Ministry of Energy

Integrated Resource Plan for the Power Sector in Zambia

OCTOBER 2023

Summary Report

info@moe.gov.zm | +260 211 230840

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FOREWORD

The energy sector plays a central role in enabling the economic and human development of any country, and Zambia is no exception. The Government of the Republic of Zambia (GRZ) has set an ambitious agenda for economic diversification and industrialisation, with the objective of turning Zambia into a prosperous middle-income country with diversified income sources and universal access to electricity. The agenda envisions, among other changes, growth in copper production to 3 million tonnes of refined copper per annum, increased mining of several other minerals, a transformation of the agricultural sector to allow for mass production and export of wheat, maize and soya, the electrification of inter-city and urban rail transport, and the establishment of industrial zones for the beneficiation and processing of minerals from Zambia and the region. With equal priority, the agenda sees the extension of electricity access to all Provinces of Zambia, with a target of attaining universal access by 2030 through a combination of on-grid and off-grid technologies.

Against this background and acknowledging that a significant increase in electricity generation capacity and enhanced infrastructure are needed to power Zambia's development agenda, the Ministry of Energy has produced the first ever Integrated Resource Plan (IRP) for Zambia's electricity sector. The IRP caters to the Government's vision of ensuring energy sufficiency and surplus as the economy grows, attaining universal access to electricity by 2030, and positioning Zambia as a regional electricity trading hub.

Zambia's energy sector gains through the IRP a roadmap for the development of the sector and clarity over the levels of investment required across all segments of the power delivery value chain to deliver on the Government's agenda. At the core of the IRP is an analysis of existing and future electricity demand by Zambian province and an assessment of the generation and network development needed to satisfy the projected demand for electricity at the least cost. Recognising that grid extension is not always the least cost mode of electrification, the IRP proposes an extensive deployment of mini-grids, solar home systems and localised energy solutions in areas where these are able to provide the required level of service at a lower cost.

The IRP takes into account issues relating to climate change, environmental protection, gender and social inclusion, not only in the proposed location of projects, but also through the recommended process of developing, constructing and operating projects. To this effect, the IRP has proposed a Social Safeguards Framework that addresses the social risks as well as the economic and employment opportunities associated with new power projects. The Framework provides a blueprint that is sensitive to Zambian social and cultural factors and reflective of learning points from projects undertaken in previous years.

The process of preparing the IRP was highly consultative, engaging over 120 local experts in energy-related fields and enabling many stakeholders to contribute by providing information, expert staff and resources at the technical and governance levels. The entities that were part of the consultative process are listed in the Acknowledgements section following this foreword.

The Zambian electricity sector will greatly benefit from this IRP. This least cost roadmap to the development of the sector provides the basis for provincial planning across Zambia and offers clear direction for stakeholders and investors to create the conditions for sustainable development and social equity in Zambia over future decades. The Ministry of Energy will work with other stakeholders in a multi-sectoral approach to implement the IRP over the coming years and decades. The energy models that have been developed through the IRP will be maintained and updated so that the IRP can be revised in the future and evolve to adequately inform Government planning, policy and financing.

Hon. Peter Chibwe Kapala
Minister of Energy

ACKNOWLEDGEMENTS

The development of Zambia's first Integrated Resource Plan (IRP) has been a complex process involving a wide range of experts in power systems, renewable energy, natural resources, economics, financing, climate, environment, public policy, gender and youth to name but a few. The technical workstreams required the input of more than 120 experts in these fields over a period of 30 months. Some of these experts were seconded to the IRP on a full-time basis, but most provided assistance on a part-time basis on secondment from their employer.

Members of the project's Technical Committee and Steering Committee provided oversight of quality control and peer review of key findings and recommendations.

Appreciation is extended to all stakeholders who contributed to the development of the IRP. The following lists the key institutions that contributed to the development of the IRP through their seconded representatives separated into Government, Non-government and regionally represented institutions[1]:

<u>Government:</u>

Energy Regulation Board
Industrial Development Corporation
Ministry of Agriculture
Ministry of Finance and National Planning
Ministry of Green Economy and Environment
Ministry of Mines and Mineral Development
Ministry of Transport and Logistics
Office for Promoting Private Power Investment
Rural Electrification Authority
The University of Zambia
Zambia Environmental Management Agency
ZESCO Limited

<u>Non-Government and Regional:</u>

Africa GreenCo
Chamber of Mines
Copperbelt Energy Corporation
Engineering Institution of Zambia
The World Bank Group
Zambezi River Authority (Regional)
Zambia Institute for Policy Analysis and Research

The development and publication of the IRP would not have been possible without financial and technical support of the UK's Foreign, Commonwealth and Development Office (FCDO) and the World Wide Fund for Nature-Zambia Country office (WWF-ZCO), through the technical assistance provided by the Cities and Infrastructure for Growth Zambia (CIGZambia) programme whom we sincerely thank for their continued support to the Ministry of Energy and the Zambian Government.

The IRP Summary Report compiles the essential findings from six core reports: Demand, Generation, Transmission, Distribution, Gender, Equity, and Social Inclusion, and Climate. These core reports

[1] In alphabetical order.

underwent development between 2019 and 2023. Should readers seek to access and reference the core reports, they are available on the IRP website[2].

The outcomes of the IRP are derived from the technical and financial modelling assumptions that underpin it. The goal is to preserve and enhance the models established through developing the IRP to facilitate regular updates of the plan by the Ministry of Energy. This approach ensures the continued capability to model various planning scenarios, considering emerging technologies, government policy directives, and evolving economic, social, demographic and environmental variables that may change over time.

Mr. Peter Mumba
Permanent Secretary – Technical
Ministry of Energy

Dr. Chisangano Francesca Zyambo
Permanent Secretary – Administration
Ministry of Energy

[2] GRZ, Integrated Resource Plan, Resource Library, www.moe.gov.zm/irp/?page_id=228

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List of Acronyms

AC	Alternating current
CEC	Copperbelt Energy Corporation
C&I	Commercial and industrial
DFI	Development finance institution
DRC	Democratic Republic of the Congo
DSM	Demand side management
EAPP	Eastern African Power Pool
ERB	Energy Regulation Board
ESMAP	Energy Sector Management Assistance Program (World Bank)
EV	Electric vehicles
FCDO	Foreign, Commonwealth and Development Office
GRZ	Government of the Republic of Zambia
GW	Gigawatt
GWh	Gigawatt hour
IPP	Independent power producer
IRP	Integrated resource plan
km	Kilometre
kV	Kilo volt
kWh	Kilowatt hour
LCGEP	Least Cost Geospatial Electrification Plan
LPG	Liquefied petroleum gas
MDB	Multinational development bank
MoE	Ministry of Energy
MW	Megawatt
MWh	Megawatt hour
NDC	Nationally Determined Contributions
OPPPI	Office for Promoting Private Power Investment
PV	Photovoltaic
REA	Rural Electrification Authority
REMP	Rural Electrification Master Plan
SAPP	Southern African Power Pool
SHS	Solar home system
VRES	Variable renewable energy sources
WWF	World Wide Fund for Nature
ZESCO	State-owned power company in Zambia

1 Executive Summary

1.1 Context

The objective of Zambia's Integrated Resource Plan (IRP) is to provide a comprehensive, forward-looking least cost plan for the development of the country's power sector, including both on-grid and off-grid. The plan is forward looking to 2050, but with a greater emphasis on the period to 2030.

The IRP project commenced in the first quarter of 2021. Sophisticated energy modelling software was used for different segments of the IRP including demand analysis, generation modelling, transmission and distribution modelling and rural electrification modelling which will be maintained through an Energy Planning Centre through which energy planning models will be curated and updated. The process of developing the IRP has been coordinated by the Ministry of Energy (MoE) and to gain perspectives from a broad range of consumers and experts involved around 120 experts from Zambia including the Government of the Republic of Zambia (GRZ) (ZESCO, Energy Regulation Board (ERB), Rural Electrification Authority (REA), Ministries of Mines, Finance, Green Economy and the Environment, Agriculture among others), private sector (including Copperbelt Energy Corporation (CEC) and Africa GreenCo), World Wide Fund for Nature (WWF), the financial community, civil society and academia. The development of the IRP was supported by the Cities and Infrastructure for Growth in Zambia (CIGZambia) programme, which is funded by the UK Government's Foreign, Commonwealth and Development Office (FCDO) and provided access to a number of international energy experts and facilitated capacity building, where required.

The main recommendations were initially presented to the IRP Steering Committee in July 2022, and incorporated plans to increase production of refined copper to 3 million metric tonnes per annum by 2040 and facilitate access to electricity for all of Zambia's population by 2030. The assumptions were revised in the first half of 2023 to reflect GRZ's transformative growth plans for the economy in agriculture, transport and electric vehicle battery manufacturing. The final IRP recommendations have now been fully aligned to the growth plans of the different GRZ ministries.

Zambia currently has installed generation capacity of 3,705 MW, which includes the 750 MW Kafue Gorge Lower Hydro Plant recently commissioned by ZESCO and the 34 MW Riverside Solar Plant recently commissioned by CEC. However, the power shortages experienced in the final quarter of 2022 and first quarter of 2023 provided a clear indication that there is insufficient generation to meet demand, partially attributable to insufficient availability of water to operate Zambia's large hydro schemes to the maximum design capacity. The energy modelling process undertaken through the IRP has determined the quantum of additional grid connected generation capacity required to meet the electricity demand of the economy across all sectors to 2050, as well as an increase in the export of energy to take advantage of Zambia's pivotal position within the Southern African Power Pool (SAPP) and the designated point of connection to the Eastern Africa Power Pool. In addition to recommending an increase in generation capacity, the IRP recommends a diversification of both power generation technologies and locations. Zambia currently relies heavily on hydropower, constituting 85% of its installed capacity, most of which is generated from the Zambezi catchment area. The proposed development of a more diversified mix of generation sources exploiting the hydro resource in the north of Zambia, which is anticipated to be less susceptible to climate change over future decades, will enhance resilience of Zambia's energy supply. The IRP recommends the development of new generation resources in all 10 provinces of Zambia, with associated investment in transmission capacity, taking account of available resources in each Province and the anticipated climate trends.

1.2 Sectoral Breakdown of On-Grid Demand Growth

Assumptions on demand in various sectors and across different provinces of Zambia provide the input for energy modelling. The key assumptions are summarised below based on a baseline year of 2020.

Figure 1.1: Peak Demand by Sector for Electricity 2020 – 2050 (MW)

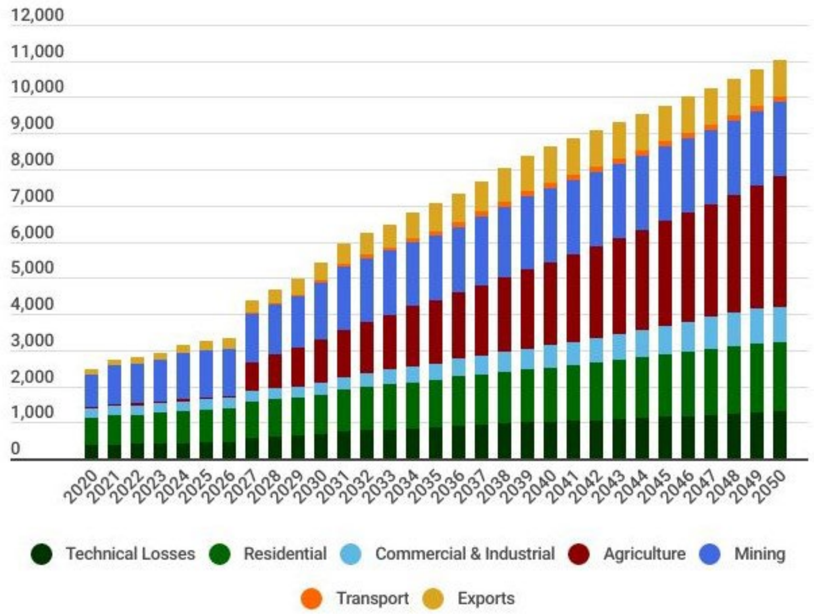


Table 1.1: Peak Demand for Electricity 2020 – 2050 (MW)

Demand Indicators (MW)	2020	2026	2030	2040	2050
Peak Demand	2,318	3,038	4,922	7,624	10,031
Peak Power Exported	138	300	500	1,000	1,000
Total Peak Demand	**2,456**	**3,338**	**5,422**	**8,624**	**11,031**

Table 1.2: Variances in Demand by Sector 2020 – 2050 (MW)

Maximum Demand (MW) by Sector	2020	2030	2050	% increase by 2030	% increase by 2050	Factors Driving Demand Increase
Mining	886	1,552	2,052	75%	132%	• Copper production increased to 3 million tonnes per annum by 2040 • Increased mining of other minerals (manganese, tin, gold, lithium etc.)
Residential	769	1,079	1,923	40%	150%	• New connections increase from 60,000 per annum to 120,000 per annum
Commercial and Industrial	257	337	984	31%	283%	• Industrialisation of economy • Electric vehicle battery manufacturing facility in Ndola
Agriculture	48	1,200	3,625	2,400%	7,500%	• 85-fold increase in wheat production to 15 million tonnes per annum • Increased maize production to 6 million tonnes per annum • Increased soya production to

						3 million tonnes per annum • Significant irrigation and agro-processing to support the above
Transport[3]	0	67	153	-	-	• Inter-city and urban electric rail networks
Exports	138	500	1,000	262%	625%	• Key export markets include DRC and Namibia
Technical Losses	358	687	1,294	92%	261%	• Losses are mainly a function of network size and topology
Total Demand Including Losses	**2,456**	**5,422**	**11,031**	**121%**	**349%**	

The above tables reflect an increased diversification of the economy. While there is significant growth in all sectors, the relative rate of growth in the agriculture, commercial and industrial and export sectors is significantly higher than the rate of growth in mining.

1.3 On-Grid Generation Required to Meet Demand

The energy modelling systems used in the development of the IRP, namely Antares for generation modelling, and DIgSILENT for transmission and distribution modelling, are used to recommend solutions that represent the lowest overall cost to consumers taking into account both capital investment and operating costs, that will ultimately need to be recovered through tariffs. The planning for generation has considered available resources and their location within the country, and has dimensioned the required reserves to ensure energy sufficiency, taking account of plant availability and risk factors. The financial information was sourced from ZESCO for existing plants connected to the grid. The planning software used standard international benchmarks for the cost of future plants yet to be constructed and commissioned to avoid bias between projects in the development pipeline. The overall objective of the energy planning process is to recommend the appropriate capacity and mix of generation plants to be connected to Zambia’s grid over the plan period, and to recommend the location of such plants (within a reasonable tolerance). These recommendations can then be used to guide generation procurement decisions, so that generation procurement is aligned to the least cost generation plan, which is important so as to keep tariffs as low as possible and to minimise the future financial burden on consumers and Government.

The system considered the generation sources listed below but did not consider gas, as no indigenous resources have been discovered and developed and no gas pipeline has yet been constructed into Zambia connected to a developed gas resource. Emerging and early-stage technologies such as generation from hydrogen were not considered but may be considered in future iterations of the IRP to the extent that such technologies are further developed and proven internationally.

[3] The transport sector in the IRP is currently focused on electricity needs for planned rail and tram electrification projects. Electric vehicles (EVs) are not yet explicitly included in this segment but may be in the future. This is likely to change in future iterations of the IRP.

Table 1.3: Generation Sources Considered in Antares Generation Model

The Antares system considered the following technologies as possible generation sources:	
Non-Variable Sources[4]	Hydro, Geo-thermal, Bio-mass, Nuclear, Concentrated Solar Power
Non-Variable Carbon Emitting Sources	Coal, Heavy Fuel Oil, Petroleum/Diesel
Variable Renewable Energy Sources (VRES)	Solar, Wind

The results of the modelling presented in Table 1.4 below are based on the reference years of 2026, 2030, 2040 and 2050 with a baseline generation capacity established in June 2023.

Table 1.4: Generation Results from Antares Generation Model for 2026, 2030, 2040 and 2050

Technology	Installed Capacity June 2023	Capacity Addition (MW)				Total Cumulative Installed Capacities (MW)			
		2023 - 2026	2027 - 2030	2031 - 2040	2041 - 2050	2026	2030	2040	2050
Hydro	3,147	650	1,555	1,480	1,420	3,797	5,352	6,832	8,252
Thermal – Steam (Coal/other fuels)	435	-	600	600	600	435	1,035	1,635	2,235
Geothermal	-	-	30	480	480	-	30	510	990
Renewable – Biomass	-	51	270	300	600	51	321	621	1,221
Renewable – Solar PV	123	1,555	405	1,373	1,440	1,678	2,083	3,456	4,896
Renewable – Wind	-	400	792	2,272	2,135	400	1,192	3,464	5,599
Total Generation	**3,705**	**2,656**	**3,652**	**6,505**	**6,675**	**6,361**	**10,013**	**16,518**	**23,193**
Percentage VRES	3%	74%	33%	56%	54%	33%	33%	42%	45%
Percentage Carbon Emitting	12%	0%	16%	9%	9%	7%	10%	10%	10%

Grid-connected generation capacity required to meet demand will grow by 165% from 3,705 MW in June 2023 to 10,013 MW by 2030 and by a further 132% to 23,193 MW by 2050.

Hydro remains the dominant source of generation through the plan period comprising 85%, 53% and 36% of total installed capacity in 2023, 2030 and 2050 respectively. The IRP recommends that the future priority for hydro development should be to develop projects in the North-Eastern area of the country which forms part of the Congo River catchment area, which is anticipated to have more stable hydrology over future decades than the Zambezi catchment area.

Table 1.4 above demonstrates the extent to which the Zambian grid is able to absorb variable renewable energy sources (VRES) through the plan period. VRES generally provide energy which is cheaper than other sources. However, there is a limit to the capacity of VRES that can be connected to the grid without causing grid instability. This is because energy dispatch from VRES is inherently difficult to predict, and, moreover, VRES do not have as many advantages as non-variable generation sources in ensuring stability of frequency and voltage as grid load conditions vary.

VRES provide 3%, 33% and 45% of grid capacity in the years 2023, 2030 and 2050 respectively. However, the contribution to energy from VRES in the same years is significantly lower as the capacity factor (CF) of VRES is generally much lower than the CF of non-variable generation sources.

[4] The term 'non-variable source' is used to describe power generation sources that can be dispatched based on the level of demand on the system at any time, in accordance with the operating regime of the particular technology type. Variable renewable energy sources (VRES) on the other hand are non-dispatchable as the level of production is considered unpredictable due to inherent variability in wind and solar yields based on daily weather patterns.

Overall, the IRP generation plan proposes a significant diversification in sources and location of generation sources, while also considering the resources available within Zambia.

The Zambian generation system is considered to have low carbon emissions in comparison to most power systems worldwide. The percentage of electricity that is generated from carbon emitting sources is currently 12% (June 2023), reducing to 10% in 2030 and remaining at 10% in 2050 based on the modelling results summarised in Table 1.4. Recognising that Zambia has made commitments to reduce emissions by at least 25% in absolute terms through its Nationally Determined Contributions (NDCs) submitted to UN Framework Convention on Climate Change (UNFCCC). This creates an opportunity to explore alternatives to avoid some of these emissions through clean energy alternatives in future provided that concessional external funding sources are identified.

1.4 Transmission

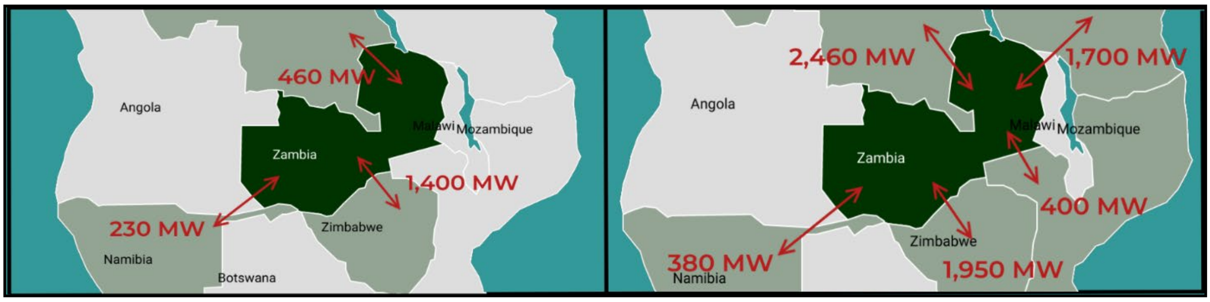
The IRP transmission plan envisages an increase of 82% in the length of transmission lines from 12,705 km in 2023 to 23,072 km by 2050, as summarised in Table 1.5 below.

Table 1.5: Length of New Transmission Lines Required by Voltage Level to 2050

Transmission Line Additions	June 2023	Addition Line Lengths (km)				Cumulative Line Lengths (km)			
		2026	2030	2040	2050	2026	2030	2040	2050
330 kV Transmission Line	5,112	2,722	1,392	1,618	1,713	7,834	9,226	10,844	12,557
220 kV Transmission Line	893	151	11	651	39	1,044	1,055	1,706	1,745
<220 kV and 66 kV Transmission Line	6,700	892	40	584	554	7,592	7,632	8,216	8,770
Total Transmission Line Length	**12,705**	**3,765**	**1,443**	**2,853**	**2,306**	**16,470**	**17,913**	**20,766**	**23,072**

Map 1.1 refers to interconnector developments that are guided by the regional planning process undertaken by the SAPP. The left-hand map below highlights interconnector capacity as of June 2023 with neighbouring countries, and the right-hand map shows the cumulative interconnector capacity that is planned to be created by 2050 through investment in the transmission network, which indicates how Zambia will become a power trading hub for the region.

