unaffected by changes in PV and battery storage costs. This is because even at predicted prices, there are no additional investments in PV or battery storage. Instead, the energy system heavily relies on other sources, with substantial investments in nuclear energy amounting to 15,600 MW. The LCOE experiences a moderate 5% increase across the range of cost scenarios.

In the HighRE80 scenario, increasing equivalent annual costs led to a reduction in PV and battery investments. Specifically, there was a 12% decrease in PV investments and a 7% decrease in battery storage capacity when comparing the least expensive and most expensive scenarios. However, the LCOE showed a significant 185% increase. The choice of transportation options varies based on equivalent annual costs. In the most cost-effective scenario, green H2-powered airplanes become a competitive choice compared to traditional kerosene-powered aircraft due to lower electricity costs for green H2 production. Conversely, at current predicted costs, kerosene remains the preferred option. In the most expensive scenario, biofuel vehicles gain prominence due to reduced investments in PV and battery storage.

The FullRE100 pathway exhibited significant variations in response to changing equivalent annual costs for PV and battery storage. Notably, PV and battery storage investments experienced a reduction of 30% and 12%, respectively, when comparing the most affordable and most expensive scenarios. However, the LCOE depicted a substantial increase of 205%. One noteworthy shift was observed in the transportation sector. As equivalent annual costs rise above predicted levels, green H2 production and storage become competitive alternatives to PV and battery storage for electric vehicles. This shift in competitiveness prompts the need for larger green H2 storage capacities to compensate for reduced PV capacities. These storages play a crucial role in ensuring a consistent supply of green H2 to meet the demands of the transportation sector.

Notably, the full and high RE pathways have a lower LCOE than BAU, even at the extreme assumption of 200 percent higher prices of PV panels and battery storages as the predicted prices (HighRE80: 0.111 USD/kWh. FullRE100: 0.143 USD/kWh, BAU: 0.196 USD/kWh, Table 3-1). This underpins the strong economic advantages of an RE -based transition in comparison to the development of nuclear energy in BAU.

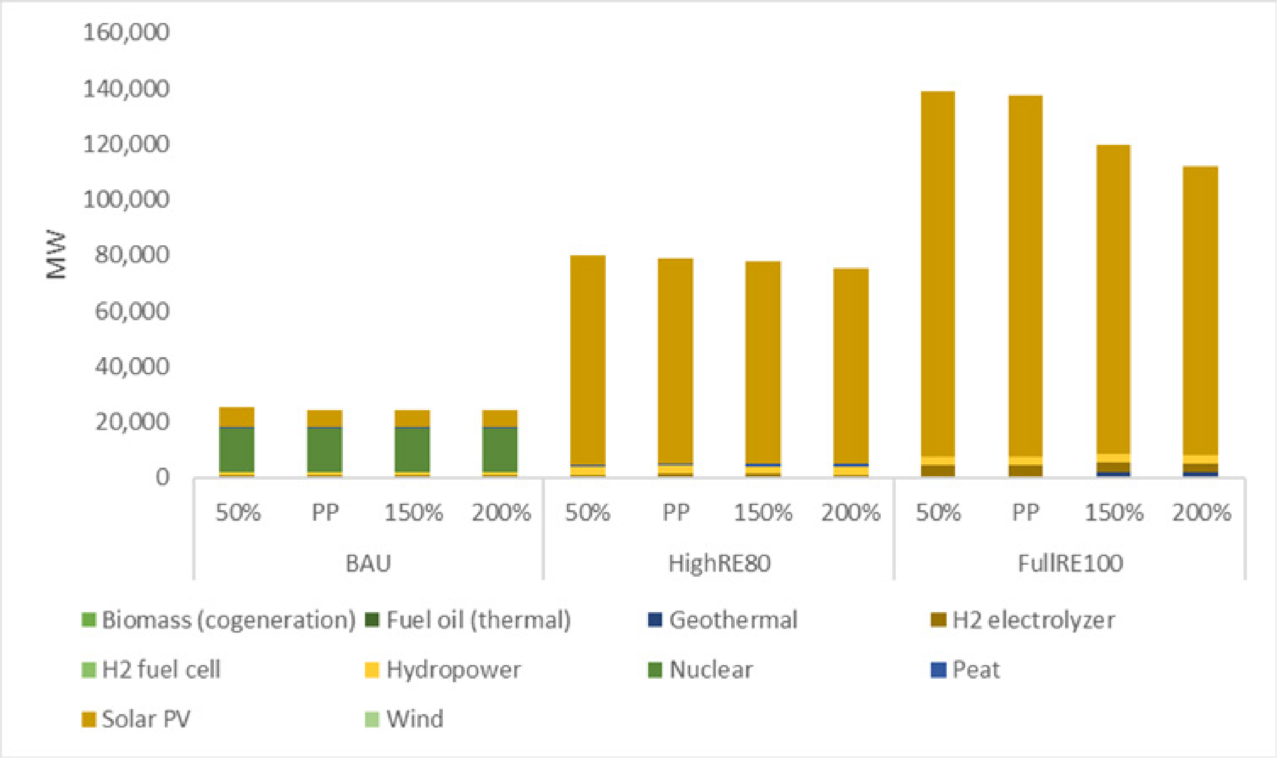


Figure 3-10: Installed capacities for sensitivity analysis on PV and battery storage equivalent annual costs