Map 1.1: Interconnector Development of the Zambian Transmission System (2023 – 2050)



1.5 Distribution

The distribution planning under the IRP focused on the 33 kV network and substations, through which power is distributed to most consumer groups except large energy consumers such as mines who generally receive power directly from the transmission network.

The network expansion projects for the 33 kV distribution network are captured in Table 1.6 below, which summarises the overall increase in network length and distribution substation additions required to support grid densification and grid expansion projects planned during the IRP implementation period.

Table 1.6: Highlights of 33 kV Distribution Investments to 2050

Investment in Zambia's 33kV Network Required by 2050	
Capacitor Banks	
Number of capacitor banks	14
Total MVAr of capacitor banks	80
Overhead Lines	
km of 33kV overhead line required	11,312
11kV Panels	
Number of 11kV panels	441
Grid Transformers	
Number of grid transformers	134
Total MVA of grid transformers	2,595
Distribution Transformers	
Number of distribution transformers	8,504
Total MVA of distribution transformers	788

Note: MVA: megavolt amperes; MVAr: megavolt amperes reactive

The demand forecast and distribution plan have taken into account consumer trends, policy developments and technology innovations that may impact future customer demand and distribution network design as summarised in Table 1.7 below.

Table 1.7: Consumer Trends, Policy Developments and Technology Innovations Considered

Trends	Mode of Consideration in IRP
Energy Efficiency	Increasing deployment of energy efficient plant, equipment and devices has been assumed based on the Energy Efficiency Strategy and Action Plan (EESAP)[5].
Demand Side Management (DSM)	No direct impact on IRP recommendations. However, interruptible contracts and schemes to reduce non-essential loads in times of power shortage will be considered to the extent that power demand exceeds power supply at certain times. Furthermore, DSM may be considered as a mechanism to defer network investments where capacity constraints have developed until funds are available to complete the required network enhancements.
Clean Cooking	Use of electric appliances including efficient electric cook stoves to replace some use of charcoal with electricity for cooking at household level has been assumed. Electric cooking provides one alternative to charcoal for domestic cooking alongside clean cooking fuels and liquefied petroleum gas (LPG).
Electric Vehicles (EVs)	Government policy supports deployment of EVs. Gradual uptake is expected in the first few years with greater impact in the 10 – 30 year horizon of the IRP. Network enhancements to accommodate

[5] GRZ, 2022, Energy Efficiency Strategy and Action Plan. www.moe.gov.zm/wp-content/uploads/2022/08/Zambia-Energy-Efficiency-Strategy-and-Action-Plan-2022.pdf

	widespread charging of EVs will be considered in future iterations of the IRP.
Embedded Storage	Significant storage already exists in storage dams at Kariba, Kafue Gorge and Itezhi Tezhi at national level. Embedded grid storage is recommended to be considered in future for parts of the network that are constrained, and to provide an alternative to costly grid reinforcement projects.
Green Hydrogen	An emerging technology, no current impacts to IRP but may be considered in future iterations when technology matures and is better understood in the context of a least cost grid design.

1.6 Electricity Access

GRZ's Vision 2030 was first adopted in 2006 and envisaged that Zambia would attain 51% access to electricity by 2030[6]. In 2015, universal standards were adopted through the UN Sustainable Development Goals (SDGs). SDG7 seeks to provide "affordable, reliable, sustainable and modern energy for all"[7] by 2030. All UN member states adopted SDGs and multilateral development banks have designated funding towards developing countries attaining SDG7 and the other SDGs.

Zambia's Least Cost Geospatial Electrification Plan (LCGEP), which was funded by the World Bank, was prepared by an international consulting firm on behalf of the MoE in 2022. The objective of the plan was to establish the least cost mode of universal electrification for Zambia by 2030 using geo-spatial technology using available inputs, including the location of existing grid networks and costing algorithms which calculate the least cost mode of electrification for each locality and household in Zambia.

The plan considered three potential modes of electrification based on the principles of least cost connection per household and the service level required, namely through:

- grid access through densification or extension, or
- mini-grids (localised grids and generation sources typically located at rural growth centres, usually using solar with batteries as a generation source), or
- solar home systems (SHS) designed to provide service at household level.

The plan distinguishes the service level available from these systems based on proximity to the grid and level of demand, linked to ability to pay, in each area of the country.

Based on the above assumptions, the projected electrification of Zambia's population through the three modes of electrification is summarised in Table 1.8 below, with projected increases across the planned period.

Table 1.8: Projections Electricity Access through Grid Access, Mini-Grids and Solar Home Systems

Trends in Electricity Access over Plan Period	2020	2023	2026	2030	2040	2050
% of Population with Access	44.5%	51%	78%	100%	100%	100%
% of Population with Grid Access	31%	34%	38%	44%	44%	43%
% of Population with Off-Grid Access	13%	17%	40%	56%	56%	57%

[6] GRZ, 2006, GRZ National Long Term Vision 2030. www.moe.gov.zm/irp/?wpdmpro=grz-national-long-term-vision-2030
[7] UN, 2020, Affordable and Clean Energy: Why it Matters. www.un.org/sustainabledevelopment/wp-content/uploads/2016/08/7_Why-It-Matters-2020.pdf

Number of People with Grid Access (Tier 4 and 5) (Million)	5.9	6.8	8.4	10.8	14.1	18.5
Number of People with Mini Grid Access (Tier 3 and 4) (Million)	0.1	0.1	1.5	4.8	6.4	8.4
Number of People with SHS Access (Tier 1 and 2) (Million)	2.4	3.3	7.3	8.9	11.8	15.6
Number of People with No Access (Million)	10.5	9.9	4.7	-	-	-
Total (Million)	**18.93**	**20.15**	**21.89**	**24.45**	**32.22**	**42.47**

1.7 Total IRP Investment Requirement

Table 1.9 below summarises the total power sector investment required in all aspects of the IRP using standard capital costs by technology type from international and local data sources. In the case of access, the cost estimates are based on the cost per connection used in the LCGEP. Figures represent standard estimates of capital costs under a competitive procurement environment and exclude project development costs (e.g. feasibility studies), financing costs, and costs of environmental remediation which would need to be considered on a project-specific basis.

Table 1.9: Summary of Electricity Sector Investment Required Defined in IRP

IRP Investment Summary	Incremental Investments ($millions)				Cummulative Investments ($millions)			
Year	2023 to 2026	2027 to 2030	2031 to 2040	2041 to 2050	2026	2030	2040	(Total) 2050
Generation ($m)	2,943	4,281	7,801	7,805	2,943	7,224	15,026	**22,830**
Transmission ($m) including 66kV	953	457	745	231	953	1,410	2,156	**2,386**
Investment in Distribution - 33kv Network ($m)	247	259	364	107	247	506	870	**976**
Investment in On-Grid Access ($m)	143	166	235	309	143	308	544	**853**
Investment in Off-Grid Access ($m)	698	1,488	749	991	698	2,185	2,935	**3,926**
Total IRP Planned Investment ($m)	**4,983**	**6,650**	**9,895**	**9,442**	**4,983**	**11,634**	**21,529**	**30,971**
Generation %	59%	64%	79%	83%	59%	62%	70%	74%
Transmission %	19%	7%	8%	2%	19%	12%	10%	8%
Distribution %	5%	4%	4%	1%	5%	4%	4%	3%
On Grid Access %	3%	2%	2%	3%	3%	3%	3%	3%
Off Grid Access %	14%	22%	8%	10%	14%	19%	14%	13%
Total IRP Planned Investment ($m)	100%	100%	100%	100%	100%	100%	100%	100%

It is notable that on-grid generation is the largest cost component of the IRP, comprising 62% of the capital investment of $11.6 billion required by 2030, and 74% of the capital investment of $31.0 billion required by 2050.

The cost of off-grid energy access is the second-largest cost component, comprising 19% of the overall required capital investment by 2030 and 13% by 2050.

1.8 Procurement Recommendations

Generation procurement recommendation

The current IRP generation recommendations mainly point to a combination of hydro, solar, wind, coal and geothermal as being the optimal solution for Zambia. Many projects in Zambia across all technologies have completed feasibility studies, and some have also completed procurement defined as establishing a mutually agreed power purchase agreement between buyer and seller in accordance with local legislation and best practice. Taking account of the development timescales of various generation project technologies, and the quantum of new generation required according to the generation modelling, the IRP recommends the procurement actions as summarised in Table 1.10 below.

Table 1.10: Immediate Generation Procurement Recommendations Based on IRP Modelling

Technology	Recommended Procurement	Rationale
Hydro (run of river)	2,205 MW	Represents recommended capacity by 2030, due to long development timescales.
Solar	1,555 MW	Represents recommended capacity by 2026 due to shorter timescales for financing and construction.
Wind	400 MW	Represents recommended capacity by 2026 due to shorter timescales for financing and construction.
Coal	600 MW	Represents recommended capacity by 2030, but if completed earlier will compensate for potential delays in other projects. Coal generation is a base load/non-variable source and (like hydro and geothermal) makes a greater contribution to system stability than VRES.
Geothermal	30 MW	Represents recommended capacity by 2030, due to long development timescales.

The IRP is agnostic as to the commercial model for development of these generation projects. The Electricity Act of 2019 allows for private sector participation in project ownership (independent power producers (IPPs)) and for private sector off-take arrangements, with power wheeling/transmission services provided by the licensed transmission and distribution network operators.

For transmission, distribution and off-grid investments, it is recommended that procurement processes are initiated immediately for all IRP projects that are envisaged to be completed by 2030.

1.9 Conclusion

The IRP outlines a comprehensive and strategic approach to address Zambia’s energy challenges and ensure sustainable development in the power sector. The plan's focus on diverse energy sources, grid expansion, electrification and integration of emerging technologies underscores Zambia’s commitment to providing reliable, affordable and environmentally responsible energy for the country. By embracing a mix of hydro, solar, wind, coal and geothermal energy, Zambia aims to achieve a balanced and resilient energy portfolio that not only meets growing demand but also aligns with global sustainable development goals.

2 INTRODUCTION

Zambia's Integrated Resource Plan (IRP) constitutes a comprehensive, long-term strategy for the nation's power sector, aiming to address challenges and establish a reliable and cost-effective electricity framework. Designed with a forward-looking vision until 2050, with a focal point on the period leading up to 2030, the IRP is driven by a collective effort involving diverse stakeholders, including government bodies, private sector entities and civil society representatives[8]. The IRP addresses Zambia's full electricity landscape, covering power demand, generation, transmission, distribution and off-grid access, thereby developing a roadmap for a robust, resilient and sustainable energy future that aligns with Zambia's developmental aspirations.

While focusing mostly on the on-grid sector, the IRP incorporates recommendations for off-grid solutions where appropriate, highlighting the least cost approach[9] for inclusive energy access based on modelling work undertaken for the Least Cost Geospatial Electrification Plan (LCGEP). This approach embraces grid expansion, mini-grids, and solar home systems (SHS), allowing the IRP to harmoniously support the Rural Electrification Authority's (REA) initiatives for universal energy access by 2030.

While the IRP is a blueprint for a 30-year energy transformation, with particular attention on the near-term from 2026 to 2030, it echoes the nation's commitment to sustainable energy by replacing the Power System Development Master Plan published in 2010. The publication of this report is a significant step that positions Zambia in line with regional and global trends, joining fellow Southern African Development Community (SADC) nations and African peers that have embraced integrated energy planning to secure their energy future. Through a collaborative effort and informed decisions, Zambia paves the way for a resilient and prosperous energy landscape that drives economic growth, enhances social welfare, and safeguards the environment for generations to come.

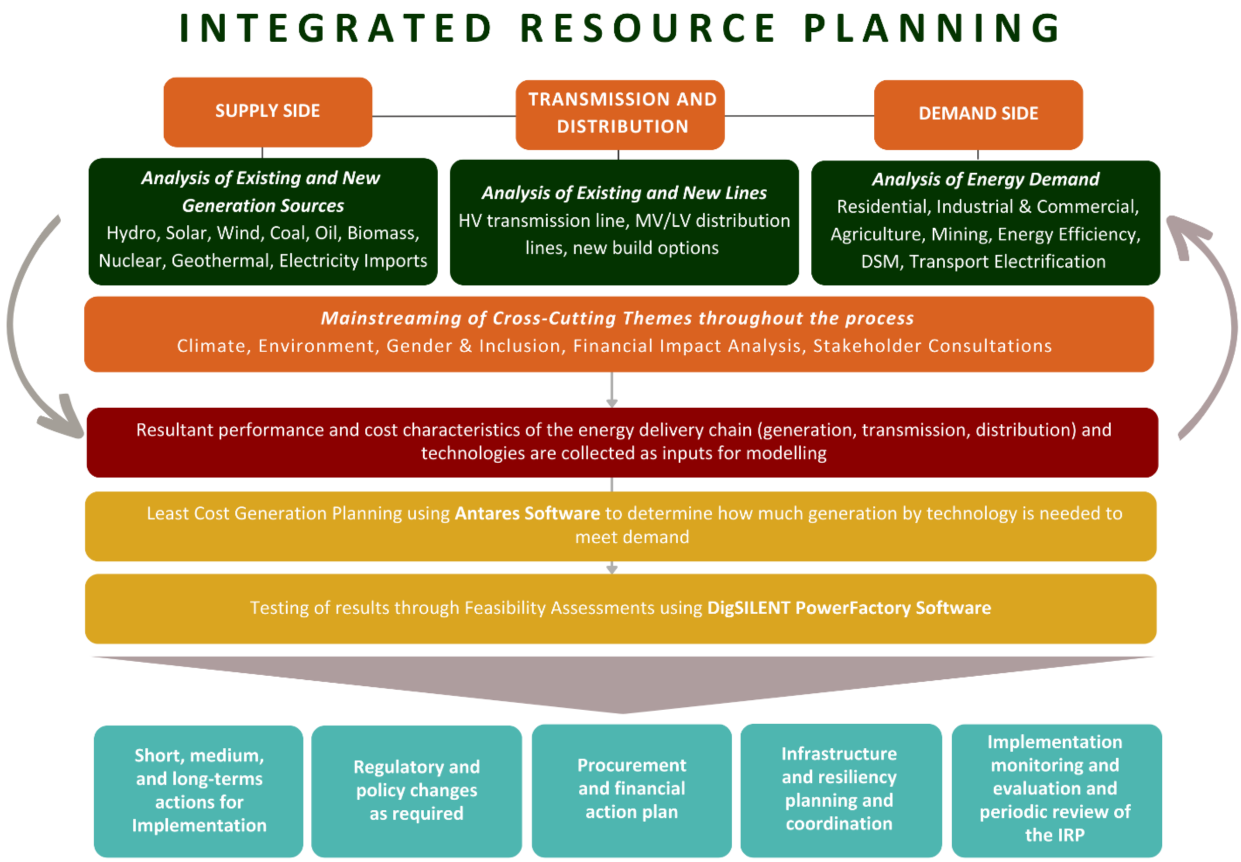
[8] For a list of the entities that input into the IRP process, refer to Ministry of Energy Acknowledgements on page *3*.

[9] A least cost approach compares the overall cost of providing a solution to consumers using alternative modes of delivery, taking into account both capital and operating costs, and deriving an anticipated tariff for each. This enables a comparison to be made between different potential solutions, so that the solution providing best value for money is recommended.

3 METHODOLOGY

The IRP delivers a plan for the energy sector based on extensive modelling of the expected changes to on-grid electrical load over a 30-year planning period, up to 2050. Its main objective is to propose a cost-effective investment strategy for the three components of the electricity supply chain, namely **generation**, **transmission** and **distribution**, in order to meet growing energy demand and deliver surplus electricity for export.

Figure 3.1: Generalised On-grid Framework for Integrated Resource Planning



The IRP development process for on-grid service provision followed the conceptual framework depicted above in Figure 3.1. The process involved three key areas of analysis: demand, supply (generation), and power networks comprising transmission and distribution[10]. In addition to the three areas of analysis, key cross-cutting issues of gender, climate and environment were considered throughout the process. By looking at all these aspects together, an *integrated* approach to the development of the IRP was taken; indeed, it is *integrated* because it examines both demand side (conservation, energy efficiency, etc.) resources as well as supply side (generation/power plants, transmission lines, etc.) resources in making its recommendations on how best to meet a country's future energy demands at the lowest possible cost whilst maintaining required service delivery standards.

[10] Both transmission and distribution refer to the transportation of electricity. Transmission focuses on the long-distance movement of electricity from power plants to central locations, typically at high voltages, while distribution involves delivering electricity from those central locations to consumers in localised areas, usually at lower voltages. Both transmission and distribution are essential components of the electricity supply chain.

It is important to note that an IRP-based power sector plan is dynamic. In other words, the IRP is a 'living' document that depends on a set of underlying assumptions, which are outlined in this section and described in greater detail within each of the core IRP reports[11]. Since assumptions are bound to evolve over time. IRP-based energy planning is best approached as a process, in which periodic reviews are crucial to ensure the ongoing relevance and validity of the IRP's assumptions, inputs and strategic recommendations.

The below further describes the framework presented above in Figure 3.1.

Demand forecasting: The foundation of the IRP's development lies in the demand forecast, which projects electricity needs over a 30-year horizon. This forecast considers various factors, including sectoral economic growth plans, national development strategies, energy policies, technological advancements, energy efficiency efforts and plans to increase electricity exports. The IRP not only gauges demand magnitude but also growth locations and timing, providing input data for the systems used to plan generation plant requirements and transmission and distribution networks. The demand analysis also factors in technical losses, recommended reserve margins, and temporal variations in demand across customer segments.

Supply (generation) planning: Generation, in the context of the IRP, pertains to the identification of the power sources and production volumes needed to effectively meet Zambia's demand for energy over a 30-year horizon. By building on a comprehensive assessment of Zambia's existing generation capacity, generation planning determines the optimal mix of future power sources and their capacities based on available resources to ensure a cost-effective, reliable and sustainable energy supply for the future.

For the purpose of generation planning, the IRP employs a dual-phase approach that includes both static and dynamic studies[12] for an accurate simulation of Zambia's power system. The initial phase identified optimal generation investments using the Antares Simulator[13]. Accounting for historical performance and costs, Antares recommended optimal generation sources, their respective capacities and location. This yielded a total generation capacity plan for existing and new power plants over the 30-year period. To ensure the overall reliability and stability of the electricity system under the proposed plan, dynamic studies were performed using DIgSILENT[14] which facilitated modelling of transient behaviours, assessing the system's ability to handle disturbances while adhering to Energy Regulation Board (ERB) and Southern African Power Pool (SAPP) reserve requirements.

Transmission and distribution planning: The third aspect of the IRP framework involved planning the secure transmission and distribution of electricity from generation sources to demand centres. A detailed analysis of the alternating current (AC) power system using DIgSILENT PowerFactory software enabled the IRP to assess operational dynamics and contingencies of the proposed plan down to the

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[11] IRP Core Reports: IRP Demand Forecast; IRP Generation Planning; IRP Transmission Planning; IRP Distribution Planning

[12] Undertaking both a static and dynamic generation study on the same dataset provides a comprehensive understanding of the power system's behaviour and performance. A static study focuses on the steady-state conditions of the system, helping to optimise the overall configuration and assess factors like power flows and voltage levels. On the other hand, a dynamic study delves into transient behaviours, considering system responses to disturbances like faults or sudden load changes. This combined approach ensures that the generation plan is not only optimised for normal operations but also robust enough to handle dynamic events, ultimately enhancing system reliability, stability and security.

[13] Antares-Simulator is an open source standalone software. It is a sequential Monte-Carlo simulator designed for short to long-term studies of large, interconnected power grids. It simulates the economic behaviour of the whole transmission-generation system, throughout the year and with a resolution of one hour.

[14] PowerFactory by DIgSILENT is a software used for power system modelling and simulation that is able to conduct steady state, time domain, frequency domain and stochastic simulations for balanced and unbalanced systems.

33 kV level[15]. This was an important step to ensure enhanced rigor to system performance and stability in the transmission and distribution lines, based on the proposed capacity additions. This process assessed the security of transmission and distribution systems against grid codes and security of supply standards, where these were available. While there is no Zambian standard for evaluating security of supply at the distribution level, a UK security of supply standard (P2/7) was employed to assess the security of supply at various points in the distribution network. The results informed network reinforcement and development requirements.

Cross-cutting considerations: The IRP went beyond modelling for an optimal, least cost system expansion plan by actively integrating key **climate**, **environment**, **gender, social inclusion and economic empowerment** considerations throughout its development. Seeing the extent to which climate change acts as an exacerbating force for existing climate drivers, a thorough analysis of climate risks, such as droughts and heatwaves, was a critical first exercise in the IRP to effectively identify climatic parameters of interest for energy modelling. Generation expansion plans were later subjected to rigorous environmental impact assessments, to identify and mitigate any risk of negative environmental externalities and quantify related carbon emission changes. In parallel, social and inclusion assessments of the electricity sector were conducted, which informed the design of measures to address gaps in social protection, enhance the inclusion of marginalised groups and promote local economic empowerment opportunities as the sector expands per the IRP. These processes were all highly consultative and aimed to ensure that the IRP is not only cost effective but also resilient, balanced and inclusive.

3.1 IRP General Assumptions and Limitations

The following list outlines key assumptions and limitations in the IRP. While this document aims for accessibility, the complexity of energy systems requires transparency regarding these factors, which may be of greater interest to technical readers.

- Aggregate demand is a function of the assumptions for economic growth for the different segments of the economy, which have been informed by emerging Government policy that aspires to radically transform the Zambian economy. It incorporates a blend of econometric and policy-driven growth trajectories. Achieving this demand growth within the defined timescales is subject to public and private sector investments in new mining, agriculture and transport projects taking place in line with these timescales.
- In the absence of feasibility studies, global references were used to estimate demand for the electrification of transport (electric vehicles (EVs) and trains/trams) and agriculture. Furthermore, it was assumed that most of these investments would materialise after 2026 and grow steadily reaching their full capacity at different times of electrification of transport and agriculture.
- Global figures for marginal and investments costs for various generation technologies were used to determine least cost generation investments rather than Zambia-specific figures, mainly due to lack of consistent and reliable local data and to avoid any bias between future competing potential projects across the various possible technologies.
- The future load profiles were assumed to be uniform at all nodes and were based on average historical profiles.

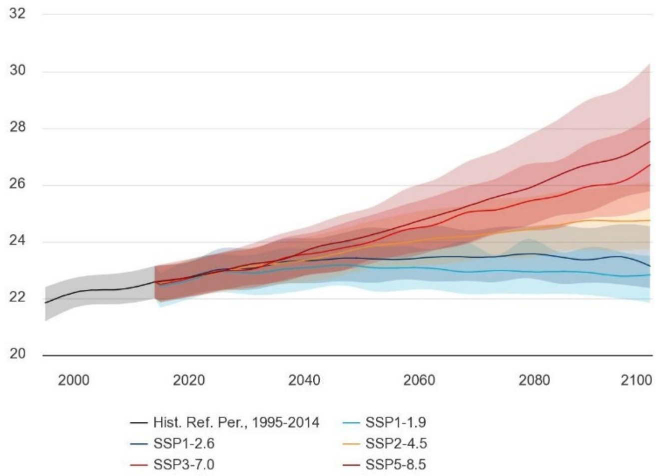
[15] It should be noted that due to time and resource constraints, the 2026 and 2030 reference years were modelled in both Antares and DIgSILENT, while the 2040 and 2050 milestones were limited to Antares modelling only.

- The introduction of EVs was catered through an econometric approach to forecasting commercial and industrial and residential demand. This assumption will be reviewed in future iterations of the IRP if rapid deployment of EVs materialises in the near to medium-term, enabling EV charging to be modelled based on specific policies and plans that address the technical and commercial dimensions associated with the widespread installation of EV charging stations.
- Transport demand growth levels off after 2036 when all planned projects are expected to have been completed. Further developments in the transport sector beyond 2036 will be incorporated in future iterations of the IRP as guided by national plans.
- The interconnectors to SAPP system were based on the SAPP Plan of 2017, which is currently being updated. As these plans are developed on a regional basis, a detailed analysis of interconnectors was excluded from the scope of the IRP. Interconnector costs were not included in the overall transmission investment costs, except for the interconnector between Zambia and Tanzania which includes a significant element of network reinforcement in the northern eastern region of Zambia.
- Only transmission and distribution technical losses were included in the system losses (i.e. figures exclude commercial losses). This is because commercial losses fall outside the technical design of the system and are inherently variable and controllable.
- Only the 330 kV network was modelled in Antares for the sake of simplicity. However, a full network model down to 33 kV was included in the AC static and dynamic studies in DIgSILENT PowerFactory, ensuring the proposed system is feasible. The 11 kV network was excluded because it is very extensive, and no credible data was available that could be included in the model. Projections of costs at the 11 kV and 400 V levels (i.e. customer connections) were made using an average cost per connection, as recommended in the LCGEP, multiplied by the projected number of connections, split between grid densification and grid extension.

4 Climate Assumptions

Despite being only a marginal contributor to international greenhouse gas emissions, Zambia is highly vulnerable to the impacts of climate change. Global rising temperatures are driving several climatic shifts in Zambia that include increases in temperatures, changes in the current rainfall patterns across the country and an increase in the frequency and intensity of extreme events such as heatwaves, floods and droughts. As a result of an electricity sector that relies heavily on climate-vulnerable hydropower generation (hydropower constitutes 85% of Zambian's current generation capacity), the electricity sector in Zambia is exposed to a wide array of climate hazards.

Figure 4.1: Zambian Projected Mean Temperatures – 5 Shared Socio-economic Pathways to 2100



Climate considerations were a key input into the IRP modelling. The IRP examined the impacts of climate risks on hydropower production, considering existing risks, future scenarios incorporating climate change, and resilience measures, to ensure an adaptive generation strategy. Aligned with the Government of the Republic of Zambia (GRZ)'s climate targets, the IRP recommends the adoption of climate resilient designs for individual hydro plants, spatial diversification between hydro plants, and a holistic climate-proofing approach to the overall design of Zambia's power system.

4.1 Zambia's Climate Change Commitments

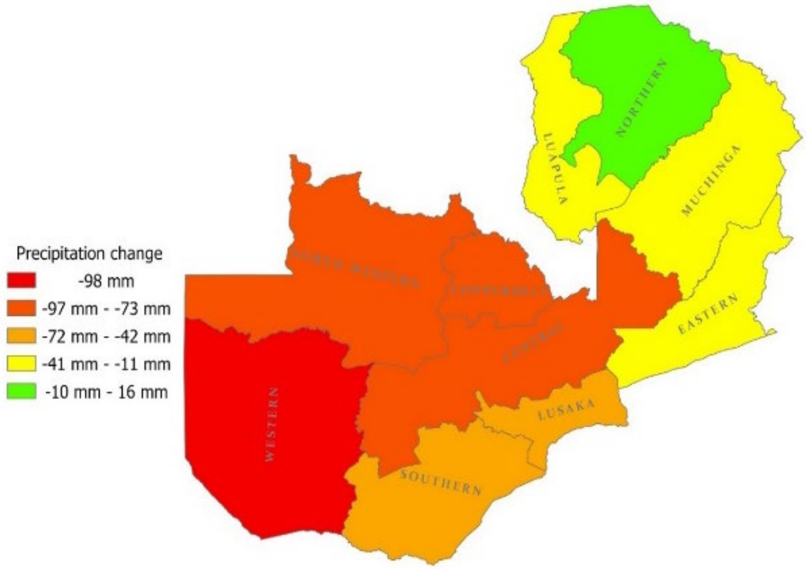
As a party to the Paris Agreement of 2015, Zambia has submitted Nationally Determined Contributions (NDCs) that outline the country's climate change commitments until 2030, which state an intention to reduce greenhouse gas emissions by 25% (at business-as-usual level of international support) and 47% (with substantial international support) compared to 2010 levels. The NDCs also outline goals towards enhancing the resilience of economic sectors, productive systems and communities to climate-related shocks. In addition to the NDCs, Zambia is currently developing a National Adaptation Plan (NAP), which will outline key national priorities for adapting to the impacts of climate change. Zambia also has key policy documents on climate change, including the National Policy on Climate Change and the National Climate Change Response Strategy. While the energy sector is overall viewed as a net contributor to greenhouse gas emissions, it is critical to note that electricity generation in Zambia is relatively low in carbon emissions, because of a strong reliance on hydropower.

4.2 Evaluating the Climate Change Impacts on Electricity

During the development of the IRP, the various sub-sectors of electricity supply (demand, generation, transmission and distribution) were assessed using a three-step methodology. Firstly, existing climate risks to the various sub-sectors were assessed. Climate change predominantly acts as an exacerbating force for existing climate drivers, so understanding existing climate risks (such as droughts or heatwaves) is crucial to adequately identifying climatic parameters of interest. Secondly, future climate change scenarios were explored to assess potential future risks. Thirdly, potential climate resilience measures to reduce risks were identified.

Map 4.1 and Map 4.2 depict the regional rainfall and temperature change projections for Zambia for the period 2040 – 2059 across Zambia under a moderate climate change scenario. South-western regions are predicted to experience temperature increases and rainfall decreases.

Map 4.1: Zambia Regional Rainfall Projections (2040 – 2059) Moderate Climate Change Scenario



Climate impacts to electricity generation: The most significant climate change impacts to electricity generation are expected to be in the hydropower sector. Given the significant uncertainty associated with future hydrology, a decline of 7.5% in output over the plan period was assumed for hydro generation plants in the Zambezi catchment area in determining modelling results, notwithstanding some modelling results that suggest the decrease may be as high as 15%. With respect to future hydro plants recommended by the IRP, it was assumed that investment would predominantly be in the north of Zambia in the Congo catchment area such as the Chambeshi and Luapula Rivers, which are less susceptible to climate change, and therefore able to provide consistent annual power output over the IRP plan period.

Map 4.2: Zambia Regional Temperature Projections (2040 – 2059) Moderate Climate Change Scenario

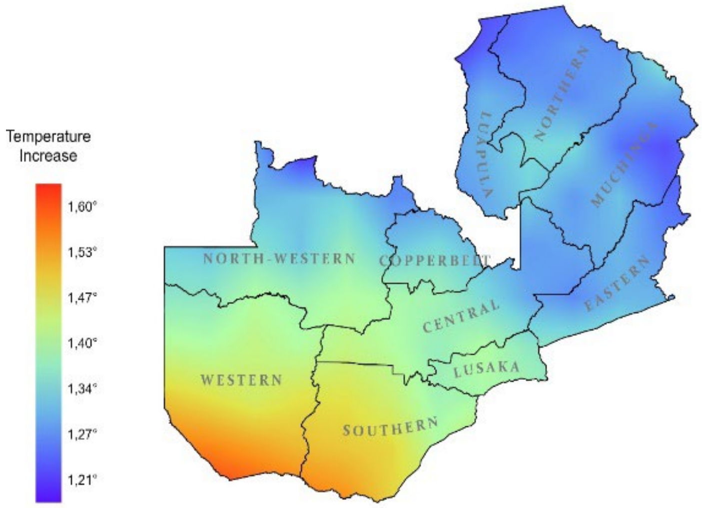


Table 4.1 shows changes of water availability in Zambia's river basins for two climate scenarios, indicating declines in available water for hydropower and other uses.

Table 4.1: Changes of Water Availability in Zambia's River Basis for Two Climate Scenarios

			Absolute Water Availability (km)			Relative Change (%)		
Basin Name	**Climate Scenario**	**Current Water Availability (km^3)**	**2030**	**2050**	**2080**	**2030**	**2050**	**2080**
Zambezi	4.5	48	46	45	45	-4%	-6%	-6%
Zambezi	8.5	48	45	43	41	-6%	-10%	-15%
Kafue	4.5	11	10.5	10.3	10	-5%	-6%	-9%
Kafue	8.5	11	10.1	10.4	9.8	-8%	-5%	-11%
Luangwa	4.5	17	16.4	16.2	16.2	-4%	-5%	-5%
Luangwa	8.5	17	16.3	16	15.8	-4%	-6%	-7%
Luapula	4.5	26	25	25.5	25.2	-4%	-2%	-3%
Luapula	8.5	26	25.5	25.1	24.9	-2%	-3%	-4%
Lufubu	4.5	0.4	0.4	0.4	0.4	0%	0%	0%
Lufubu	8.5	0.4	0.4	0.4	0.4	0%	0%	0%

Moreover, hydropower installations are also likely to be exposed to flood risks, increases in upstream erosion and competition with other water users. Climate change impacts on solar, wind and thermal power were determined to be minor, though rising temperatures may adversely affect their efficiency. Biomass energy and biomass fuels may also be vulnerable to climate change shocks that affect the upstream production of biomass feedstock. For example, droughts and floods could negatively affect the agricultural production of feedstock.

Climate impacts to demand, transmission and distribution: Climate change is expected to impact electricity demand primarily in two ways. First, increasing temperatures are expected to increase the overall cooling demand of the country. However, as a result of the existing low baseline of electricity demand for cooling requirements, the added impact of climate change is difficult to estimate and disaggregate from economic factors currently limiting or enabling the uptake of cooling technology. Second, declines in water availability and shifts in rainfall patterns may increase energy requirements for water transfers. For transmission and distribution, the main climate hazards that are likely to be of relevance are increases in extreme climate events such as flooding, landslides or wildfires that may result in direct damage to infrastructure. Transmission losses because of rising temperatures were considered and assumed to be negligible.

4.3 Adapting to Climate Change

The most marked impacts on hydropower generation in Zambia require priority attention to ensure a stable supply of generation capacity under climate change conditions. The IRP recommends a number of actions that should be considered in hydropower design in the future. These include both spatial diversification away from the most affected catchment areas as well as increased input from other renewable energy sources that are decoupled from hydrological parameters. Further, individual installations should be assessed to determine if negative impacts from evaporation can be reduced, as well as to identify integrated watershed management practices that assure equitable water access during periods of low water availability. While other generation technologies are less climate vulnerable, key infrastructure should also be assessed for potential exposure to increasing extreme hazards such as droughts and floods.

In demand, transmission and distribution, climatic changes are expected to only pose severe risks because of extreme events, and potentially exposed infrastructure may need to be climate proofed. A framework for assessing climate risk in electricity infrastructure for both new and existing infrastructure would ensure that climate-smart decision making is mainstreamed and that site-specific risks can be identified and incorporated into the design and planning process.

4.4 Maintaining a Low-Emissions Trajectory

While the impacts of climate change are expected to negatively impact Zambia's low-emissions electricity generation capacity, the country remains committed to reducing carbon emissions. To maintain the twin objectives of building climate resilience in the electricity sector while not increasing emissions from electricity generation, Zambia can make use of international concessional finance flows dedicated to dealing with the issues of climate change. Such finance is already being used in Zambia and the region, and with two national entities already having been accredited to handle funding from the Green Climate Fund, Zambia is in a prime position to benefit from concessional climate financing. Under the current scenario, emissions from coal are likely to increase as a result of increasing thermal capacity of approximately 1,616 MW by 2050 (corresponding to generation of approximately 8,999 GWh per annum), which is likely to increase carbon emissions from this energy source by around 5.9 million[16] tonnes per year. Opportunities for offsetting these emissions should be sought via rural electrification and decreasing emissions from deforestation and the use of charcoal and biomass as heating energy.

In summary, climate change impacts on the electricity sector in Zambia have been identified and considered in the development of the IRP. These impacts will require a collaborative and cross-sectoral effort by stakeholders to ensure that the implementation of the IRP will build the resilience of the existing system without jeopardising Zambia's goals for emissions reduction. To achieve this, Zambia is well-positioned to make use of the current climate finance landscape to implement the IRP in a climate-resilient manner that does not unduly increase emissions.

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[16] Assumes an average emissions factor of 0.83 tonnes CO_2e per MWh for coal, and that all thermal generation is coal fuelled.

5 DEMAND PROJECTIONS

Demand forecasting is the cornerstone of effective electricity planning, offering an informed view of power consumption trends. It safeguards against inadequate supply during peak demand and excessive investment in generation and network infrastructure. The IRP's 30-year demand projection incorporates a spectrum of variables including demographic shifts, national strategies, technological advancements, electrification initiatives and export ambitions. Beyond estimating demand magnitude, the forecast pinpoints growth hotspots and timing, aligning the energy supply system with Zambia's evolving ambitions. By capturing daily and seasonal demand variations (load profiles), the IRP ensures a unique strategy for different consumer segments. Demand forecast data forms the backbone for generation, transmission and distribution investments planning.

5.1 Aggregate Electricity Demand Projections (2020-2050)

In the aggregated demand analysis, the IRP focuses on four primary demand segments that capture the most crucial drivers of electricity demand in Zambia. These segments are residential, commercial and industrial (excluding mining), mining, and agriculture. Furthermore, to adequately showcase the GRZ's strategy to electrify the transport sector, transport is presented as a distinct demand segment. Finally, the IRP incorporates two additional demand segments: exports and technical losses. The inclusion of exports recognises Zambia's potential as a regional exporter of clean power, while accounting for technical losses addresses the inevitable power losses during transmission and distribution[17].

Aggregate demand scenario analysis: In the baseline year of 2020, peak electricity demand was 2,456 MW, mainly driven by mining (36%), residential (31%), and commercial and industrial (10%) sectors. The IRP's projected peak demand scenario for 2050 is 11,031 MW (a 349% increase), nearly 3.5 times the 2020 level, with a significant shift in the relative weighting of demand then forecast to be agriculture (33%), followed by mining (19%) and residential (17%). This economic shift in relative contributions to aggregate demand emphasises the transformative investments in industrial-scale agriculture and agro-processing, mining and energy access planned by GRZ for the next three decades. For a detailed visual representation of the data, please refer to Figure 5.1, Figure 5.2, Table 5.1 and Table 5.2.

[17] For further information on the methodology of the demand forecasting, refer to the IRP Demand Report.

Figure 5.1: Peak Demand by Sector for Electricity 2020 – 2050 (MW)

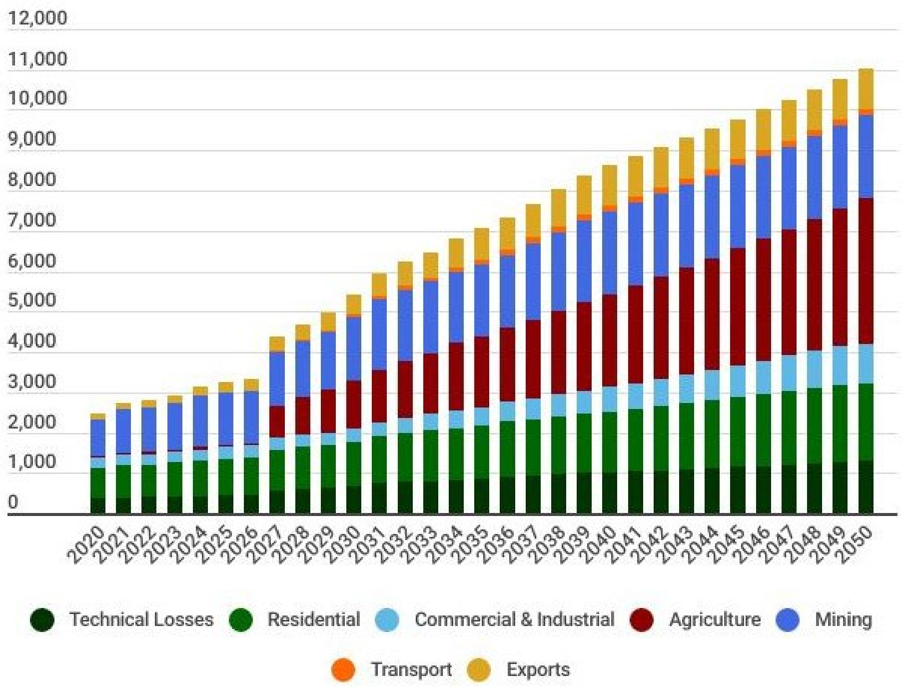


Figure 5.2: Consolidated Base Case Demand by Sector 2020 – 2050 (GWh)

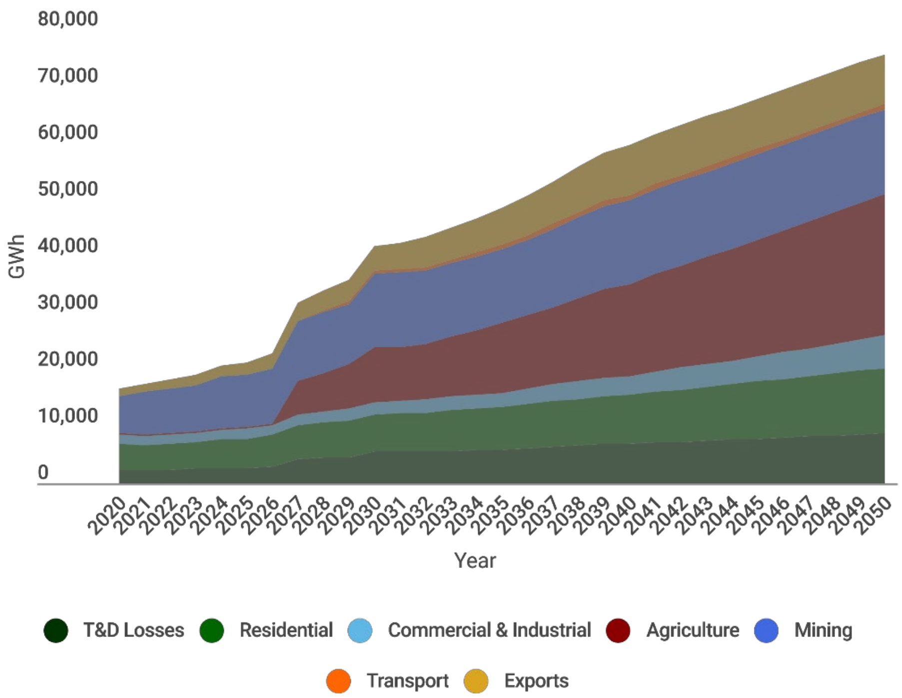


Table 5.1: Peak Demand for Electricity 2020 – 2050 (MW)

Demand Segments	2020	2026	2030	2040	2050
Residential	769	960	1,078	1,505	1,923
Commercial and Industrial	257	281	337	609	984
Agriculture	48	50	1,200	2,301	3,625
Mining	886	1,311	1,552	2,046	2,052
Transport	-	-	67	151	153

Electricity Exports	138	300	500	1,000	1,000
Technical Losses	358	436	687	1,012	1,294
Total Demand MW	**2,456**	**3,338**	**5,422**	**8,624**	**11,031**

Table 5.2: Consolidated Base Case Demand 2020 – 2050 (GWh)

Demand Segments	2020	2026	2030	2040	2050
Residential	4,618	5,605	6,704	8,647	11,535
Commercial and Industrial	1,645	1,757	2,193	3,373	5,737
Agriculture	252	260	9,519	16,102	24,869
Mining	6,569	9,747	13,127	14,853	15,009
Transport	-	-	457	994	1,000
Exports	1,210	2,628	4,380	8,760	8,760
Transmission and Distribution Losses	2,391	2,918	5,545	6,945	8,840
Total Demand GWh	**16,685**	**22,916**	**41,925**	**59,674**	**75,748**

5.2 Residential Electricity Demand

Residential demand is a critical component of any demand forecast with a linkage to UN Sustainable Development Goal (SDG) 7 and the need for social equity in facilitating universal access to electricity. The demand scenario presented in this section focuses exclusively on on-grid demand. The off-grid expansion assumptions to meet universal access are addressed in Section 7, Access to Electricity.