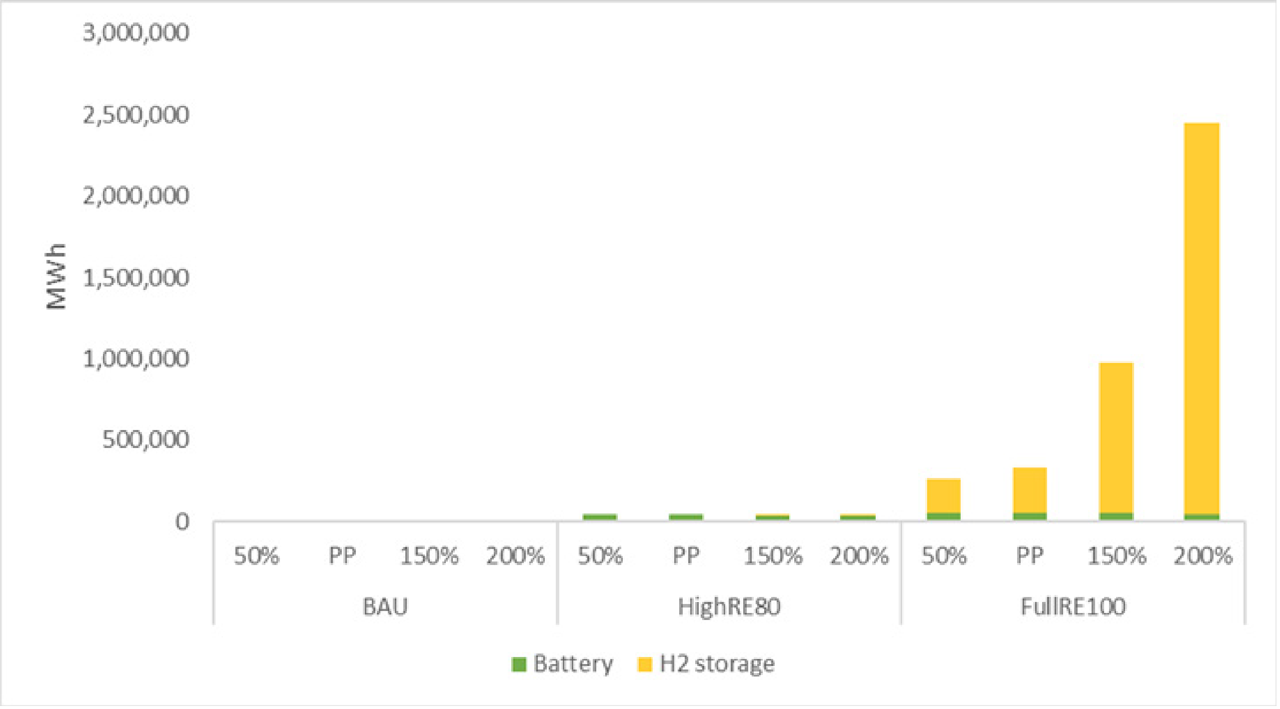


Figure 3-11: Installed storage capacities for sensitivity analysis on PV and battery storage equivalent annual costs

Table 3-1: Key Performance Indicators (KPIs) for sensitivity analysis on PV and battery storage equivalent annual costs

Scenarios	PV and battery storage equivalent annual costs	LCOE (USD/ kWh)	RE share (%)	Investments in PV (GW)	Investments in battery storage (GWh)
BAU 2050	50% of PP	0.187	30	0	0
	PP (predicted price)	0.190	30	0	0
	150% of PP	0.193	30	0	0
	200% of PP	0.196	30	0	0
High RE 80% 2050	50% of PP	0.039	80	42.3	40.6
	PP (predicted price)	0.063	80	40.8	40.4
	150% of PP	0.088	80	39.6	38.6
	200% of PP	0.111	80	37.1	37.9
Scenarios	PV and battery storage equivalent annual costs	LCOE (USD/ kWh)	RE share (%)	Investments in PV (GW)	Investments in battery storage (GWh)
FullRE100% 2050	50% of PP	0.047	100	93.1	53.5
	PP (predicted price)	0.085	100	91.2	52.5
	150% of PP	0.118	100	72.1	48.7
	200% of PP	0.143	100	64.9	47.1

3.8 CO2 emissions reduction potential

The expected annual direct CO2 emissions for each pathway were calculated by accounting for specific CO2 emissions of various fuels per used resource using data from Quaschning and Siegel (2022). The total expected annual emissions for the baseline year 2019 were 38 million tons of CO2 equivalent. Unsustainable biomass and fuel oil were the largest contributors to the total emissions of the energy system, despite hydropower being the largest installed capacity (1,070 MW). The direct annual emissions for each technology for the considered pathways are illustrated in Figure 3-12.

After a short dip in 2030 due to the switch from unimproved to improved stoves, the emissions in BAU rise due to ongoing and unrestricted biomass and peat usage. With increasing renewable energy share along the HighRE80 pathway, emissions switch from being predominantly based on unsustainable biomass (2030) to being based on fossil fuels (LPG, Peat, Fuel oil, Kerosene). The resources in the FullRE100 causing net CO2 emissions in 2030 and 2040 are unsustainable biomass, LPG and kerosene. The FullRE100 pathway reduces direction emissions to 0 in 2050 and indicates the path to CO2 neutrality.