Figure 5.3: Residential Electricity Demand 2020 – 2050 (MW)

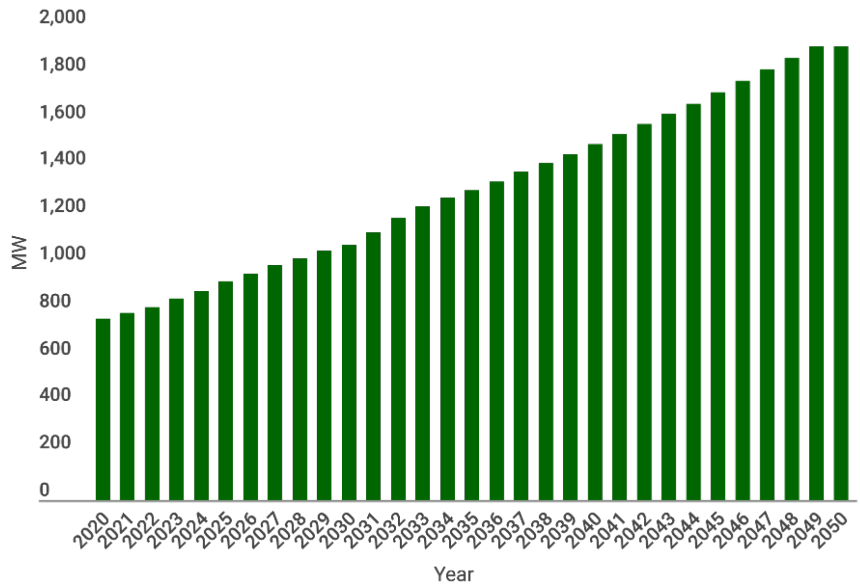


Figure 5.4: Residential Electricity Demand 2020 – 2050 (GWh)

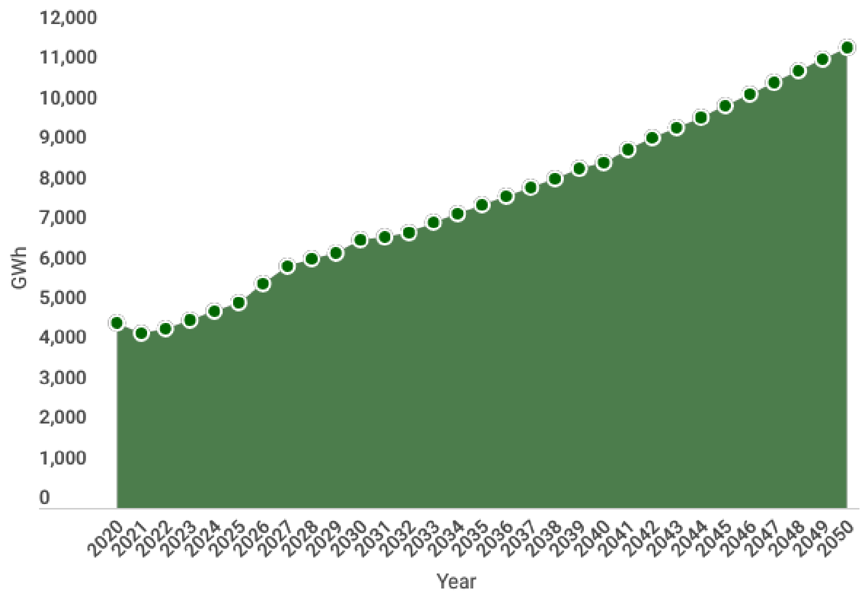


Table 5.3: Residential Electricity Demand 2020 – 2050 (MW and GWh)

Demand Segment	2020	2026	2030	2040	2050
Residential Demand (MW)	769	960	1,078	1,505	1,923
Residential Demand (GWh)	4,618	5,605	6,704	8,647	11,535

Residential Demand Scenario Results: The GRZ has set an ambitious target of achieving universal access to electricity by 2030, and the IRP scenario is carefully designed to align with this objective. As a result, there is a sustained increase in residential demand, with a projected 40% increase from the baseline year of 2020 (769 MW) to 2030 (1,078 MW). Thereafter, the IRP forecasts an 83% increase in demand from 2030 to 2050 (1,078 MW to 1,923 MW, respectively).

Residential Demand Scenario Methodology: The IRP residential demand combines outputs from the LCGEP model with detailed analysis of recent household demand trends in Zambia. The LCGEP model identifies the least cost mode of delivering electricity access for each site throughout Zambia and determines the year in which access should be provided to achieve universal access by 2030.

To understand the evolution of on-grid demand over time, a detailed analysis of ZESCO's meter point residential demand data was performed, specifically examining the annual demand per household for different connection year cohorts. The analysis also considered actual regional variations in demand, with households in more urban areas having a greater ability to pay and, consequently, higher per household demand. The findings from this analysis, combined with the LCGEP outputs, were used to project future residential demand and peak demand for the residential sector in Zambia.

To align with practical constraints impacting the rate at which grid densification and grid extension can be implemented, the number of new grid-based connections was capped at 50,000, 85,000 and 120,000 for 2023, 2024 and 2025, and 120,000 for each year thereafter. Off-grid solutions namely mini-grids and solar home systems are deployed for sites where grid connection cannot be delivered by 2030.

5.3 Commercial and Industrial Electricity Demand

The commercial and industrial (C&I) segment of the demand scenario encompasses energy requirements from various businesses, factories and enterprises operating within Zambia. This category comprises a diverse range of activities, including manufacturing, services and commercial establishments (excluding mining and electrified public transport).

Figure 5.5: Commercial and Industrial Electricity Demand 2020 – 2050 (MW)

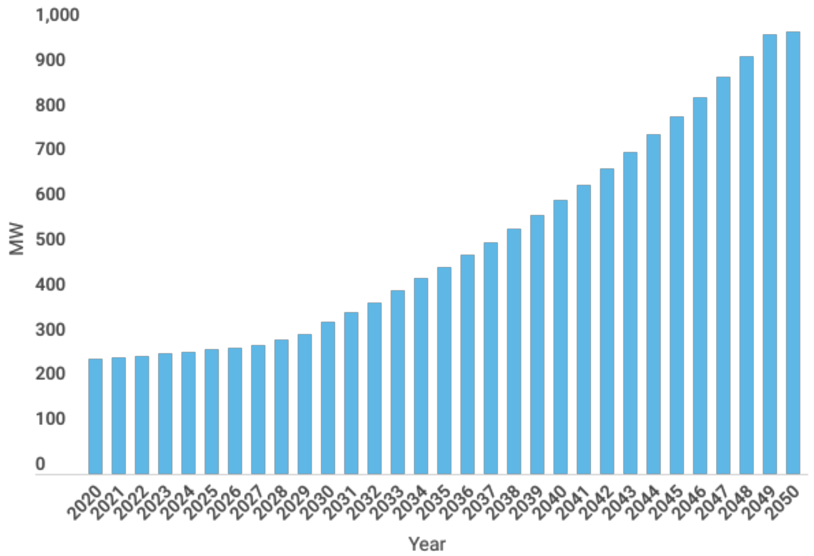


Figure 5.6: Commercial and Industrial Electricity Demand 2020 – 2050 (GWh)

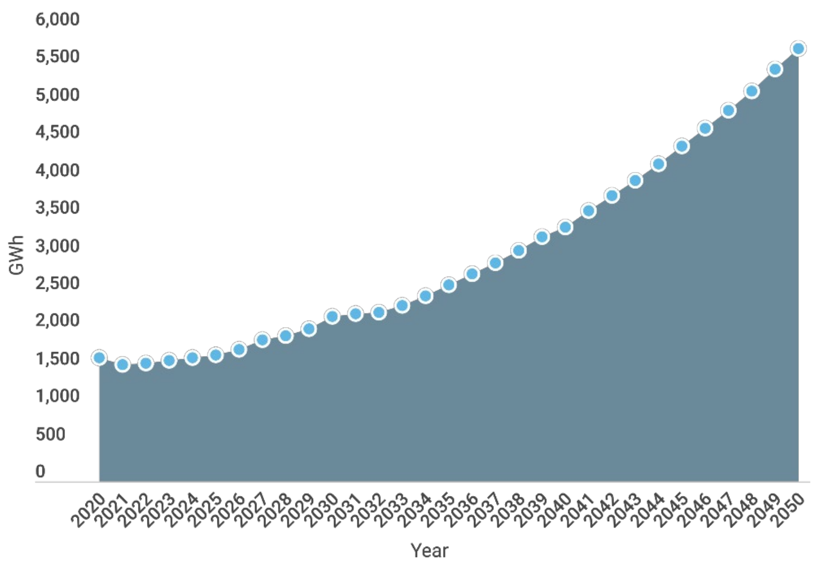


Table 5.4: Commercial and Industrial Electricity Demand 2020 – 2050 (MW and GWh)

Demand Segment	2020	2026	2030	2040	2050
Commercial and Industrial Demand (MW)	257	281	337	609	984
Commercial and Industrial Demand (GWh)	1,645	1,757	2,193	3,373	5,737

Commercial and Industrial Demand Scenario Results: The C&I demand percent increase from its 2020 base is projected to be 9%, 31% and 283% in the reference years of 2026, 2030 and 2050 respectively. Throughout the lifespan of the plan the C&I component varies between 6% and 10% of the overall contribution to the aggregate demand profile.

Commercial and industrial demand methodology: Demand for the C&I segment has been modelled using a combination of econometric and bottom-up methodologies.

For the econometric approach, demand from existing C&I customers is projected to increase in line with official projections for gross domestic product (GDP) growth. In addition, a bottom-up approach was taken to forecast the demand requirements for an electric vehicle battery manufacturing plant that GRZ plans to establish in Ndola, and which is assumed to be commissioned by 2030. Of the overall C&I demand numbers, 8 MW, 52 MW and 102 MW are comprised specifically from the bottom-up approach associated with the battery plant in 2030, 2040, and 2050 respectively.

5.4 Agricultural Electricity Demand

The agriculture sector in Zambia is not currently a main driver of demand consumption as it constituted only 2% of the overall electricity demand in Zambia in 2020. However, at scale the agricultural sector (crop cultivation, livestock farming and agro-processing) is a large power consumer. As represented in Figure 5.7 and Figure 5.8, the demand scenario modelled for the IRP sees a significant expansion of the agriculture sector, which reflects the GRZ's plan to modernise and grow the sector.

Agriculture demand scenario results: In the agricultural demand scenario, the sector goes from a 2% driver of 2,456 MW to a 33% driver of demand of 11,031 MW in 2050. While the overall demand has over a 4-fold increase in this forecast, the most significant driver of this increase comes from the industrialisation of the agricultural sector. The agricultural demand is forecast to increase by more than 74 times between 2020 to 2050 and is set to overtake mining to become Zambia's largest consumer of power by 2050 (3,625 MW to mining's 2,052 MW).

Figure 5.7: Agricultural Electricity Demand 2020 – 2050 (MW)

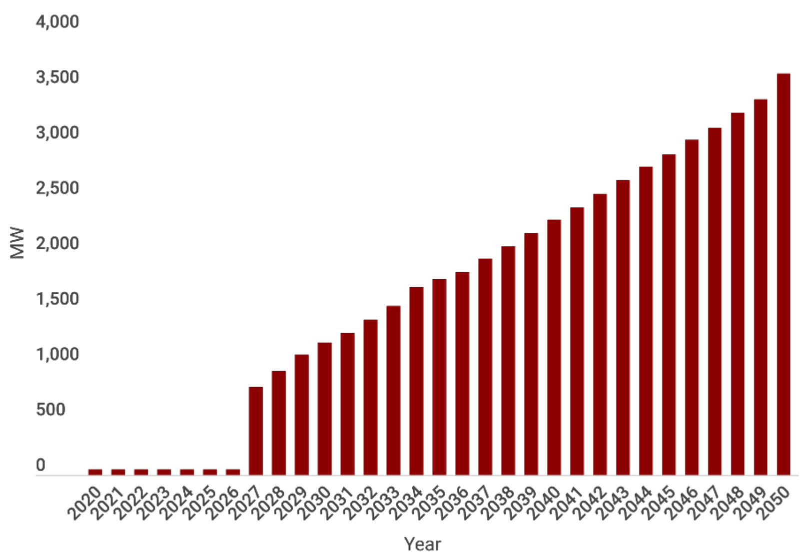


Figure 5.8: Agricultural Electricity Demand 2020 – 2050 (GWh)

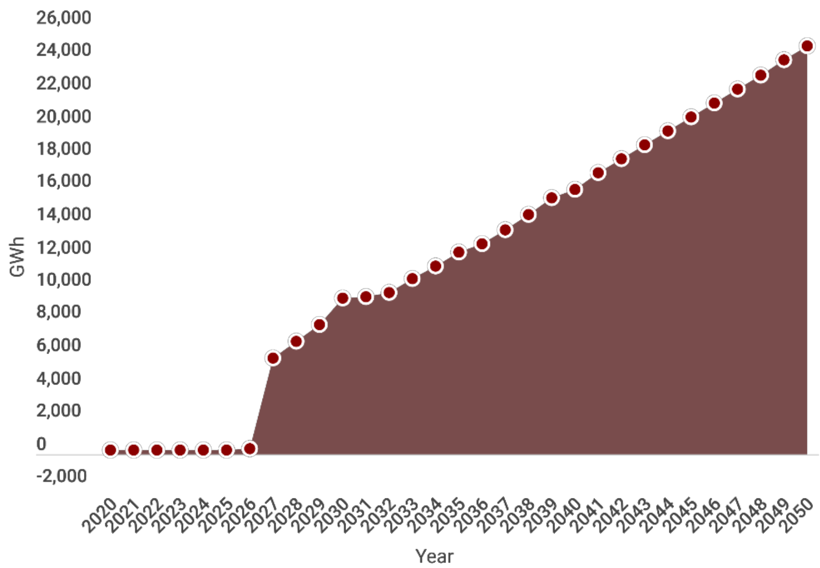


Table 5.5: Agricultural Electricity Demand 2020 – 2050 (MW and GWh)

Demand Segment	2020	2026	2030	2040	2050
Agricultural Demand (MW)	48	50	1,200	2,301	3,625
Agricultural Demand (GWh)	252	260	9,519	16,102	24,869

Agriculture demand forecasting methodology: The bottom-up approach was used to forecast agricultural demand. Agricultural demand is primarily driven by Government targets and informed by the Ministry of Agriculture, to substantially increase production of wheat, maize and soya beans for export through large-scale mechanised operations requiring significant energy for irrigation and agro-processing. The projected increases between 2020 and 2050 are outlined below:

- Annual wheat production will increase from 175,000 metric tonnes to 15 million metric tonnes.
- Annual maize production will increase from 3 million metric tonnes to 6 million metric tonnes.
- Annual soya bean production will increase from 329,000 metric tonnes to 3 million metric tonnes.

5.5 Mining Electricity Demand

In Zambia, mining is such a significant driver of electricity demand it warrants its own segmental analysis. Currently, mining is the leading driver of Zambia's electricity demand. Additionally, GRZ has set ambitious targets to significantly increase mining production to 3 million tonnes of refined copper per annum from current levels of 763,000 tonnes per annum[18].

[18] Newsletter Issue No 7, Zambia Chamber of Mines, 2022, http://mines.org.zm/newsletter-issue-no-7-out-now

Figure 5.9: Mining Electricity Demand 2020 – 2050 (MW)

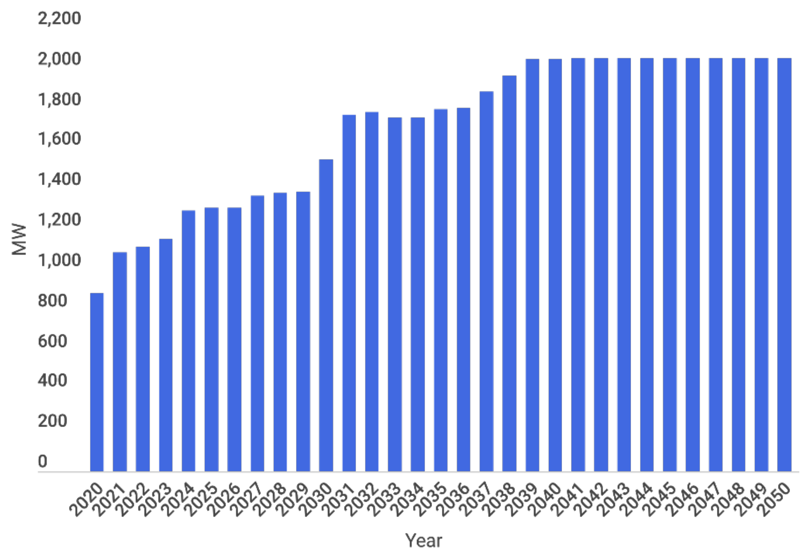


Figure 5.10: Mining Electricity Demand 2020 – 2050 (GWh)

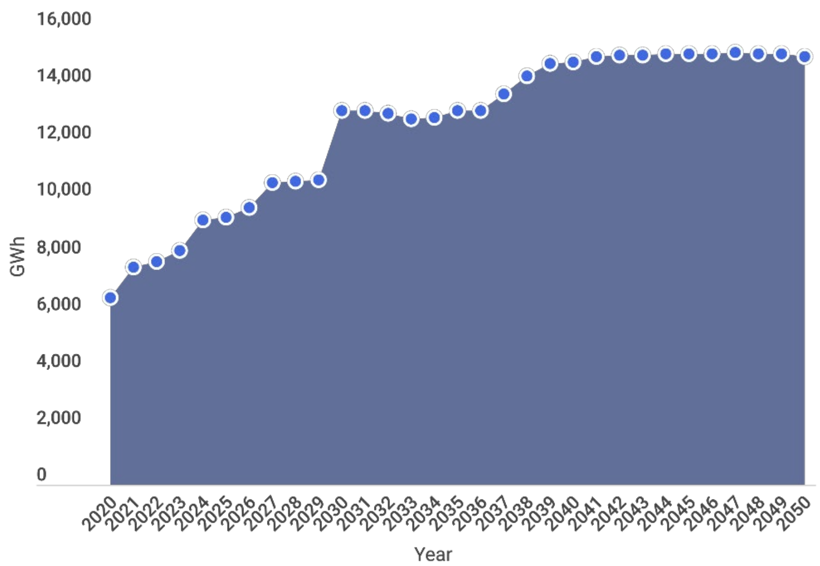


Table 5.6: Mining Electricity Demand 2020 – 2050 (MW and GWh)

Demand Segment	2020	2026	2030	2040	2050
Mining Demand (MW)	886	1,311	1,552	2,046	2,052
Mining Demand (GWh)	6,569	9,747	13,127	14,853	15,009

Mining demand scenario results: From 2020 to 2026, the Zambian mining sector is anticipated to witness a 48% increase in its electricity demand. Subsequently, by 2030 and 2040, there are projected increases of 18% and 32% respectively. Over the IRP plan period from 2020 to 2050, the mining sector's energy demand is expected to increase by 132%. While mining remains a significant driver of energy demand, its role shifts from primary to secondary between 2030 and 2040. During this period, agriculture is foreseen to surpass mining and become the largest contributor to increased electricity demand.

Mining demand forecasting methodology: A bottom-up approach was used to forecast mining electricity demand based on detailed electricity demand projections provided by the Chamber of Mines, Copperbelt Energy Corporation (CEC) and ZESCO. Mine-level forecasts of electricity demand for existing mines were provided and used directly. The demand forecast also incorporates the Government's ambitious target to increase refined copper production by around 300% to 3 million tonnes per annum. The Chamber of Mines provided data that substantiated this increase in production to 3 million tonnes per year by 2040 taking account of the time period for development of new mines, which is typically around 15 years. The load forecasting takes account of both mining and associated mineral processing and support services, and the trend towards more energy-efficient mining production processes through open cast rather than deep mines.

The main locations for new copper mines are Copperbelt Province, North Western Province and Central Province. The forecast also recognises that there will be an increase in mining of other minerals such as manganese, for which significant deposits are proven in Luapula Province and Central Province.

5.6 Transport Electricity Demand

GRZ plans a transformative shift in the electrification of transport driven by advancements in electric vehicle technology and the introduction of electrified public transport. As the world increasingly embraces sustainable and energy-efficient modes of transportation, Zambia stands posed to integrate EVs and related infrastructure into its transport sector. This pivotal transition holds the potential to not only address the country's transportation challenges but also contribute significantly to supporting ambitious growth while continuing to meet its climate and environmental goals.

Figure 5.11: Transport Electricity Demand 2020 – 2050 (MW)

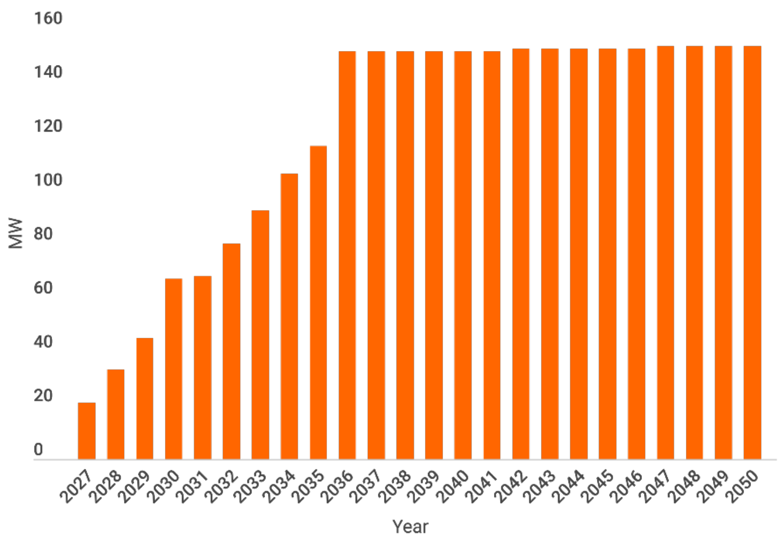


Figure 5.12: Transport Electricity Demand 2020 – 2050 (GWh)

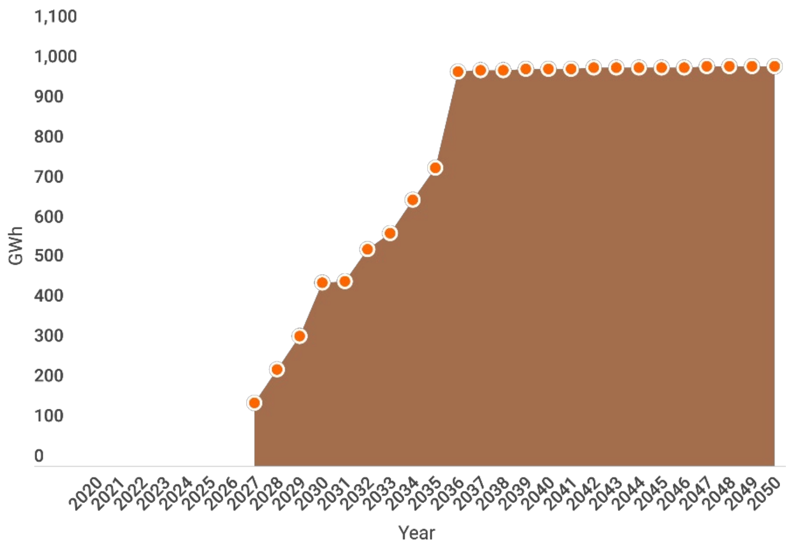


Table 5.7: Transport Electricity Demand 2020 – 2050 (MW and GWh)

Demand Segment	2020	2026	2030	2040	2050
Transport Demand (MW)	-	-	67	151	153
Transport Demand (GWh)	-	-	457	994	1,000

Transportation demand scenario results: This category of demand relates only to electrified public transport. Demand from EVs (residential, commercial, industrial and mining) has been incorporated into the respective demand categories. There is no demand from electrified public transport until 2030, where it goes from 67 MW in 2030 to 153 MW in 2050, an increase of 128%. While the overall demand from electrified public transport is not projected to exceed 2% of the Zambia's total power demand, its symbolism in terms of Zambia's transition to a green economy warrants continued monitoring and reporting of this category of demand.

Transportation demand forecasting methodology: The demand projection for transport incorporates electrified train and tram systems that are planned by the Ministry of Transport to relieve urban congestion and improve rail connectivity between Zambia's main cities, mining areas and international rail connections. The specific projects included in the IRP demand projection are detailed below.

Tramways

Lusaka Tram: Commuter routes 50 km in length by 2030 (Phase One), 100 km in length by 2035 (Phase Two) and 140 km in length by 2040 (Phase Three) are planned to cater for 5,700, 11,400 and 17,100 passengers per day respectively. Peak demand requirement by Phase Three has been estimated as 2.9 MW and annual energy consumption 71.8 MWh using international benchmarks.

Kitwe Tram: A commuter route 26 km in length catering for 1,710 passengers per day by 2040 is planned. Peak demand requirement by 2040 has been estimated as 0.06 MW and annual energy consumption 1.3 MWh using international benchmarks.

Intercity trains

Katima Mulilo – Solwezi (ZRL Project): An intercity train from Katima Mulilo to Solwezi for a length of 1,250 km via Lusaka, Kabwe and the Copperbelt is planned which will cater for 1,400 passengers per day by 2040. The train will also facilitate transportation for export of minerals including copper, nickel and manganese via the Walvis Bay in Namibia. The peak demand requirement is projected as 28.4 MW and the annual energy consumption 217 MWh using international benchmarks.

Kapiri Mponshi – Nakonde (Tazara Project): An intercity train from Kapiri Mposhi to Nakonde for a length of 820 km is planned which will cater for 2,800 passengers per day by 2040. The train will also facilitate transportation for export of minerals including copper, nickel and manganese from mining via Dar-es Salaam in Tanzania. The peak demand requirement is projected as 62 MW, and the annual energy consumption 543 MWh using international benchmarks.

Government policy supports the use of EVs for road transport, which will increase as EVs and associated rapid charging equipment become more affordable and accessible in future years. The projected demand from EVs has been incorporated into the demand for C&I, mining and residential categories. Future iterations of the IRP will seek to disaggregate the demand for EVs within these categories.

5.7 Electricity Exports Demand

Aligned with the GRZ's aspiration for Zambia to evolve into a net power exporter, the IRP scenario envisions a trajectory that includes the forthcoming interconnector linking Zambia to the Eastern African Power Pool (EAPP), complemented by the existing connections to the SAPP. Moreover, with the GRZ's strategic focus on establishing Zambia as a renewable energy hub in the region, the nation is poised to emerge as a regional power exporter in the coming 30 years.

Figure 5.13: Electricity Export Demand 2020 – 2050 (MW)

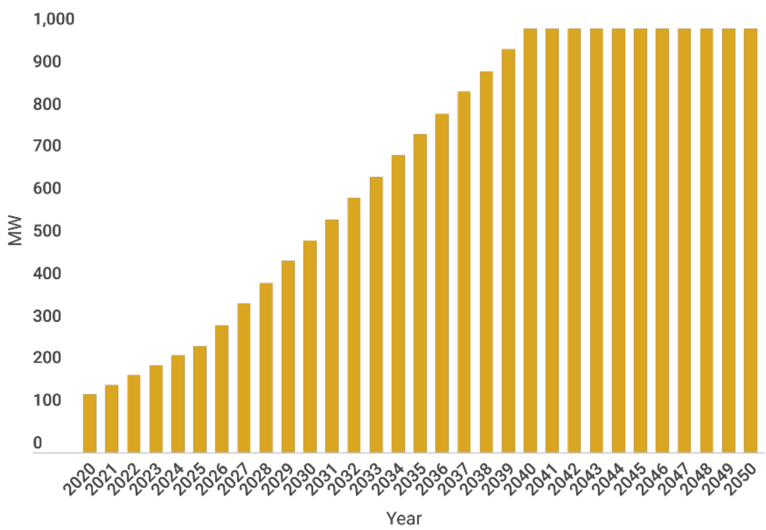


Figure 5.14: Electricity Export Demand 2020 – 2050 (GWh)

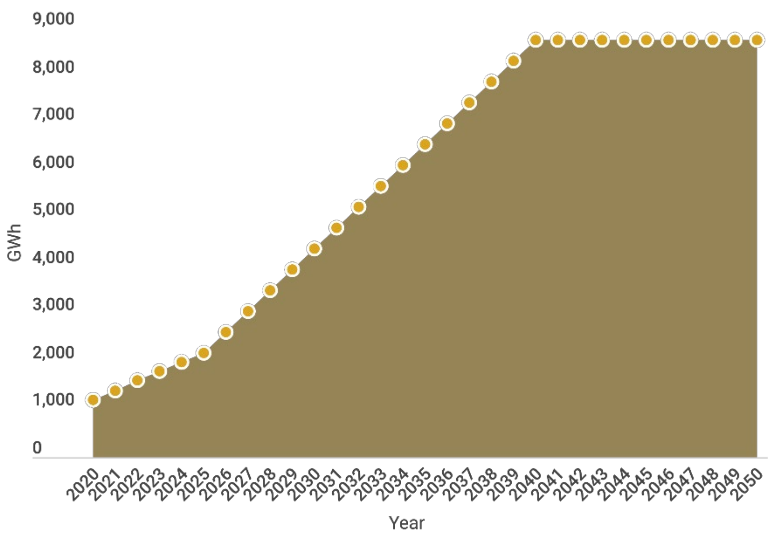


Table 5.8: Electricity Export Demand 2020 – 2050 (MW and GWh)

Demand Segment	2020	2026	2030	2040	2050
Electricity Export Demand (MW)	138	300	500	1,000	1,000
Electricity Export Demand (GWh)	1,210	2,628	4,380	8,760	8,760

Electricity export demand scenario results: The projection indicates a notable increase in electricity exports, more than doubling from 138 MW in 2020 to 300 MW by 2026. Subsequently, power exports peak at 1,000 MW in 2040, and are maintained at this level from 2041 to 2050. Throughout the 30-year strategic span, the proportion of overall demand fulfilled by electricity exports exhibits fluctuations within the range of 6% to 12%, while exhibiting an average of approximately 9%.

Electricity export demand forecasting methodology: Assumptions on power exports are informed by existing power trading arrangements and anticipated future trends in power development and power trading in markets to which Zambia is connected through SAPP or expects to be connected through EAPP when the interconnector between Zambia and Tanzania is constructed. Viable export markets for Zambia include the Democratic Republic of the Congo (DRC) and Namibia. The regional trading of renewable power generated in Zambia is likely to attract climate financing where there are opportunities to displace generation from carbon emitting sources.

5.8 Technical Losses

Technical losses refer to the power that is lost as heat in the transmission and distribution networks when power is transported from generation sources to demand centres. These losses can be minimised by optimal voltage management by for example avoiding movement of large amounts of reactive power from generation sources to demand centres. This is achieved through a variety of ways including installation of power factor correction and reactive compensation equipment. There is, however, a technical limit below which losses cannot be reduced any further. It has been assumed that technical losses fall between 11% and 14% during the IRP plan period for transmission and distribution losses combined, with a gradually improving trend. For customers who take power at transmission-level voltages (such as mines), losses will be lower. Technical losses are measured so as to accurately balance supply with demand through the models used for the IRP.

Table 5.9: Technical Losses 2020 – 2050 (2020-2050)

Demand Segment	2020	2026	2030	2040	2050
Technical Losses Demand (MW)	358	436	687	1,012	1,294
Technical Losses Demand (GWh)	2,391	2,918	5,545	6,945	8,840
Percent of Technical Losses	17%	15%	15%	13%	13%

Figure 5.15: Technical Losses 2020 – 2050 (MW)

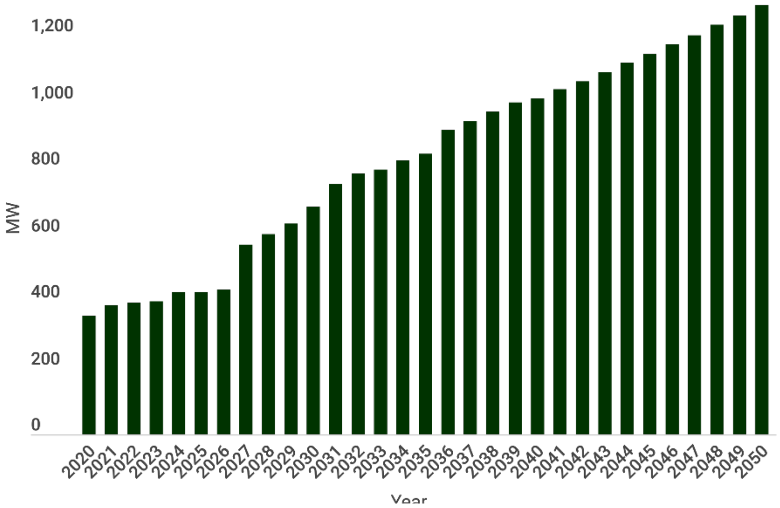
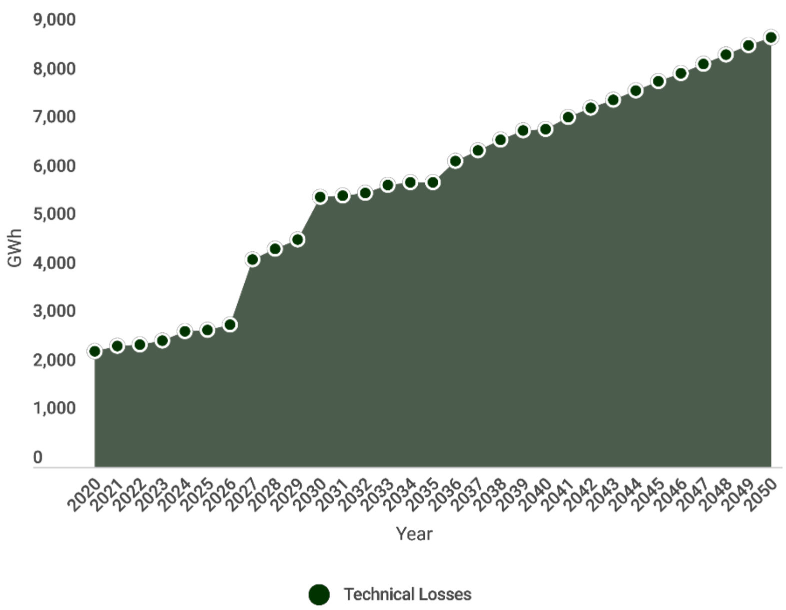


Figure 5.16: Technical Losses 2020 – 2050 (GWh)



6 INTEGRATED PLANS FOR ON-GRID POWER SECTOR INVESTMENT

6.1 Approach to the Integrated Generation Plan

The generation strategy of the IRP uses existing generation facilities as a baseline and identifies new power sources that can meet projected demand at the lowest cost, while maintaining security of supply. Potential sources are chosen based on available resources in country, spanning large hydro with reservoirs, run-of-river hydro, small hydro, thermal generation (coal and biomass), nuclear energy, solar photovoltaic (PV) and concentrated solar power, wind and geothermal technologies. This methodological approach equips decision-makers with essential information for planning grid-connected generation resource in Zambia.

The generation plan was prepared using the Antares generation planning software in conjunction with the DigSILENT power system model (2026 and 2030 data only), taking inputs from the provincial demand forecast at every high voltage substation throughout Zambia. The additional modelling through DIgSILENT provided a further layer of optimisation to the recommendations from Antares, taking account of the power system architecture, and constraints that relate to the transmission of power across the network under a range of possible scenarios. The modelling involved both static (Antares) and dynamic (DigSILENT) system studies[19] that were able to optimise the number of new generation sources and the level of VRES connected to the grid. The modelling embedded principles of sufficiency and security of supply at all times within guidelines issued by ERB and in accordance with reserve requirements specified by SAPP[20].

The models used accurate performance data for the Zambian power system from a baseline date of June 2023 for both generation plants and the transmission system. This baseline data provides a realistic representation of the existing state of the power system, enabling the models to account for actual operational characteristics, efficiencies and constraints. As the modelling exercises are aimed at shaping future energy investments, this baseline data ensures that the resulting strategies are well-informed by the present system dynamics and capabilities, leading to more practical and effective outcomes.

A prudent approach was taken to modelling, such that the Zambian system was assumed to be operating in 'interconnected mode' i.e. with interconnection to neighbouring countries. This is the normal operating mode of the Zambian system where it is interconnected to a number of its neighbours through SAPP, which provides added resilience to the system. However, even when the Zambian system occasionally detaches from SAPP, a rare occurrence, the continuity of secure operations has been validated, underlining the robustness of the future plans outlined in the IRP.

Generation planning risks

The key risks considered in the development of the generation plan are listed in Table 6.1 below, excluding cross-cutting risks associated with climate, environment and gender and social inclusion which are considered in the relevant sections of this report.

[19] See Footnote 12

[20] Meeting ERB guidelines guarantees operational reliability and safeguards against disruptions, reinforcing a seamless energy supply. Conforming to SAPP's reserve stipulations provides not only an intrinsic safety net but also aligns Zambia with regional energy dynamics, enhancing collective resilience.

Table 6.1: Key Generation Planning Risks 2023 – 2025

Risk	Impact
Too Little Generation	Insufficient generation in Zambia resulting in power-deficit driven load shedding, or the import of power at tariffs above what is affordable.
Too Much Generation	Generation capacity becomes stranded (i.e. energy not sold to customers) but the cost of capacity will typically be passed on to Government and/or customers in any case as this is a requirement of the financing structure of such projects.
Wrong Mix of Generation	Grid instability/load shedding due to technical challenges in managing the grid when there is a mismatch between the availability of dispatchable energy and customer demand at any time, and subject to available grid capacity at each location. This factor is discussed in the context of VRES below.
Wrong Location of Generation	Even if the generation mix is optimal, electricity can only be transmitted if there is sufficient grid capacity along the transmission path, and there has been sufficient investment in grid stabilisation equipment. Connecting generation sources as close as possible to customer demand generally minimises technical losses and the overall requirement for investment in the grid, which can sometimes be of a similar magnitude to the cost of generation.

Generation resources

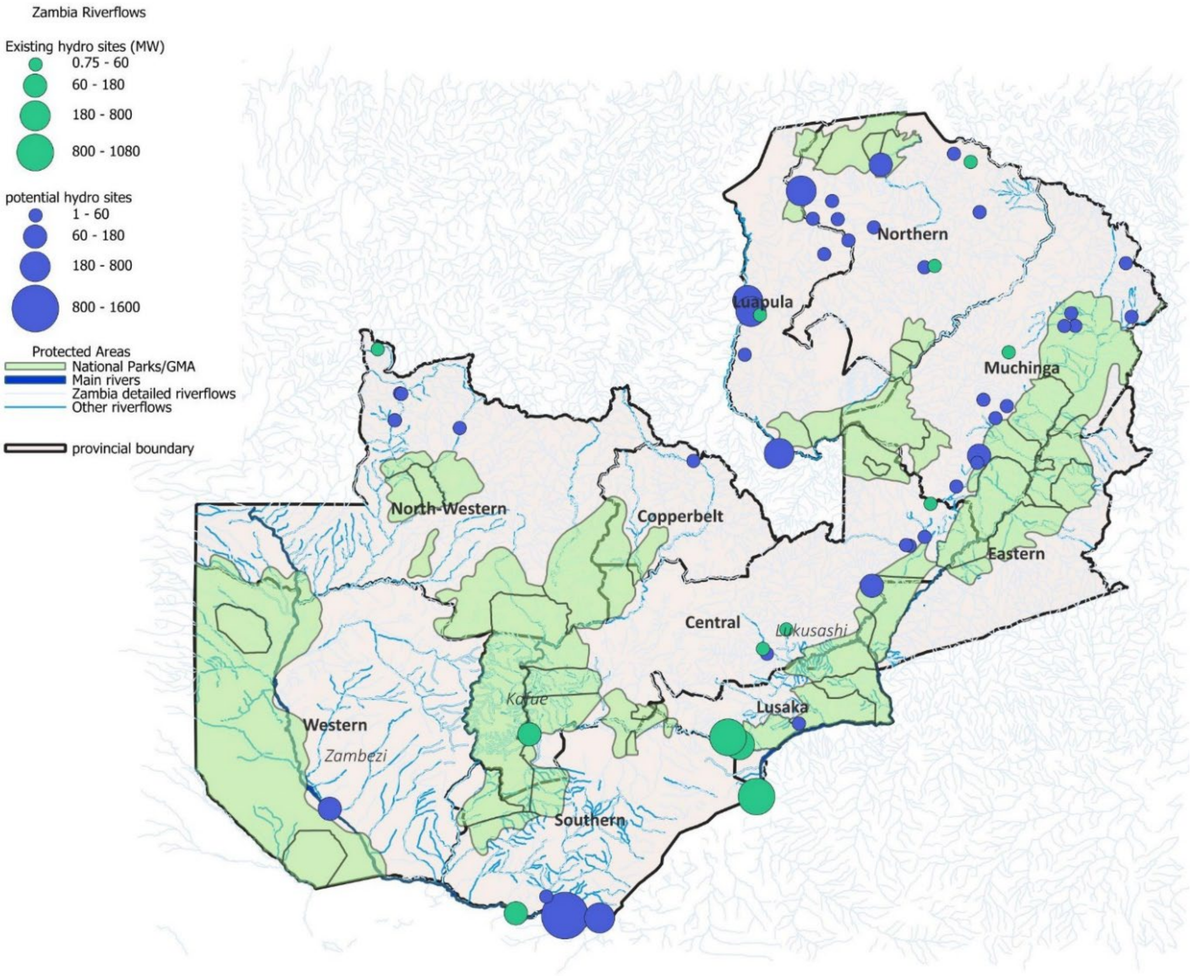
Zambia is endowed with abundant resources that can be used to generate electricity, most particularly from renewable sources. The generation modelling process has taken account of the available capacity, quality and availability of generation resource across Zambia's 10 provinces. The Office for Promoting Private Power Investment (OPPPI) is a department within the Ministry of Energy (MoE) that coordinates the process of allocating feasibility study rights and project development rights for generation projects to both public and private sector developers. OPPPI therefore has the most accurate records of potential sites for power generation using different technologies throughout Zambia.