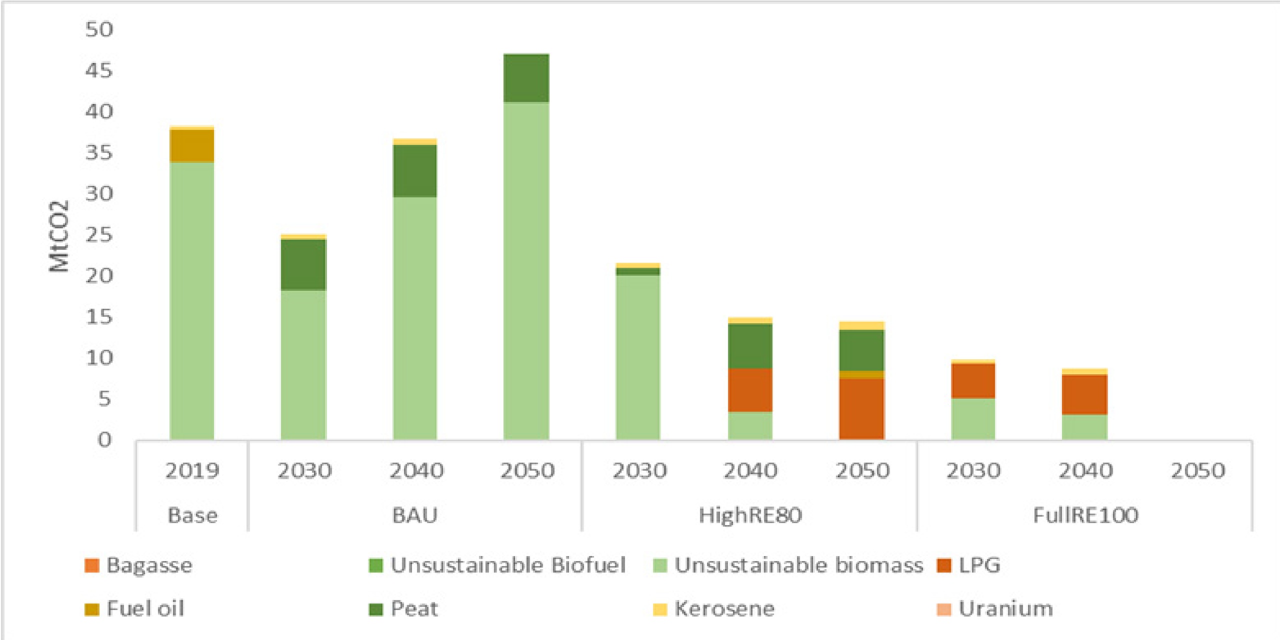
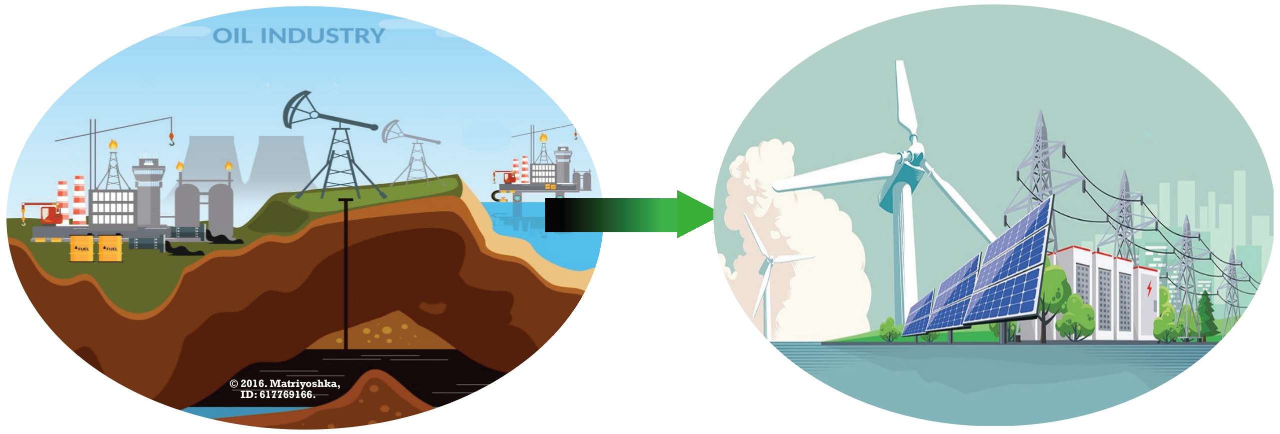


Figure 3-12: Direct CO2 equivalent emissions for defined pathways

4 POLICY RECOMMEDATIONS

Based on the pathways scenarios developed by RLI, this 100RE Policy Roadmap outlines strategic actions and technologies for a transition to 100% renewable energy by 2050, based on energy generation and use data, modeling projections, stakeholder consultations, and references to national and regional plans, aligning with Uganda's Vision 2040, National Development Plan, Green Growth Development Strategy, Updated Nationally Determined Contributions, and the National Energy Policy (2023).

4.1 Energy Supply recommendations



i. Enabling Policy and Regulatory frameworks

The government of Uganda has established favorable policies for renewable energy, including the Energy Policy of 2023, which aims to ensure that households have at least one source of clean and modern energy on- and off-grid by 2040 (MEMD 2023). Electricity access for all in Uganda should be powered by 100% renewable energy. The FullRE100 pathway, in addition to increasing access, offers non-quantifiable benefits like reduced air pollution and increased employment, necessitating the government's commitment to leveraging existing policies and providing instruments to allocate resources for the successful implementation of renewable energy and energy efficiency projects. Recognizing the need for a transition to 100% renewable energy by 2050, new policies and reviews are recommended to promote sustainable electricity access for all in the long run. The recommended interventions for the government should include:

- Strengthen and increase the Uganda National Bureau of Standards' (UNBS) capacity to create, approve, and enforce the control of the quality standards for RE and EE technology procurement and deployment, which is critical in successfully implementing projects along the FullRE100 pathway.