The generation modelling approach in the IRP includes specific projects only if they are already commissioned or under construction with fully committed financing. For other projects, recommendations are made using generic cost and technical parameters, considering available resources in Zambia. This approach ensures that generation projects go through appropriate procurement and financing processes, promoting competition for the best solution among competing projects.

Hydropower

Zambia has an operating hydropower capacity of 3,153 MW as of June 2023, and has a further hydro-generation potential of 4,553 MW based on the aggregate capacity of potential hydro project sites that have been registered with OPPPI as of June 2023. Map 6.1 below shows all the currently developed and potential hydro site locations in Zambia above 0.75 MW as advised by OPPPI.

Map 6.1: Zambian Existing and Potential Hydropower Sites



Source: Actual and potential site locations provided by OPPPI, June 2023

It should be noted that the OPPPI records include project sites with feasibility studies, and in some cases, ongoing development activities. The IRP generation modelling has not chosen individual projects to recommend. Rather, the IRP has suggested types of projects based on the relative performance and cost of different generation technologies. The selection of future hydro projects will be governed by the GRZ's procurement and financing processes in collaboration with power off-takers and project developers.

A summary of existing and potential sites by province is shown in Table 6.2 below. If all sites registered with OPPPI were developed, the total grid connected capacity would be 7,706 MW.

Table 6.2: Zambia's Potential and Existing Hydro Capacity (MW)

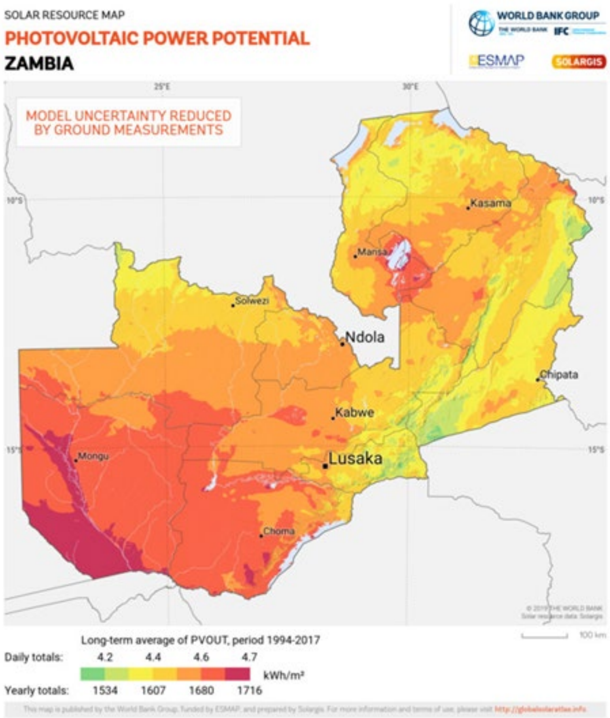
Province	Potential Hydro Capacity (MW)	Existing Hydro Capacity (MW)
Central	49	188
Copperbelt	43	-
Eastern	111	-
Luapula	1,123	10
Lusaka	20	-
Muchinga	272	1
North Western	74	1
Northern	263	25
Southern	2,418	2,928
Western	180	-
Total	**4,553 MW**	**3,153 MW**

Of the hydro capacity that has already been developed, 93% is situated in Southern Province and 99% falls within the Zambezi catchment area. The climate workstream of the IRP identified risks associated with hydro development in the southern and western areas of Zambia, with an anticipated reduction in rainfall and higher climate variability than is anticipated to be experienced in the North of Zambia. Consequently, the IRP recommends that hydro sites in Northern Province and Luapula Province, in which there is undeveloped hydro capacity of 1,386 MW, are prioritised for future development.

Solar

A solar atlas for Zambia has been developed by the World Bank-funded Energy Sector Management Assistance Program (ESMAP) which provides PV generation potential throughout the country. Solar PV electricity output in the range of 1,550 kWh/m2 to 1,700 kWh/m2 is possible in most areas of the country. The seasonal variability is small compared to other countries further away from the equator, qualifying Zambia as a country with high solar potential. Solar irradiation levels are relatively higher in the southern and western regions of Zambia.

Map 6.2: Zambia Photovoltaic Power Potential



Source: ESMAP/World Bank. April 2019 – Solar Resource and PV Potential in Zambia
https://documents1.worldbank.org/curated/en/139281556198757322/pdf/Solar-Resource-and-PV-Potential-of-Zambia-Solar-Resource-Atlas.pdf

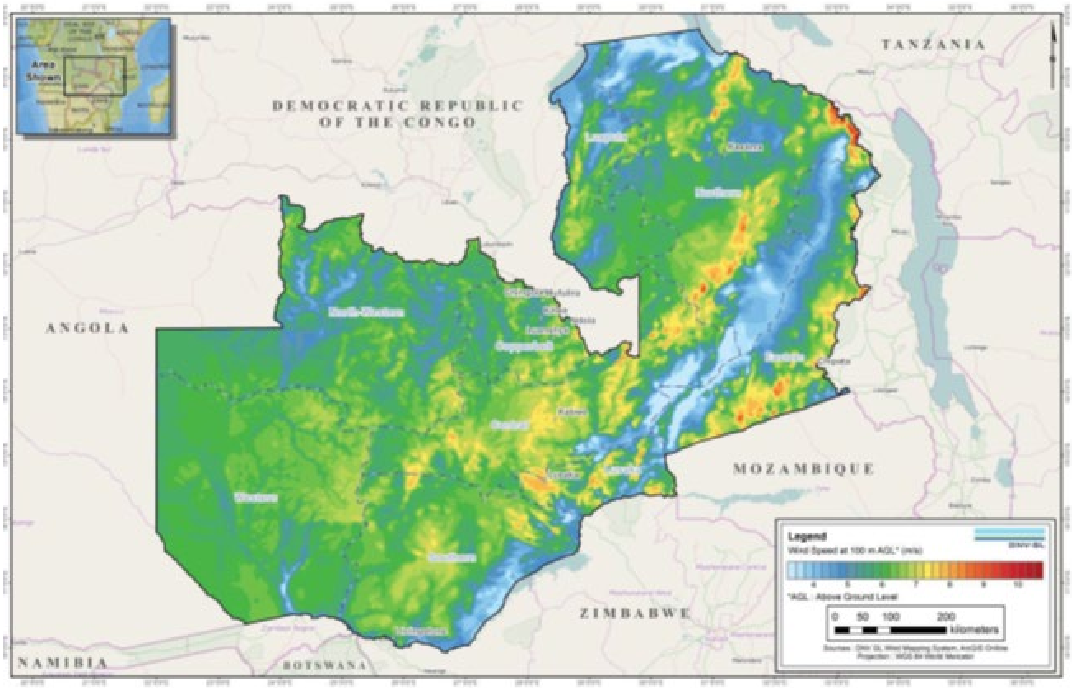
Wind

Wind speeds of between 7.0 and 8.2 m/s were measured based on a study of eight possible wind generation locations published by the World Bank ESMAP programme in 2018[21]. A wind atlas for Zambia published by ESMAP is shown in Map 6.3 below. It is observed that specific areas, particularly Eastern

[21] World Bank and ESMAP, 2018, Wind Resource Mapping in Zambia – 12 Month Site Resource Report. https://documents1.worldbank.org/curated/en/528711526549758961/pdf/Renewable-energy-wind-mapping-for-Zambia-12-month-site-resource-report.pdf

and Muchinga Provinces, serve as the primary wind corridors, while moderate wind levels are also measured in Central and Lusaka Provinces.

Map 6.3: Zambia Wind Generation Potential



Source: ESMAP/World Bank. Zambia - Wind Measurement Data. 2 km resolution mesoscale wind atlas for Zambia. [*https://energydata.info/dataset/zambia-wind-measurement-data*](https://energydata.info/dataset/zambia-wind-measurement-data)

Coal

Zambia also holds at least 170 million tonnes of coal reserves as of 2013[22]. Maamba Collieries Limited (MCL) is the largest coal mining company in Zambia and commissioned a 300 MW independent power producer (IPP) in 2016 – 2017 with coal as the fuel source. MCL has proven reserves in excess of 200 years.

Geothermal

The MoE and the private company Kalahari GeoEnergy ('Kalahari') have undertaken significant geological studies to ascertain the potential for geothermal power generation in Zambia. It is estimated that generation potential of 1,100 MW may exist. A feasibility study was completed in 2022 by Kalahari for the construction of an 8.5 MW geothermal plant at Bweengwa River in Southern Province, which is likely to be the first site to be developed. The additional resource is located at various locations around Zambia, including Kalomo, Itezhi Tezhi (Southern Province), Lake Mweru (Luapula Province) and Luangwa (Eastern Province).

Biomass

[22] Environmental and Social Impact Assessment Summary, Maamba Collieries Power Generation Project.

Based on a study published in 2000[23], Zambia could generate 1,192 MW of electricity through a combination of gasification and combustion technologies. In particular, by-products from agricultural crops and livestock residues hold potential as renewable energy sources for grid-connected generation.

Generation modelling approach

The Antares generation planning system used in the IRP's generation modelling employs a least cost approach to recommend generation sources based on available national resources. The Antares system considers the detailed demand profile (including time of day and location) and the operational and financial characteristics of different generation plants.

The Antares system considered the following technologies as possible generation sources:	
Non-Variable Clean Energy Sources	Hydro, Geo-thermal, Bio-mass, Nuclear
Non-Variable Carbon Emitting Sources	Coal, Heavy Fuel Oil, Petroleum/Diesel
VRES	Solar, Wind, Concentrated Solar Power

The system did not recommend all of the above energy sources as appropriate for the Zambian system based on technical performance and cost. The Antares system took into account the considerable energy storage capacity of the current Zambian system through the hydro storage dams at Kariba, Kafue Gorge and Itezhi Tezhi. This storage of energy affords considerable flexibility for Zambia to develop VRES and to provide energy storage as a commercial service to customers in Zambia and elsewhere in the region through SAPP.

Gas generation was excluded as a possible generation source as there is currently no gas pipeline to facilitate the importation of liquefied natural gas (LNG) into Zambia. Should such a pipeline be constructed in future, the modelling results may change accordingly.

Generation modelling results

The results of the modelling are presented in Table 6.3 below based on the reference years of 2026, 2030, 2040 and 2050 with a baseline generation capacity established in June 2023.

Table 6.3: Generation Modelling Results for 2026, 2030, 2040 and 2050

Technology	Installed Capacity June 2023	Capacity Addition (MW)				Total Cumulative Installed Capacities (MW)			
		2023 - 2026	2027 - 2030	2031 - 2040	2041 - 2050	2026	2030	2040	2050
Hydro	3,147	650	1,555	1,480	1,420	3,797	5,352	6,832	8,252
Thermal – Steam (Coal/other fuels)	435	-	600	600	600	435	1,035	1,635	2,235
Geothermal	-	-	30	480	480	-	30	510	990
Renewable – Biomass	-	51	270	300	600	51	321	621	1,221
Renewable – Solar PV	123	1,555	405	1,373	1,440	1,678	2,083	3,456	4,896
Renewable – Wind	-	400	792	2,272	2,135	400	1,192	3,464	5,599
Total Generation	**3,705**	**2,656**	**3,652**	**6,505**	**6,675**	**6,361**	**10,013**	**16,518**	**23,193**
Percentage VRES	3%	74%	33%	56%	54%	33%	33%	42%	45%
Percentage Carbon Emitting	12%	0%	16%	9%	9%	7%	10%	10%	10%

[23] UN Food and Agriculture Organization, 2000, An Integrated Bioenergy and Food Security Assessment (BEFS), Working Paper 84 'Sustainable Bioenergy Potential in Zambia'. www.researchgate.net/publication/349895745_Sustainable_bioenergy_potential_in_Zambia_-_An_integrated_bioenergy_and_food_security_assessment

Grid-connected generation capacity required to meet demand will grow by 170% from 3,705 MW in June 2023 to 10,013 MW by 2030 and by a further 132% to 23,193 MW by 2050, comprising an overall increase of 526% for the full plan period to 2050.

Hydro remains the dominant source of generation through the plan period comprising 85%, 53% and 36% of total installed capacity in 2023, 2030 and 2050 respectively. The IRP recommends that the future priority for hydro development should be to pursue projects in the north-eastern area of the country which forms part of the Congo River catchment area, which is anticipated to have more stable hydrology over future decades than the Zambezi catchment area in the western and southern regions of the country.

Additionally, Table 6.3 demonstrates the extent to which the Zambian grid is able to absorb VRES through the IRP plan period. VRES generally provide energy which is cheaper than other sources. However, there is a limit to the capacity of VRES that can be connected to the grid without causing power system instability. This is because energy dispatch from VRES is non-dispatchable and inherently difficult to predict, and, moreover, VRES do not have as many advantages as non-variable generation sources in ensuring stability of frequency and voltage as grid load conditions vary.

VRES provide 3%, 33% and 45% of grid capacity in the years 2023, 2030 and 2050 respectively. However, the contribution to energy from VRES in the same years is significantly lower as the capacity factor (CF) of VRES[24] is generally much lower than the CF of non-variable generation sources.

Overall, the generation plan proposes a significant diversification in sources of supply considering the resources available within Zambia. In June 2023, hydro comprises 85% of Zambia's generation supply. While the IRP continues to recommend hydro generation as the leading technology, it diversifies heavily into other technologies. Through this diversification, along with a continued investment in hydro, the overall generation supply of hydro will become 53% and then 36% in 2030 and 2050 respectively.

The Zambian generation system is considered to have low carbon emissions in comparison to most power systems worldwide. The percentage of electricity that is generated from carbon emitting sources is currently (June 2023) 12%, reducing to 10% and 10% in the years 2030 and 2050 respectively based on modelling results. Recognising that Zambia has made commitments to reduce emissions by at least 25% in absolute terms through its NDCs submitted to the UN Framework Convention on Climate Change (UNFCCC), this creates an opportunity to explore ways to avoid some of these emissions through clean energy alternatives in future provided that concessional external funding sources are identified.

Environmental considerations for generation projects

As the demand for land and water resources intensifies, it becomes critical to make more informed and strategic decisions regarding energy sources. Ill-planned and ill-located renewable energy projects may threaten the nation's biodiversity and contribute to local conflicts, impeding progress in grid transformation and climate change mitigation. By carefully selecting the appropriate renewable technologies based on least cost assumptions and climate parameters, and locating them in suitable locations, GRZ can minimise negative impacts on the environment. The aim is to achieve climate and

[24] Capacity refers to the maximum amount of electricity (measured in MW or GW) a plant can produce under optimal conditions. Energy is the actual amount of electricity generated over time (measured in MWh or GWh). Capacity factor (CF) compares actual generation to maximum potential at peak capacity. The CF of variable renewable energy sources (VRES) is typically significantly lower that the CF for non-variable generation sources.

energy objectives while safeguarding ecosystems, preserving the integrity of rivers, and supporting Zambian communities.

The IRP's environment workstream focused on highlighting the key environmental risks and recommending best practice for three key technologies – hydro, solar and wind.

Environmental risk assessments of key energy technologies

Hydro zones: The assessment of environmental impacts for hydro projects is guided by five key evaluation criteria:

- impacts on free-flowing river status;
- impacts on aquatic species;
- impacts on waterfalls;
- impacts on connectivity and flow[25];
- impacts to protected areas.

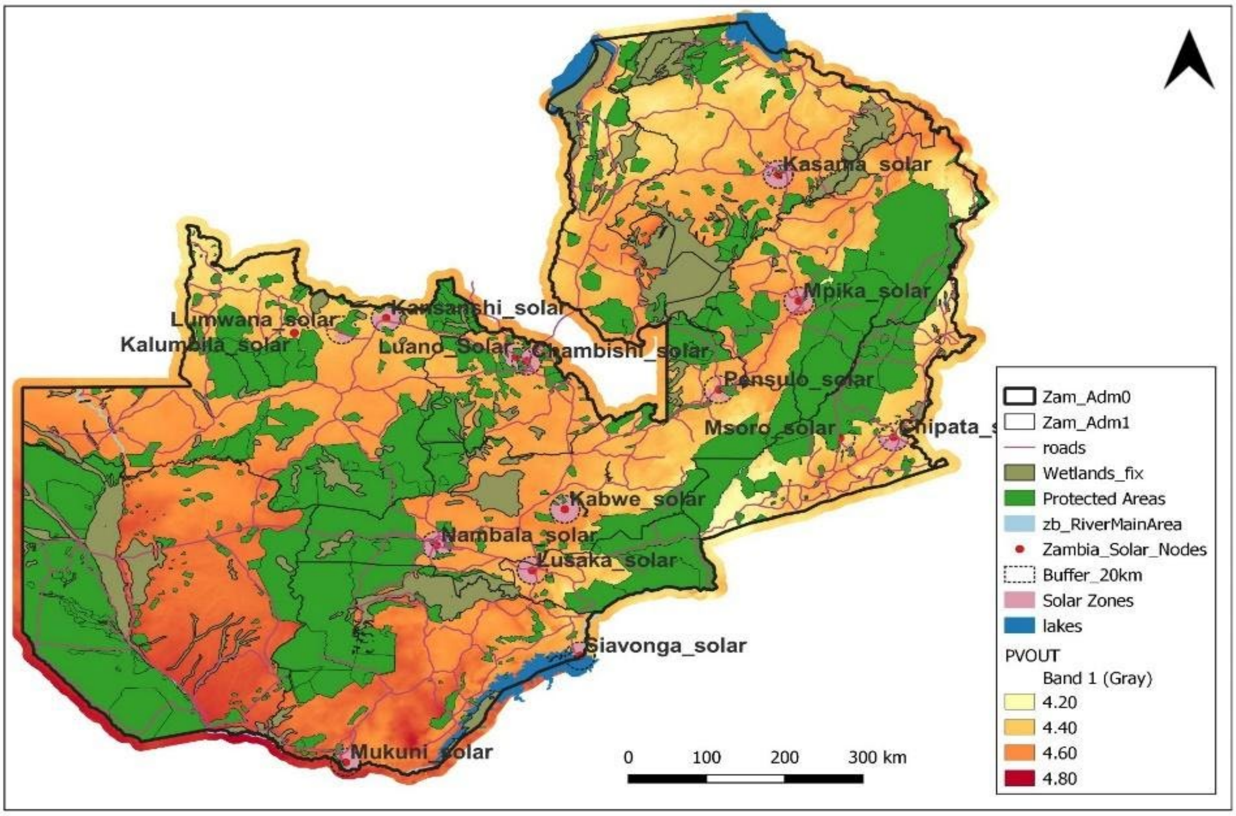
By considering these criteria, an evaluation of the environmental risk factors associated with potential hydro projects can be conducted. Based on the assessment results, an environmental risk mitigation plan can then be developed to address and minimise the identified environmental risks. These principles and criteria serve as a framework to ensure the sustainable development of hydro resources in Zambia. An environmental impact assessment of a particular proposed hydro project will need to consider both local impacts and overall impacts on the river catchment areas, taking account of other projects that have taken place or are planned to take place, whether or not associated with power generation (e.g. dams for irrigation).

Solar and wind zones: The environmental workstream of the IRP undertook an assessment for solar and wind energy resources in Zambia resulting in the identified recommended development zones, referred to as solar and wind nodes. These nodes have been determined based on their solar and wind potential while ensuring minimal overlap with protected areas, areas with natural vegetative cover, water bodies or wetlands. This approach aims to minimise the co-location of renewable energy zones with environmentally sensitive areas. The identification of these renewable energy zones used a multi-criteria methodology, considering factors such as high renewable energy resource potential, exclusion of protected areas and ecologically sensitive regions like forests, wetlands, water bodies and gaming preserves, avoidance of built-up areas, proximity to transmission substations and road networks, availability of sufficient land for hosting multiple utility-scale renewable energy projects, and geographical diversity. By employing these criteria, the selection of solar and wind nodes ensures optimal use of renewable energy resources while minimising environmental impacts and promoting sustainable development.