- Encourage commercial and industrial energy consumers to increase their share of energy storage with a mix of battery and hydrogen targets that match the implementation of storage projects alongthe FullRE100 pathway.

- Prioritize and enhance its coordination and communication strategy of all policies and instruments to critical stakeholders, especially local governments, civil society and the private sector, to reduce uncertainty and increase support.

- prioritize the development of mechanisms and guidelines for the digitalization of data collection, analysis, storage and distribution of energy-related data, especially on aspects such as off-grid data access and energy efficiency, to mention but a few, which are critical for evaluation, improvement and monitoring of RE and EE energy systems especially guidelines for open sharing to different sector players like development partners, financiers, civil society to mention but a few are in place.

- Enhance mechanisms that encourage developers to incorporate local and community involvement in the development and implementation phases while encouraging a profit-sharing structure during service delivery to increase the perception of ownership and buy-in of RE and EE projects.

- Accelerate the development of regulatory instruments for effective e-waste management that outline responsible disposal, recycling, and safe handling of material waste from renewable technologies, such as batteries and solar panels.

ii Improve the transmission and distribution infrastructure

The grid network in Uganda needs strengthening to enable it to accommodate the intermittent renewable energy power plants such as solar, wind, etc. Since the future will be powered by renewable energy, the government needs to revamp the entire transmission and distribution infrastructure, establish smart grids that can accommodate the intermittent renewable energy sources.

The government should provide the necessary investments to reduce power losses in the transmission and distribution of electricity. As of 2022, the transmission and distribution losses were 4% and 17% despite the government setting targets for reducing power losses to ≤3% and ≤10% in the transmission and distribution electricity grid networks, respectively.

iii. Invest in renewable energy using patient affordable financing

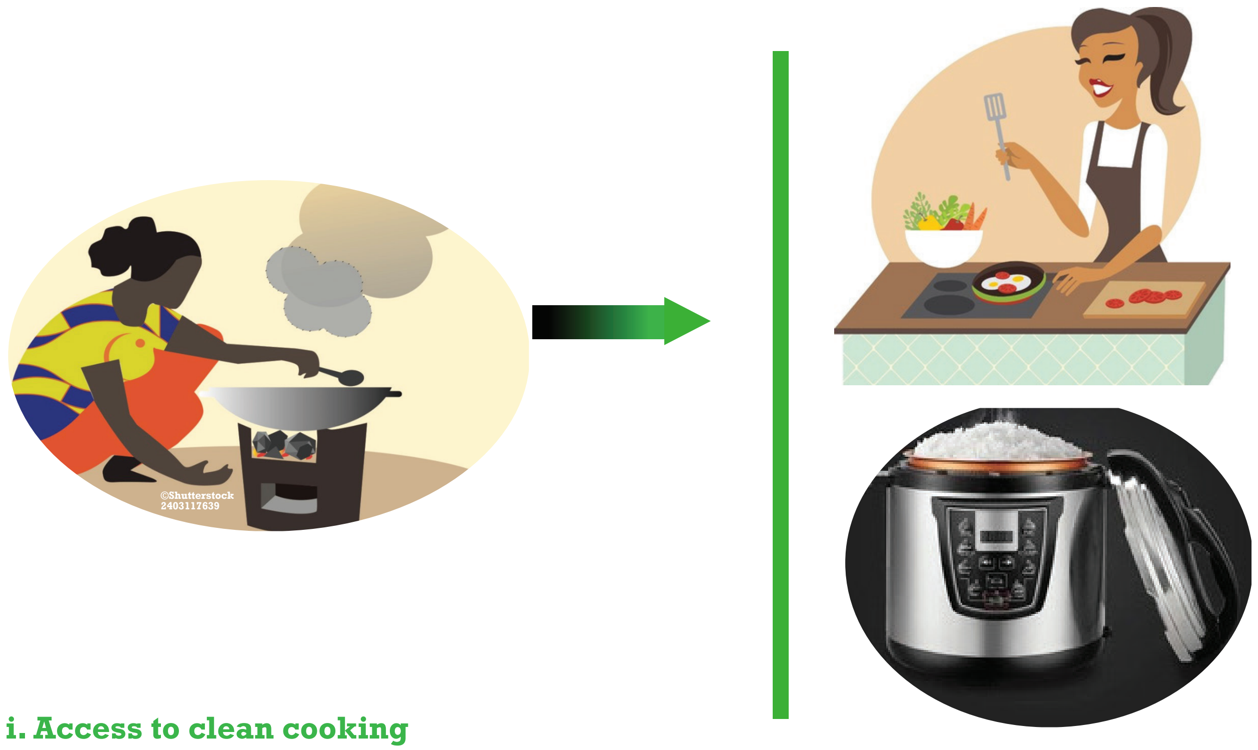
To achieve a fully renewable energy system in Uganda by 2050, the government plans to leverage the country's abundant hydro, solar, geothermal, biomass, and wind resources. Recognizing the importance of investing in renewable energy, the government intends to utilize available oil, gas, and nuclear resources to support the industry. The technical scenario predicts a lower levelized cost of electricity (LCOE) for full 100% renewable energy (RE) compared to the business as usual (BAU) scenario, with LCOE projections of 0.076 USD/kWh and 0.192 USD/kWh, respectively, in 2050. Continuous reductions in prices for renewable energy components, driven by manufacturing scale and research advancements, are anticipated. The transition requires an upfront investment ranging from 245 to 393 billion USD, contrasting with 132 billion USD in the BAU scenario. To address barriers associated with scattered settlements, the government should invest in both centralized and decentralized renewable energy systems, including mini-grids and solar home systems. Additionally, the government should ensure the availability of patient and affordable financing is crucial, with proposed mechanisms such as PayGo, blended finance, guarantees, and low-interest loans, especially in supporting the shift from diesel generators to solar systems by taking the following actions:

- Identify critical projects and sectors (such as the transport sector and e-mobility projects) along the path to the FullRE100 pathway, especially in the medium-term and long term, that are best suited for mutually beneficial PPPs (Private-Public-Partnerships) financing structures.
- Accelerate the creation of national guidelines for creating active and vibrant carbon markets to augment existing financing mechanisms for RE and EE projects along the FullRE100 pathway through carbon financing.
- Mandate Energy Efficiency as a core component in all RE projects to enhance the attractiveness and sustainability of financing for RE and EE projects along the FullRE100 pathway.
- Enhance collaboration with development funders in planning, financing and implementing large RE and EE projects along the FullRE100 pathway by tapping into climate financing channels, angel investors, and catalytic grants, to mention a few.
- Use the regional and continental power pool to increase the number of Power Purchase Agreements (PPA) and channel finances towards RE and EE projects along the FullRE100 pathway.
- Attract domestic financiers to fund RE and EE projects along the FullRE100 pathway, establishing de-risking mechanisms and reforms for RE and EE projects, which in turn reduces risks and provides guaranteed funding and risk-sharing instruments that attract private capital.

Reward innovative financing mechanisms with more significant subsidies, especially those that focus on accelerated deployment of RE and EE projects through scale, with minimal upfront investments such as bulk procurements, revolving funds, energy service contracting, and leasing models, to mention but a few.

4.2 Energy Demand Recommendations

4.2.1 Households



i. Access to clean cooking

The Uganda Energy Policy of 2023 highlights that less than 5% of the population has access to clean cooking, with unprocessed biomass fuel accounting for 90.5% of fuel use and contributing to 8.2% of infant deaths due to indoor air pollution. Thus, transitioning to energy-efficient cooking technologies such as biomass stoves, ethanol, LPG, solar, biogas, and electricity is crucial for reducing emissions and improving health. With a fullRE100 pathway, it is recommended to completely shift to electric stoves by 2050 to break the cycle of biomass dependence and the government should take the following actions:

- Accelerate the development of a national clean cooking strategy to work as a roadmap for transitioning to clean cooking with clear actions to be undertaken and clear targets set for clean fuels and technologies.
- Support the accelerated adoption of improved cooking technologies by incentivizing private-sector-led businesses to create numerous outlets that ensure easy access to these technologies at the points of consumption across the country.

- Reduce the barriers to access to carbon credits for businesses that invest in clean cooking technologies, thereby increasing private-sector-led investment.

- Set strict legal, financial, and regulatory instruments that discourage the use of unsustainable biomass in the cooking sector, thereby reducing the negative impact of deforestation due to the use of charcoal and firewood, especially in educational institutions, hospitals, and businesses.

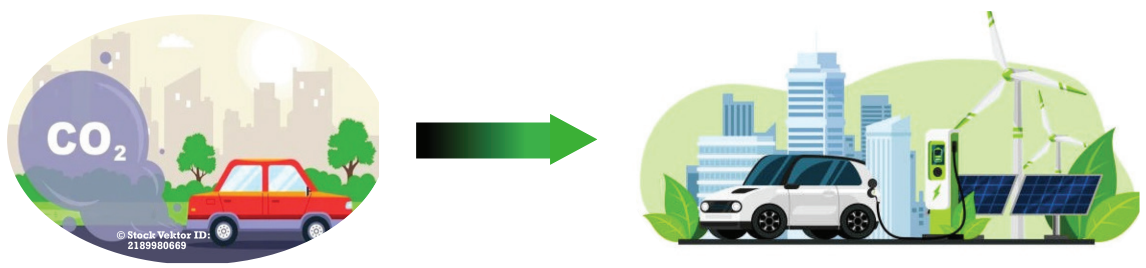
- Incentivize organizations that aim to engage in aggressive re-afforestation of the country's indigenous plant species to reverse deforestation's impacts on the environment.

- Encourage commercial and industrial energy consumers above a given energy consumption threshold to increase their share of RE and EE projects while reducing Biomass usage for commercial, industrial heating and cooling along the FullRE100 pathway, thereby reducing Biomass dependence.

ii. Accelerate Energy Conservation Bill to cater for energy efficiency in appliances

Major appliances such as lights, refrigerators, and air conditioners in Uganda lack enforcement of minimum energy performance standards (MEPS) due to the absence of appropriate regulations. However, the government can address this by accelerating the enactment of the Energy Efficiency and Conservation Bill. The Bill should mandate energy audits, promotes MEPS for appliances, and include market surveillance and energy efficiency labels to develop the nascent energy efficiency market and reduce reliance on fossil fuels. This will maximize the benefits from renewable energy along the FullRE100 pathway.

4.2.2 Transport



i. Develop and adopt biofuels and green hydrogen

There is great potential for biofuel and green hydrogen development and use in Uganda. Biofuels to be utilized include biodiesel and bioethanol. Biodiesel can be blended with diesel and used in vehicles. Bioethanol can as well be blended with petrol to be used in

petrol vehicles. Blended fuels can be used as a transition fuel in the transport sector till the sector is fully electrified by 2050.