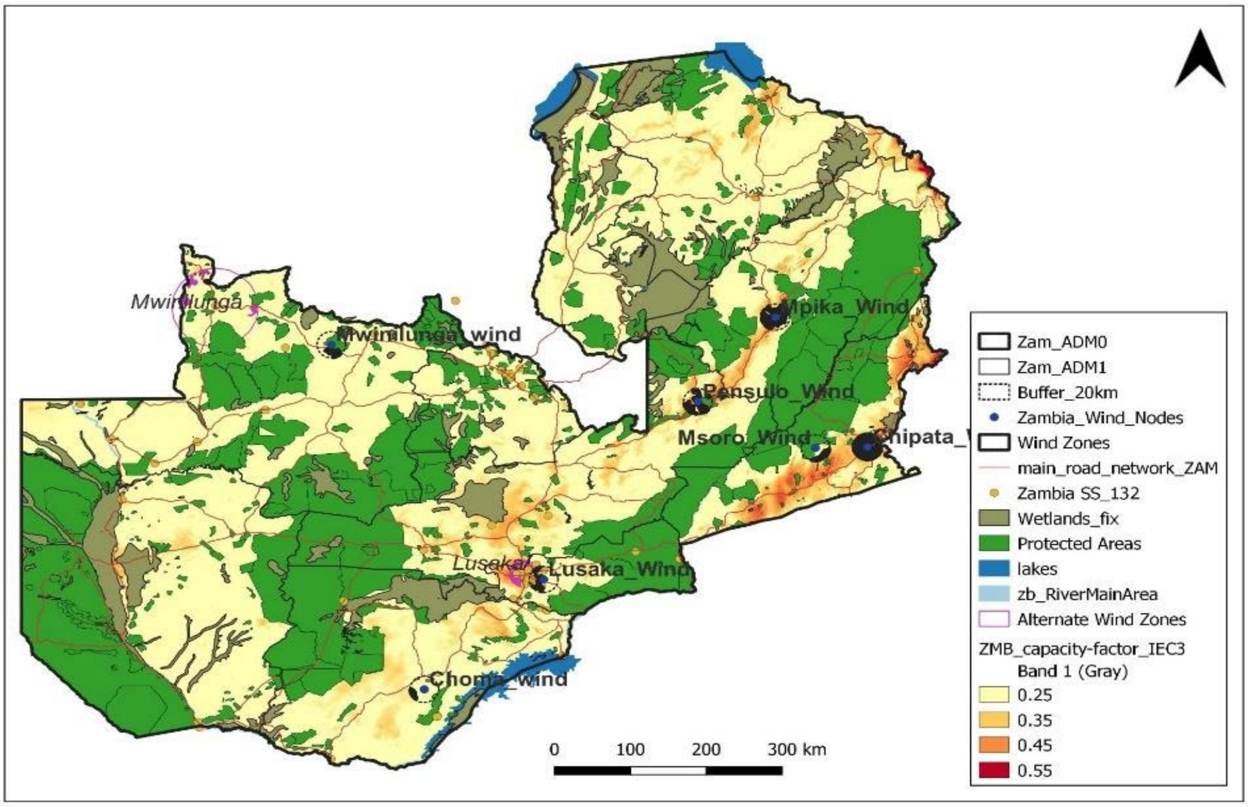
The recommended node locations for solar projects can be found in Map 6.4 and for wind projects in Map 6.5.

[25] In the context of the environment workstream of the IRP, 'connectivity' refers to the unimpeded flow and connectivity of rivers and water bodies. It emphasises the importance of maintaining natural river courses, free-flowing rivers and the connectivity between different river segments. Preserving river connectivity is essential for sustaining aquatic ecosystems, supporting fish migration, maintaining water quality and ensuring the overall health and functioning of riverine habitats. By considering connectivity in the assessment of renewable energy projects, it aims to minimise the disruption to river systems and safeguard the ecological integrity and functionality of river networks.

Map 6.4: Solar Renewable Energy Zones



Map 6.5: Wind Renewable Energy Zones



Alignment with international best practice

Numerous African nations have undertaken the task of designating specific regions for renewable energy development. South Africa, for example, undertook two Strategic Environmental Assessments in 2014 and 2019, resulting in the identification of 10 distinct zones ideally suited for large-scale wind and solar energy projects[26]. In a similar endeavour, the Renewables Readiness Assessment conducted by Tanzania in 2017[27] pinpointed nine renewable energy zones, primarily guided by economic considerations. This strategic approach, which involves the identification of these "nodes" or "zones", facilitates planning of generation resources based on a methodical approach taking account of resource availability and environmental impacts in conjunction with associated infrastructure investments in transmission, road construction and other enabling infrastructure that providing essential services. Such an approach enhances efficiency and sustainability in the development of renewable energy resources. As such, the inclusion of such recommendations in Zambia's IRP is aligned with regional best practice.

6.2 Integrated Transmission Plan

An electricity transmission network refers to the infrastructure and system that transports electrical power from power plants to distribution networks and large industrial consumers. It is a crucial part of the overall electricity supply chain, facilitating the efficient and reliable transmission of electricity over long distances. The transmission network consists of high-voltage power lines, substations,

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[26] Republic of South Africa. Forests, Fisheries and the Environment. Renewable Energy Development Zones (REDZs) and Strategic Transmission Corridors. https://egis.environment.gov.za/redz

[27] IRENA (2017), Renewables Readiness Assessment: United Republic of Tanzania, International Renewable Energy Agency, www.irena.org/publications/2017/May/Renewables-Readiness-Assessment-United-Republic-of-Tanzania

transformers and associated equipment. It is designed to transmit electricity at high voltages to minimise power losses during long-distance transportation. By increasing the voltage, the current can be reduced, resulting in lower resistive losses.

Power plants, whether they generate electricity from conventional sources such as coal, natural gas or nuclear energy, or renewable sources like wind, solar or hydro, are typically located far away from the end consumers. The electricity generated is stepped up to high voltages, typically in the range of hundreds of kilovolts (kV), for efficient transmission. The transmission network plays a vital role in ensuring the reliable delivery of electricity by managing power flow, voltage control, and maintaining system stability. It connects various power generation sources to load centres and enables the integration of different sources of energy into the grid. As such, the electricity transmission network forms the backbone of the power infrastructure.

Transmission modelling approach

An exhaustive assessment of the Zambian transmission network was conducted to develop a plan for the enhancement of the transmission network over the 30-year planning horizon, up to 2050. The objective was to assess the current transmission network by conducting desktop software analyses and propose technically and financially sound projects that need to be implemented to ensure security of supply and provide the basis for the development of generation and distribution infrastructure.

The key objectives related to transmission planning were to:

1. Ensure sufficient transmission capacities for growing generation and increasing demand.
2. Ensure that the Zambian power system can operate in an isolated/islanded mode and as part of the SAPP network.
3. Suggest technically viable and commercially sound projects which would ensure that the system is secure and stable up to 2050.
4. Rank transmission projects so that they are executed according to the priority (technical, commercial, strategic).

Load projections at high voltage substations (known as bulk supply points) were provided so that software analyses could be done for voltage levels starting from 330 kV down to 66 kV voltage level. Transmission network analyses included AC load flow calculations, security calculations simulating power system operation with single element out of service (N-1 analyses), short circuit current calculations and dynamic stability simulations.

These calculations were done for the years 2026, 2030, 2040 and 2050, including:

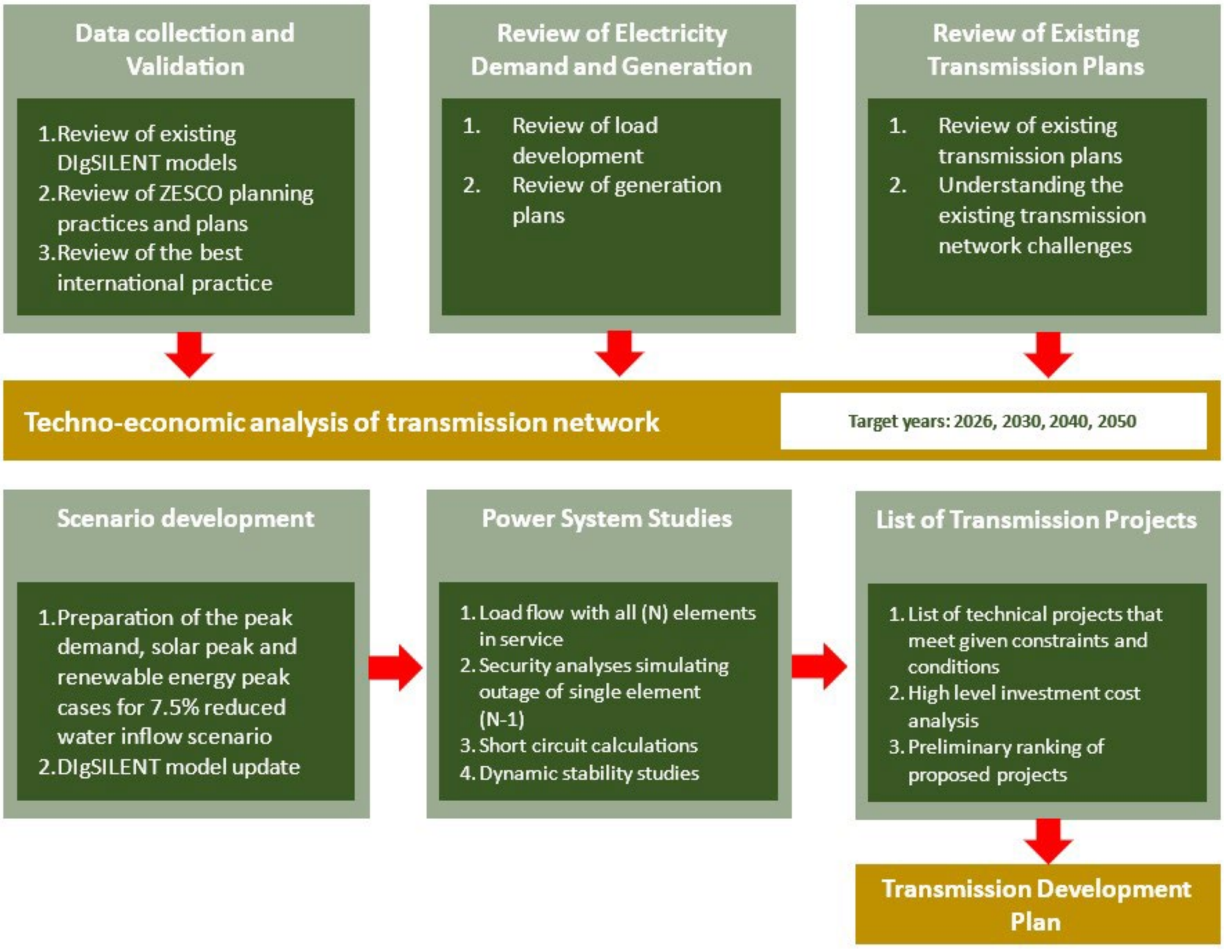
- peak system loading;
- maximum solar PV generation;
- maximum renewable generation.

All analyses were completed using the DIgSILENT PowerFactory software, which has already been used by the transmission network operators in Zambia. A summary of the transmission network planning philosophy is shown in Figure 6.1 below.

The output from the transmission modelling process in Figure 6.1 is a completed analyses for all listed scenarios and target years, that resulted in a list of a technically acceptable projects. The technically viable transmission projects for each of the studied years were ranked against a set of criteria. Rank has been assigned to each component of the project (e.g. new transmission line or new substation), although each of the components is an integral part of the project. Candidate projects were assigned with high-level investment costs.

If the projects are implemented on time, secure and reliable power supply in Zambia will be achieved by 2050. Although priority and importance for the selected projects is provided, this may also be affected by the government's strategic decisions, which are not currently factored in.

Figure 6.1: Transmission Network Planning Methodology

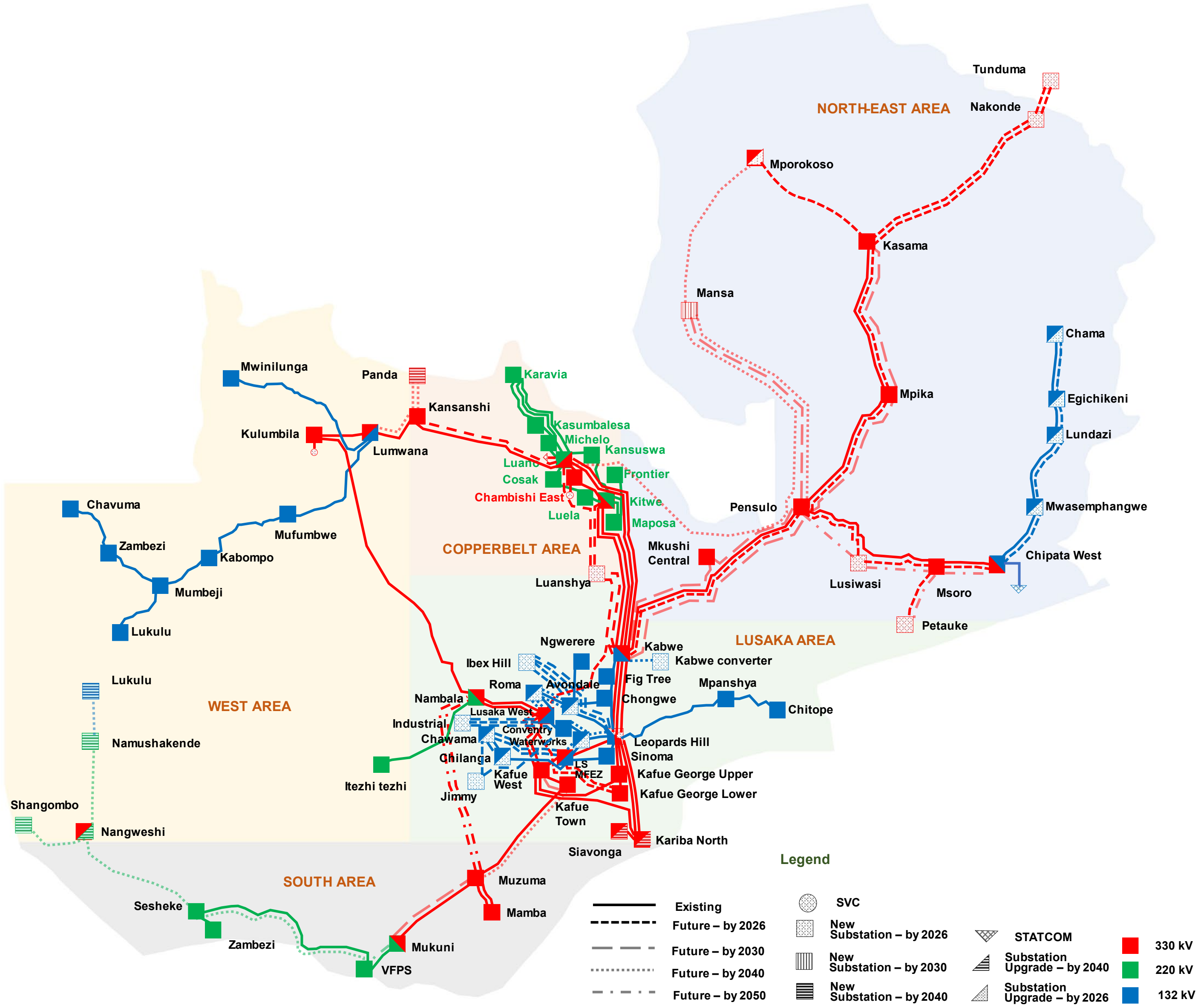


Transmission modelling results

Map 6.6 below summarises all of the transmission projects required to be implemented to guarantee security of supply under both normal and abnormal system conditions and to maintain the dynamic stability of the Zambian power system through to 2050. Detailed information on the key developments within the 330 kV, 220 kV and 132 kV transmission networks for these regions can be found in the sections that follow this summary map below. Development plans for the 88 kV and 66 kV network which have less overall significance than the projects at higher voltages are not included in the following sections but can be found in the IRP transmission system planning report.

The transmission plan for Zambia has been split into four zones for ease of presentation, each of which has different characteristics with respect to anticipated demand growth and actual or planned generation sources to be connected to the grid through the IRP plan period. The first zone covers Northern and Eastern areas, the second Copperbelt, the third Lusaka and the fourth Southern and Western areas of Zambia.

Map 6.6: Zambian Transmission Network Development Plan to 2050



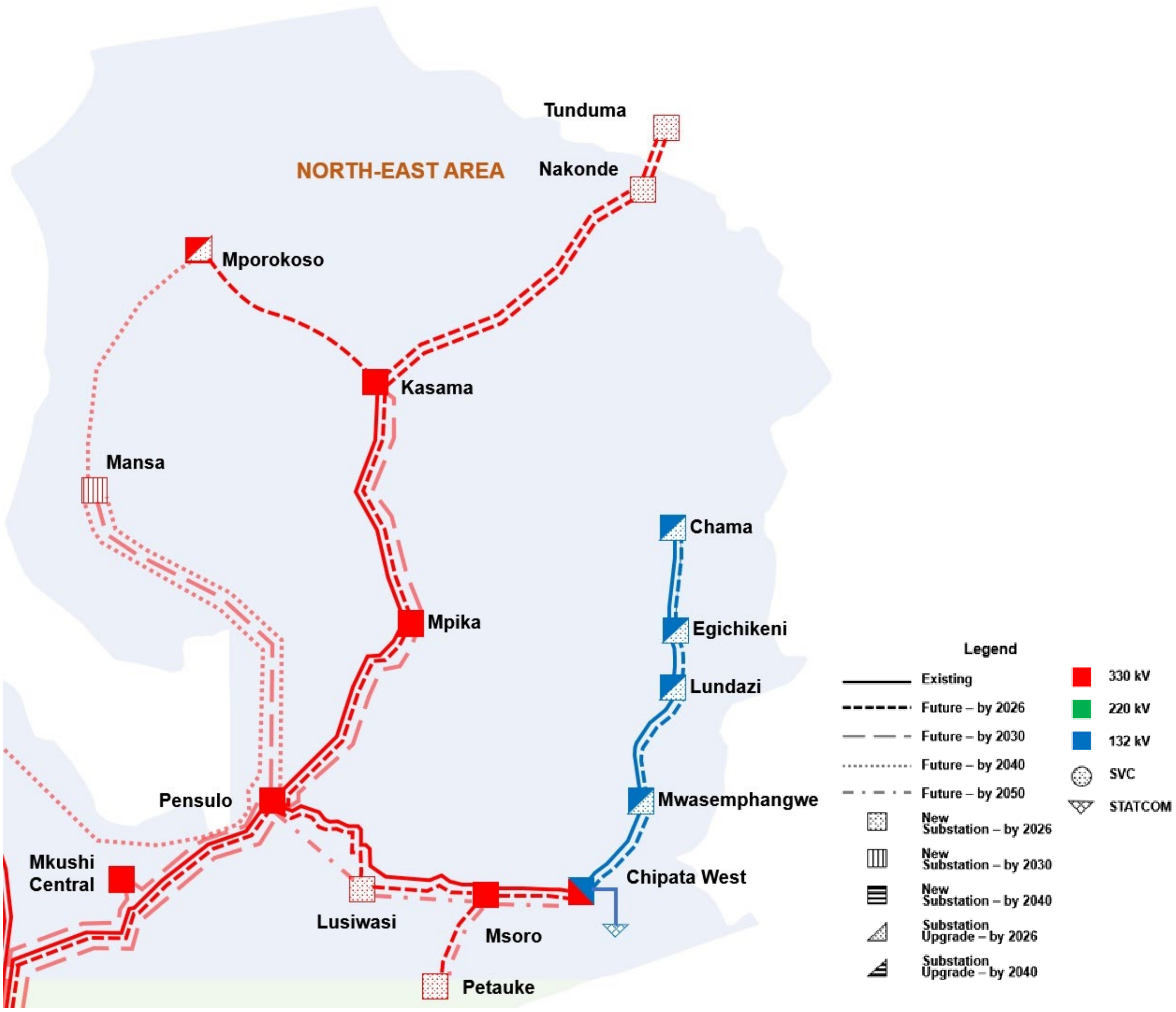
Notes:

- *Locations and routes are indicative*
- *88 kV and 66 kV network are not presented but is included in the IRP report*
- *Line type (continuous / dashed) is applicable for all voltage levels*
- *Installed capacity differs from available capacities which are which are subject to seasonal loading and generation dispatch*

Northern and eastern areas

Transmission network developments in the Northern and Eastern areas of Zambia for the period to 2050 are shown in Map 6.7 below.