Green hydrogen can be used as a combustion fuel in industries, and the transport sector. Green hydrogen has the potential to replace the use of heavy fuel oil and biomass for thermal applications in industries. It can also be used to replace diesel and petrol in the road transport sector and replace kerosene used in the aviation industry. It is therefore recommended for the government to take the following actions:

- Develop favorable policies for the development of biofuels in the short-term, and green hydrogen for the long term. The government should promote the growing of energy crops such as jatropha trees and sugarcane for biodiesel and bio-ethanol production respectively. The government can provide tax incentives to the private sector to invest in biodiesel and bioethanol production.

- Mandate a biofuels blending of up to 20% for all vehicles in the medium to long term.

- Establish incentives that encourage the citizenry's purchase of biofuel-enabled vehicles while gradually increasing carbon taxation for internal combustion engine (ICE) fossil-based vehicles to discourage their importation and purchase.

ii. Develop and promote electric mobility

Uganda's current electricity access rate, at 19% grid and 38% off-grid, poses a challenge to electric mobility. To address this, the government plans to increase electricity generation through hydropower, wind, solar, geothermal, cogeneration, oil, gas, and nuclear power. This expansion necessitates investments in electrifying the transport sector and promoting electric vehicles (EVs). The government, through Kira Motors Corporation, assembles electric cars and buses, and private companies are involved in electric motorcycles. Despite a limited charging infrastructure, the government aims to enhance it by increasing the number of charging stations for electric vehicles and motorcycles in Uganda. To enhance the electrification of the transport sector in the RE transition pathways, targeting 100% RE by 2050, the government should:

- Create an enabling environment for electric mobility so that the sector stakeholders such as government, development partners, private sector, among others can invest in electric mobility. The government should target to have the entire transport sector electrified by 2050 where the entire transport infrastructure is electrified, and all vehicles are electrified (cars, buses, motorcycles).

- Ensure that the electricity grid network is upgraded to handle the electrified transport sector. When the entire transport sector is electrified, this will exert a lot of pressure on the electricity grid.

- Establish incentives that encourage the citizenry's purchase of electric vehicles while gradually increasing carbon taxation for ICE fossil-based vehicles to discourage their importation and purchase.

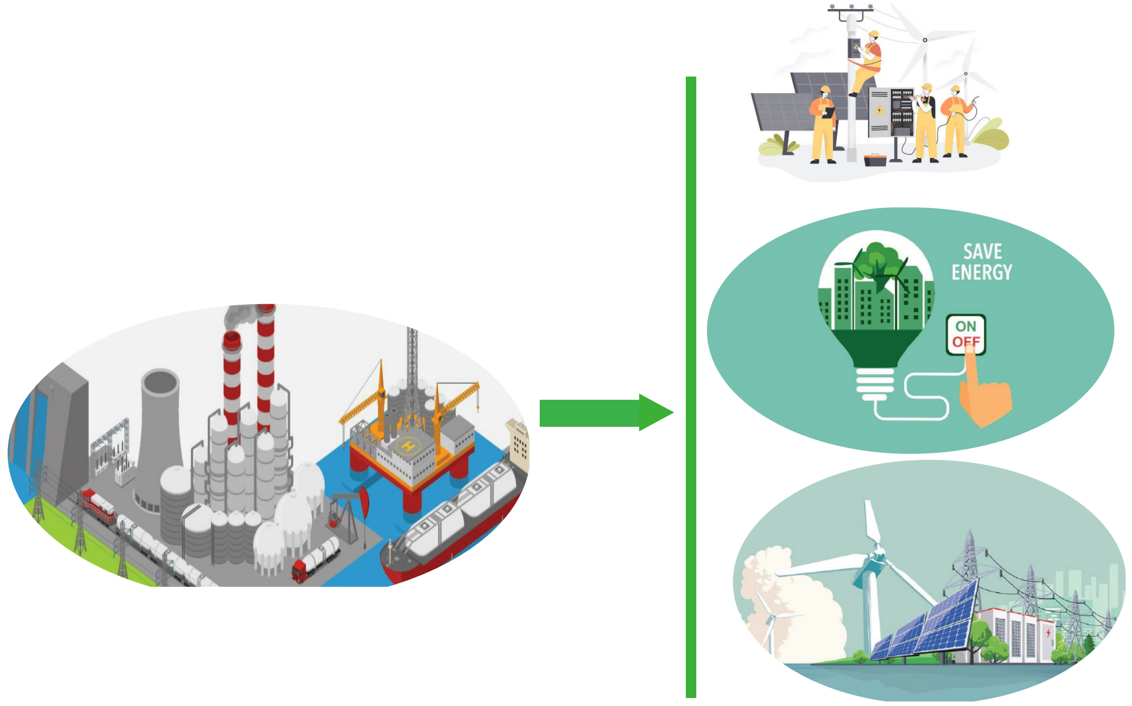
- Establish incentives such as government grants, rebates, and financial instruments that de-risk and enhance investment into electric charging infrastructure networks across the country to increase public acceptance and accelerate the adoption of electric mobility.

- Mandate all government ministries to ensure 100% electric mobility for all fleets for all personnel and channel government budgets and financing towards this goal. The Government should structure tighter and stricter regulatory instruments (say a rejection of the importation of ICE vehicles in the medium term) that control the importation of used vehicles, which are a boon for low-income earners in the country, thereby reducing the negative impacts of these vehicles on the FullRE100 pathway goals for sustainable mobility.

iii. Promotion of public transport, and railway infrastructure powered by renewable energy

Public transport in Uganda faces organization challenges, exacerbated by the lack of solar street lighting on many roads, hindering nighttime visibility. With the population growth and potential traffic congestion from private vehicles, the government needs to prioritize and promote efficient public transport infrastructure, including buses and trains. While Uganda still relies on old colonial-era railways, plans for a standard gauge railway connecting all regions are underway. To ensure sustainability, the government should prioritize electric-powered public transport vehicles and railways fueled by renewable energy sources.

4.2.3 Industry



i. Develop local manufacturing of renewable energy and energy efficiency technologies

Currently, Uganda does not manufacture renewable energy and energy efficiency technologies. The costs of renewable energy products continue to reduce annually and are expected to continue dropping in the future. However, if Uganda invested in the local manufacture of the RE and EE products, the costs could even get lower and there would be many local jobs created. Uganda has abundant minerals such as Copper, Cobalt, Lithium, Lead, Nickel, Manganese, Rare earths, Tin, Graphite and Iron ore (IEA 2023), which can be used for the manufacture of renewable energy and energy efficient technologies. There should be value addition on the available minerals for use in the manufacture of RE and EE products. The government should therefore create an enabling environment that attracts private sector (foreign and local investors) to invest in the manufacturing of RE and EE products.

ii. Promote energy efficiency in industries

Majority of industries (Large, small and medium industries) in Uganda do not deploy energy efficient technologies and systems. They do not implement the Energy Management System according to ISO 50001. Few industries in Uganda conduct energy audits and implement energy efficiency measures.

The energy efficiency sector in Uganda is not regulated by the government and energy efficiency interventions are implemented on a voluntary basis. This has affected the implementation of energy efficiency measures in industries in Uganda.

The government is developing the energy efficiency and conservation bill which will mandate designated industries to conduct energy audits, implement energy efficiency measures and adopt the Energy Management System according to ISO 50001.

The small and medium industries in Uganda are very energy inefficient because they tend to use secondhand equipment and also locally fabricated equipment where standard operating procedures have not been followed. Energy efficiency contributes to reduction of energy demand, and this reduces on the number and sizes of power plants to be developed.

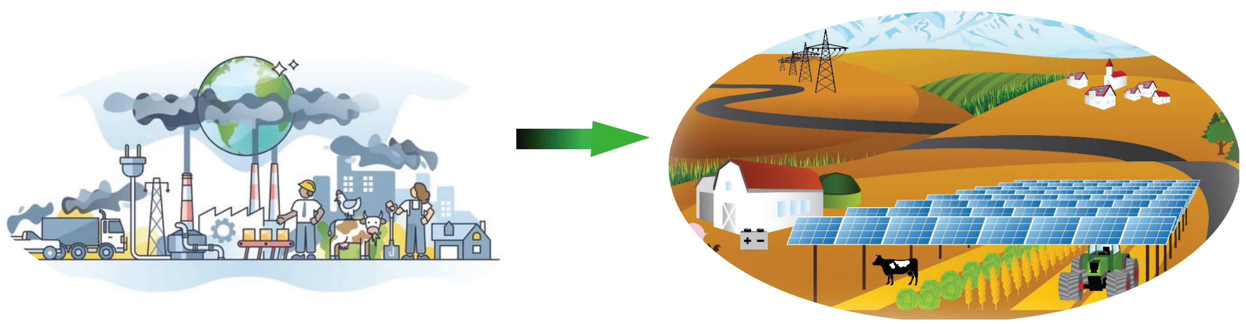
The government should therefore have an energy efficiency programme that focuses on transforming all industries to become energy efficient following international best practices and standards.

iii. Develop captive solar projects for industries

Industries have wide roof area which can carry solar panels for power generation. The industries can deploy grid tied solar systems and hybrid solar systems to satisfy part of the energy demand of the facilities.

The government should therefore create an enabling environment for the development of captive solar industry in Uganda. The government can establish policies of net metering where the energy consumers with solar PV systems can sell excess produced electricity to the national grid and import electricity from the grid if the solar generation is not enough.

4.2.4 Agriculture



In Uganda, the agricultural sector employs over 70% of the work force and has the significant potential to increase value addition across the country. Productive use of energy equipment in agriculture could increase individual monthly incomes by 30% (Open Capital Advisors, 2017). The following policy actions can be deployed in the agricultural sector;

i. Promote high quality and energy efficient solar water pumps for irrigation

Majority of farmers in Uganda are subsistence and depend on rainfed agriculture. The agricultural sector in Uganda is not well harnessed due to subsistence farming and use of rudimentary methods of farming.

Uganda is endowed with abundant fertile soils and tropical climate favorable for growing of crops and rearing of animals. Uganda should invest in modern methods of farming such as of use of solar powered irrigation.

The government should develop policies that favor deployment of high quality and energy efficient solar water pumps for irrigation.

ii. Promote solar powered cooling in the agri-food sector

Harvest and postharvest handling practices contribute to a loss of about 22% of the crop harvest. The cost associated with this loss is 17% of the output value (R. Ariong, et al, 2023). Perishable products get spoiled before reaching the market and this lowers incomes to the farmers.

The government should therefore develop policies that promote solar powered cooling technologies to increase the shelf life of perishable products. The solar powered cooling technologies to be promoted include solar refrigerators, cold rooms, and solar fridges.

iii. Promote solar drying

Some of the agricultural produce in Uganda such as coffee, maize, beans, etc require drying to increase their shelf life. Solar drying is an appropriate solution for drying agricultural produce. However, there is no wide application of solar drying in the country partly because there is limited application of the technology and is considered expensive. The government should create an enabling environment for the adoption of solar drying using technologies from locally available materials to ensure that operations and maintenance of the systems are manageable.

iv. Promote solar powered milling

Milling machines used in off-grid areas in Uganda include diesel powered generators and diesel engines which are expensive to operate due to the increasing prices of diesel. Solar powered milling is very applicable in areas which are off-grid and reduces greenhouse gas emissions to the atmosphere. Solar powered milling is clean and ensures good health of users.

The government of Uganda should develop policies and incentives that promote the development and adoption of solar powered mills. This will reduce dependence on fossil fuels which are harmful to the environment.

v. Promote adoption of alternative fuel for agricultural mechanization

Some of the farmers in Uganda use diesel powered tractors on their farms. The government of Uganda through the Ministry of Agriculture, Animal Industry and Fisheries plans to establish 10 regional agricultural mechanization centres across the country. The government should therefore promote biofuel crops such as jatropha, castor oil plants, etc.. and use blended fuels to power tractors and other machines that have been running on fossils.

The regional agricultural mechanization centres will act as centres of excellence to equip Ugandan farmers with modern agricultural mechanization skills and act as centres where farmers can have access to agricultural mechanization equipment which include tractors, planters, weeding machines, combine harvesters, among others.

4.3 Cross Cutting Recommendations

i. Deliberate cross-sectoral planning for renewable energy and energy efficiency

The FullRE100 pathway reveals several possible interventions in the agricultural sector, the transport sector, the commercial and industrial sectors, and the household sectors. It is essential for planning to be managed in an unsoiled manner, seeking interlinkages between sectors to enhance the success of the implementation of RE and EE projects along the FullRE100 pathway. Therefore, the government should take the following actions for effective implementation:

- Establish linkages between the agriculture and transport sectors, especially regarding biofuels, to increase the probability of success in achieving the goals for RE and EE projects along the FullRE100 pathway, especially in the long term.

- Establish linkages between the transport, commercial, and industrial sectors by mandating innovative charging technologies for electric vehicles augmented by incentives.

- Empower local authorities to get involved in integrated energy planning that incorporates several of the sectors mentioned in the modelling to allow for greater responsibility towards ensuring sustainable energy development across sectors and at a local level.

- Enhance the linkage between the oil and gas sector and households to enhance the sustainable production of affordable LPG resources needed for cooking in the short term and medium term as capacity increases to support a transition to full electric cooking.

- Accelerate the proposed development of an Integrated Energy Resource Master plan to enhance cross-sectoral consultation, coordination, and resource planning, which are critical to enhancing long-term gradual movement toward the success of the FullRE100 pathway due to greater clarity and certainty.

ii. Promote knowledge management in the renewable energy and energy efficiency sector

In implementing the previous six action steps towards the FullRE100 pathway, awareness is critical in ensuring that knowledge, technologies, projects, incentives and benefits reach the final consumers. The recommended actions for the government include:

- Increase investment in applied research for knowledge and technology development in RE and EE. This is essential in adapting RE and EE technologies to the Ugandan context and enhancing industry, Government, and academia linkages towards increased adoption of renewable energy and energy-efficient technologies. This also supports the development of a skilled human resource to deploy renewables at scale.

- Scale up behavioral change communication strategies on RE and EE, which will stimulate investment and increase demand for RE and EE technologies. Behavioral change communication strategies across different market segments must be developed and implemented. The need for local renewable energy and energy efficiency awareness exhibitions supported by radio, television, print and social media messaging is the core of reaching the last mile with a message to switch to renewable energy.

- Scale capacity building and skills development in RE and EE, which is critical for the FullRE100 transition pathway. These skills include energy resource assessors, system designers, manufacturers, installers, maintenance technicians, operators, financiers, energy auditors, measurement, verification and reporting professionals, and energy economists. Therefore, a significant investment must be deployed for skills development in RE and EE in Uganda to support the transition.

- Strengthen education on quality standards for RE and EE technologies through local renewable energy and energy efficiency awareness exhibitions supported by radio, television, print and social media messaging is the core of reaching to the last mile with a message to seek quality products that enhance RE adoption.

- Strengthen communication strategies that raise awareness about proper waste management, emphasizing eco-friendly disposal methods. Increased investment in research can drive innovation in recycling technologies, reducing the environmental impact of renewable energy waste.

- Strengthen multi stakeholder partnerships to ease knowledge sharing and institutional coordination of RE and EE developments.

- Prioritize the development of mechanisms and guidelines for the digitalization of data collection, analysis, storage and distribution of energy-related data, especially on aspects such as off-grid data access and energy efficiency, to mention but a few which is critical for transparent, and open knowledge sharing.

iii. Ensure monitoring and evaluation of renewable energy and energy efficiency programs, projects and activities

The success of the FullRE100 pathway is dependent on setting clear and measurable targets in the short-term, medium-term and long-term that provide quick evidence of the success of challenges in the implementation of the RE and EE projects. The government should therefore consider the following actions for the successful implementation of RE and EE programmes:

- Accelerate the approval and main streaming of the recommendations of the Energy Efficiency Roadmap developed by USAID and the Renewable Energy Roadmap developed by the World Wide Fund, which together complement the Energy Policy by providing quantifiable targets towards a low carbon climate resilient in line with Uganda's National Determined Contributions.

- Regularly review the established targets towards the FullRE100 pathway during the short-term, medium-term and long-term implementation cycles recommended in the model and uses these as opportunities to correct any shortfalls and measure successes.

- Monitor and evaluate climate change's impact on its hydro-resources to further support a transition to the FullRE100 pathway characterized by a diversity of supply, with Solar taking the lion's share.

- Establish a monitoring and evaluation department in the different sector ministries whose role is to ensure that targets are being achieved and report regularly on progress towards achievement of the same.

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