Map 6.7: Transmission Network Development – Northern and Eastern Areas (2020 – 2050)



The reinforcement of the 330 kV transmission network from Pensulo to Nakonde is part of a broader plan to expand the transmission network in the Southern Africa region to accommodate power trading with East Africa. By strengthening the north-eastern network, Zambia will enhance its energy security and position itself as a reliable electricity supplier in the region. Increased power trade will bring economic benefits, attracting investment, creating job opportunities, and fostering regional economic growth. The most high-profile project is the extension of the existing 330 kV transmission line from Kasama to a new Nakonde 330 kV substation from which an interconnection with Tanzania will be constructed, and subsequent reinforcement of the 330 kV line from Pensulo 330 kV substation in Central Province to Mpika and Kasama.

The transmission network connecting Eastern Province will be strengthened through construction of a new 330 kV transmission line from Pensulo to Chipata West, supported by a new 330 kV substation at Lusiwasi. Furthermore, the development of the sub-transmission network at 132 kV from Chipata West to Chama substations will extend electricity access to previously underserved areas, stimulating economic activities and improving the quality of life for the local population. This expansion will also facilitate the integration of renewable energy sources situated in Eastern Province, creating additional locations that can be used to connect renewable energy sources to the grid.

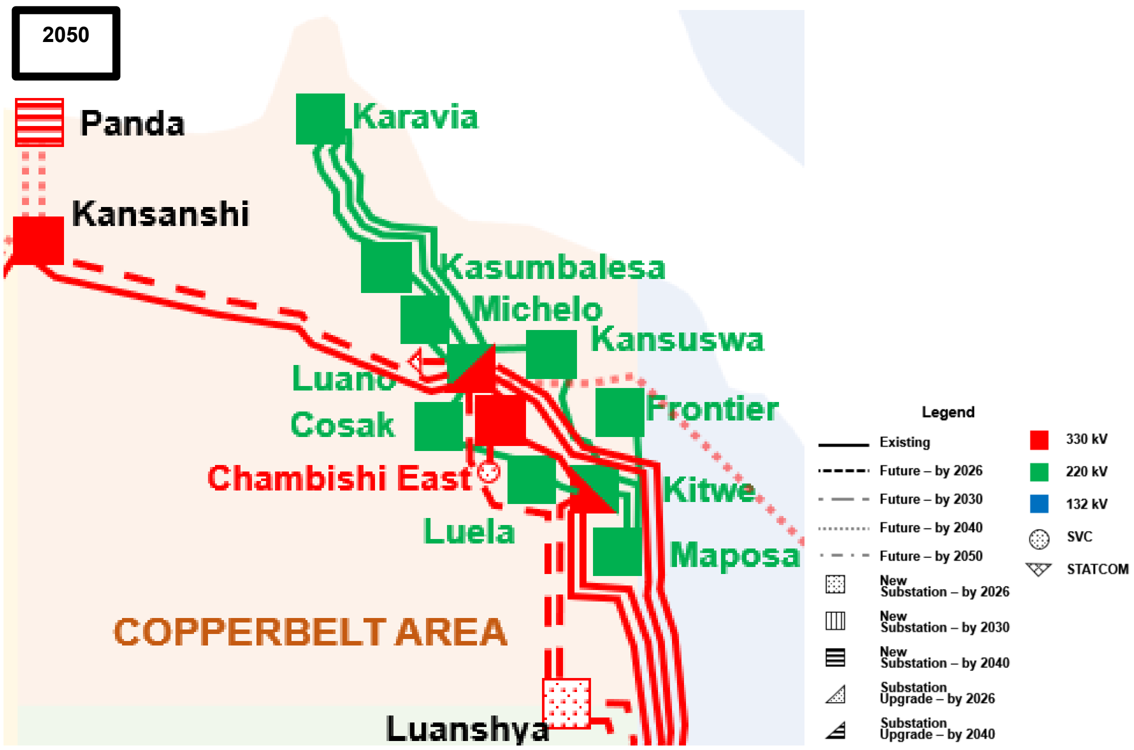
The reinforcement of the 330 kV Kabwe to Pensulo line will play a crucial role in strengthening the connection with the main 330 kV transmission system which runs from Lusaka to the Copperbelt.

The plan also includes a new 300 KV transmission line and 300 kV substations at Mansa and Mporokoso, and a 300 kV line connecting Mansa to the Copperbelt. These investments will enable the connection of renewable energy sources located in Luapula Province and Northern Province to the national grid, and the transmission of this power to the main mining load centers in the Copperbelt and North Western Province.

Copperbelt area

Transmission network developments in the Copperbelt area for the 2026 – 2050 period are shown in Map 6.8.

Map 6.8: Transmission Network Development – Copperbelt Area (2026 – 2050)



Significant improvements in the transmission network on the Copperbelt are planned, which will enhance capacity and security of supply to the mining industry and mining towns on the Copperbelt. One of the key projects involves reinforcing the network with the Luano – Kansanshi transmission line and the installation of a static VAR compensator (SVC) at the Luano substation for voltage control. These enhancements are essential to ensure a stable and reliable power supply for the mining sector, which is predominantly based in the Copperbelt and North Western Province, and which plays a vital role in Zambia's economy.

To further strengthen the transmission network in this region, a new 330/132 kV Luanshya substation is planned for construction by 2026. This substation will be interconnected with the existing Luano substation via a 330 kV line, as well as with the Chambishi East substation through another 330 kV line. This expansion will not only improve connectivity within the Copperbelt region but will also establish links with the southern Kabwe substation. These developments will provide a robust energy infrastructure, supporting the growth of the mining sector and contributing to its long-term sustainability.

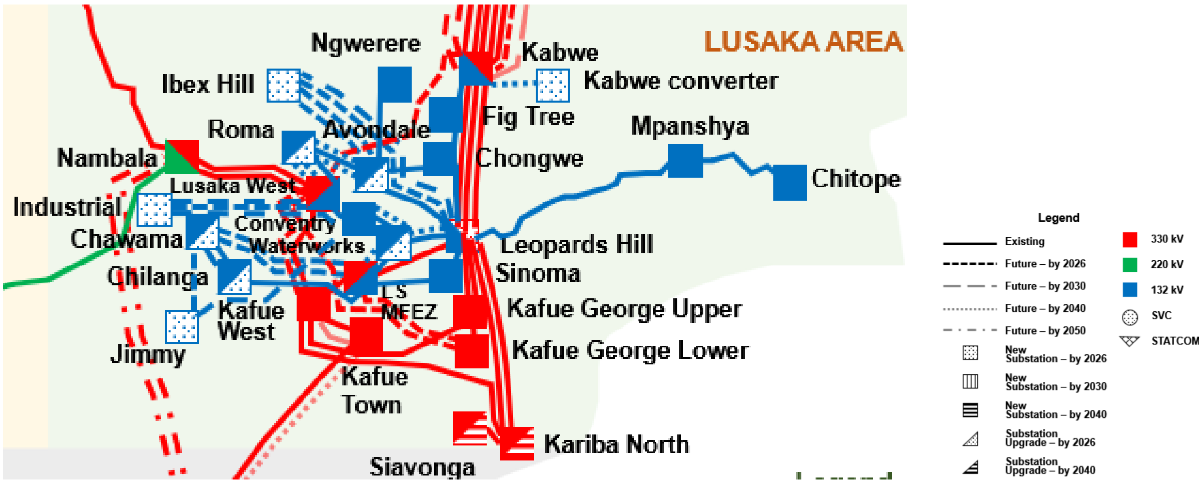
Looking ahead to 2040, the Copperbelt region will witness the interconnection of the Luano substation at 330/220/66 kV with the Mansa substation at 330/66 kV in the North-Eastern region, facilitating the transmission of renewable energy generated in Luapula Province and Northern Province to supply mining operations. This interconnection will bolster the overall transmission network, promoting better power exchange and regional development. In the long term, by 2050, the Copperbelt region will benefit from the installation of a voltage control device (STATCOM) at the Luano substation. This technology will enhance voltage stability and prevent potential voltage collapses, ensuring a reliable and consistent power supply for the entire region. This will further optimise the transmission network's performance and support the overall electricity infrastructure in the Copperbelt region.

Suggested developments will have far-reaching positive impacts. Reliable and stable power supply in the region will support the mining sector's operations, leading to increased productivity, job creation and economic growth. The enhanced transmission infrastructure will also help to attract further mining investments, stimulating industrial activities and promoting the overall development of the region.

Lusaka area

Transmission network developments in Lusaka area for the 2026 – 2050 period are shown in Map 6.9.

Map 6.9: Transmission Network Development – Lusaka Area (2026 – 2050)



The Lusaka area will benefit from significant enhancements in its transmission network, to provide resilient power supply to the nation's capital as its economy grows. By 2026, the network will be strongly reinforced through various projects including a doubling of the capacity of the transmission line from Kafue West to Lusaka West, as well as the construction of new transmission lines from Kafue George to the Lusaka South Multi-Facility Economic Zone and from Kafue George to Lusaka West. These upgrades are crucial to increase the network's capacity, improve system security and reliability, and accommodate the anticipated growth in and around Lusaka. In addition, the sub-transmission network at 132 kV is being developed as part of the Lusaka Transmission and Distribution Rehabilitation Project (LTDRP) being implemented by ZESCO. This project involves the installation of a high-capacity transformer at the Leopards Hill substation, along with the construction of new substations and transmission lines. These enhancements will improve the stability and efficiency of the power supply in the area.

The construction of substations such as Waterworks, Chawama, Chilanga, and Ibex Hill in Lusaka, along with the expansion of existing substations, will enable better power distribution and meet the increasing electricity demand. These developments will enhance the reliability of the electricity supply, reduce outages, and provide robust energy infrastructure for Lusaka's businesses and residents. The reinforced transmission network in Lusaka will support the growth of industries, such as manufacturing, services and commerce, by providing a stable and reliable power supply. This will attract investment, stimulate economic activities, and create job opportunities. The improved electricity infrastructure will also contribute to a more favourable business environment, enabling businesses to operate efficiently and effectively.

Southern and western areas

Proposed transmission network developments in the Southern and Western areas of Zambia for the 2026 – 2050 period are shown in Map 6.10.

Map 6.10: Transmission Network Development – South-West Area (2026 – 2050)

There are significant enhancements planned for the transmission network in Southern and Western areas of Zambia, which will facilitate access, mining development and connection of renewable energy sources in these areas. By 2026, the network will be reinforced with the installation of equipment at Kalumbila Mine in North Western Province to ensure the overall stability of the voltage. These improvements will provide a reliable and consistent power supply, supporting the needs of industries and businesses in the region.

To address the limited transmission network in Western Province, a new 330/220 kV Nangweshi substation is planned for construction. This substation will be interconnected with the Shangombo and Namushakende substations through new transmission lines. These developments will enhance power transmission, improve reliability, and meet the increasing electricity demand in Western Province. This, in turn, will support economic activities, attract investment and create job opportunities.

Furthermore, the 132/33 kV Lukulu substation will reinforce the transmission network in the Western Province. This will improve the connectivity between substations and enable more efficient power exchange in the province.

The reinforcement of the Lumwana – Kansanshi transmission line will also enhance power transfer capacity to the mines in North Western Province.

In Southern Province, a new 330 kV Muzuma – Mukuni transmission line is planned, further strengthening the transmission network in the province. This expansion will improve power distribution and stability in Southern Province, benefitting various industries and communities.

By 2040, additional reinforcements will be made to the transmission network, including a second line connecting the Muzuma substation to the 330/88 kV Kafue Town substation. The Victoria Falls – Sesheke transmission line at 220 kV will be reinforced in Southern Province, and the Sesheke substation will be connected to the new Nangweshi substation in Western Province. These developments will enhance power exchange and support the overall economic growth of these provinces.

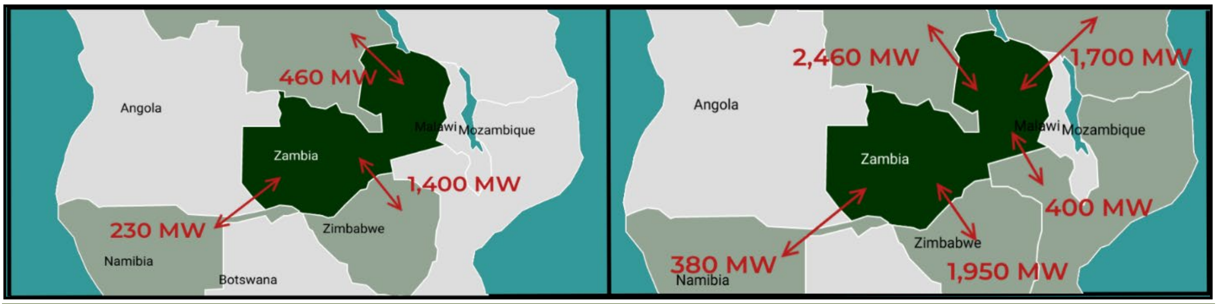
In the long term, by 2050, the Muzuma substation in Southern Province will be interconnected with the Nambala substation in Central Province through a double circuit 330 kV transmission line. This interconnection will improve power transfer and strengthen the overall transmission network in the southern and western areas of Zambia. A reliable and stable power supply network will attract investments, stimulate economic growth and create job opportunities in adjacent areas.

Interconnectors

Interconnectors are high-voltage transmission lines that link electrical grids between countries, allowing for the exchange of electricity. They are crucial for grid reliability, enable cross border electricity trade, allow customers to access diverse energy sources, and result in resource optimisation and reduced pricing of power to consumers.

Interconnections for the Zambian power system are assessed as part of the overall SAPP plan activities. This is done to ensure the sufficient interconnection capacities in the region. The development of the IRP considered the existing interconnection capacities, which are shown in Map 6.11 and later in Table 6.4 below. The left-hand map highlights interconnector capacity with neighbouring countries as of June 2023, and the map on the right indicates the cumulative interconnector capacity that is planned to be created by 2050 through investment in the transmission network in Zambia and respective neighbouring countries.

Map 6.11: Interconnection Development of the Zambian Transmission System (2020 – 2050)



Existing interconnection capacities to Zimbabwe will be upgraded with 400 kV AC Livingstone – Hwange and 400 kV AC Kariba North – Alaska transmission lines. This will facilitate an additional 550 MW of transmission capacity between Zambia and Zimbabwe.

Cross-border transmission capacities to Namibia will be upgraded with a 330 kV AC Livingstone – Zambezi transmission line, which will contribute an additional 150 MW of transmission capacity between Zambia and Namibia.

A new interconnection with DRC will be supported with the 500 kV DC Luano – Inga III line, which will have a transfer capacity of 2,000 MW.

As part of the Zambia-Tanzania interconnector project, a new capacity of 1,500 MW to Tanzania via the Kabwe – Nakonde/Mbeya line will be constructed. Furthermore, a new 400 kV Msoro – Songo transmission line will be constructed between Zambia and Mozambique enabling the transmission of 400 MW between the countries.

The combined future projects will increase the aggregated cross-border interconnection capacity between Zambia and its neighbours by 130% from 2,090 MW to 4,800 MW. This plan leverages Zambia's potential to become a regional power trading hub through its central location in Southern Africa and proximity to East Africa and Central Africa.

Table 6.4: Existing and Planned Interconnectors between Zambia and Neighbouring Countries with Associated Transfer Capacities

	Country	Voltage (kV)	Transmission Link	Capacity (MW)	Year[28]
Existing	Zimbabwe	330 kV AC	Kariba North – Kariba South	1,400	
	Namibia	220 kV AC	Sesheke – Zambezi	230	
	DRC	220 kV AC	Luano – Karavia	230	
	DRC	220 kV AC	Michelo – Karavia	230	
Total				**2,090**	
Planned	Tanzania	330 kV AC	Kasama – Mbeya (II)	200	2019
	Zimbabwe	400 kV AC	Livingstone – Hwange	250	2019
	DRC	500 kV DC	Luano – Inga III	2,000	2030
	Tanzania	500 kV DC	Kabwe – Nakonde/Mbeya	1,500	2030
	Zimbabwe	400 kV AC	Kariba North – Alaska	300	2033
	Namibia	300 kV AC	Livingstone – Zambezi	150	2035
	Mozambique	400 kV AC	Msoro – Songo	400	2040
Total				**4,800**	

[28] The years indicated are from SAPP. However, they are predicated on the availability of funding to undertake the project.

A key objective of the power system modelling process in the IRP was to ensure self-sufficiency of the Zambian power system. No reliance was placed on the above-listed interconnections to ensure system security and stability, particularly during disturbed system operation. Therefore, the transmission projects presented will facilitate a stable and reliable power system in Zambia without the requirement for support from other members of the SAPP or EAPP. Nevertheless, the commissioning of the above-listed interconnector projects will further improve the resilience of the Zambian power system.

6.3 Integrated Distribution Plan

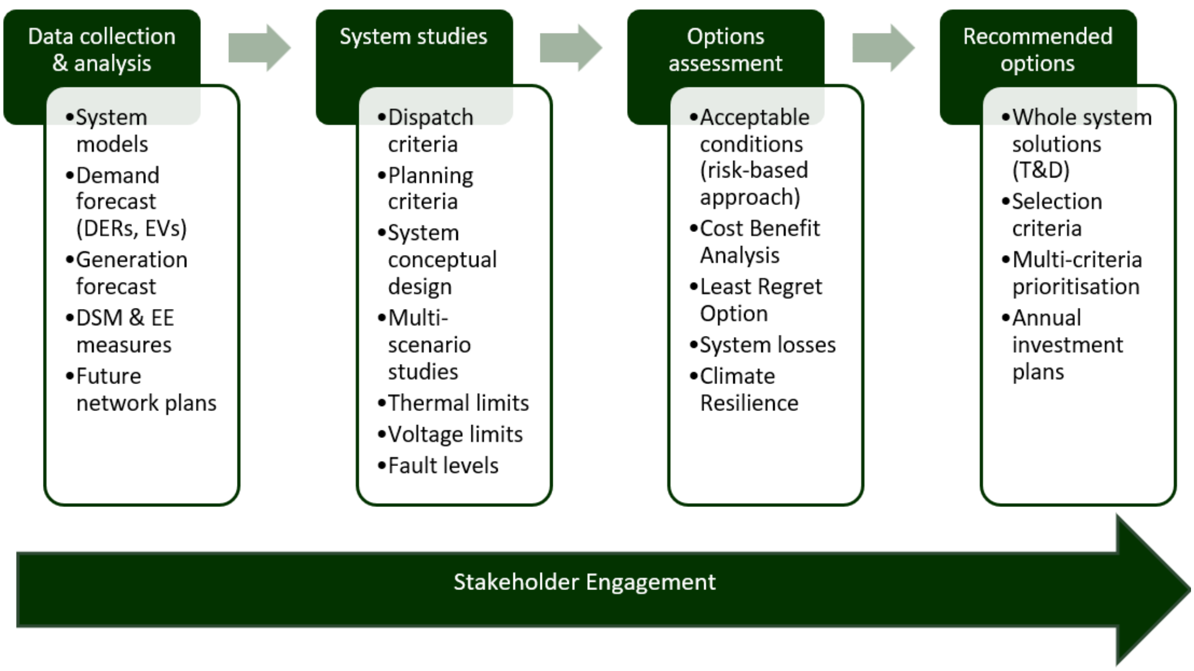
The distribution workstream of the IRP focused on the modelling of the 33 kV network in Zambia, which is used to facilitate the distribution of power to most categories of consumers, except mines and large industries which may receive power at transmission voltages. The distribution network is connected to the transmission network, and is designed so as to provide sufficient safe and reliable power to all locations across Zambia that are grid connected.

Distribution modelling approach

The distribution infrastructure planning process took a comprehensive approach by considering various factors beyond just infrastructure options to meet future system needs. This involved exploring developments in technology and consumer trends such as EVs, distributed energy resources, demand side management (DSM), and energy efficiency practices, which can influence the projected demand levels. The evaluation involved analysing a range of network solutions and non-network alternatives based on established planning objectives and criteria, using ZESCO's Design Manual and the UK's security of supply standard Energy Networks Association Engineering Recommendation P2/7 (in the absence of an equivalent Zambian standard). The latter was used to assess system security and determine appropriate network sizing to ensure compliance with security requirements.

The following were the key activities carried out in the distribution planning process as shown in Figure 6.2 below.

Figure 6.2: Distribution Planning Process



Note: DER: distributed energy resources, EE: energy efficiency; T&D: transmission and distribution

Task 1: Data collection and analysis: The initial phase of the distribution planning process involved gathering and analysing data. This data was used to model the power distribution system and examine current and future scenarios over short, medium and long-term periods as part of the IRP.

The collected data included DIgSILENT PowerFactory software models for the distribution system, existing distribution system constraints and planned projects at the time of study, distributed energy resources and EV deployment, as well as options for DSM and energy efficiency.

Task 2: System modelling and studies: The primary objective of Task 2 was to evaluate the impact of the projected demand on the distribution system and identify any system constraints that did not meet planning criteria and security standards. The outcomes from Task 2 included results for each study year, highlighting the identified constraints and the extent of non-compliance with planning criteria and security standards.

The conduct system modelling and studies, DIgSILENT PowerFactory, was used. These studies encompassed steady-state and contingency analyses, including load flow, short circuit and N-1 contingency studies. The purpose was to assess the system's adherence to thermal and voltage limits as specified by planning standards.

Task 3: Options assessment: Task 3 aimed to identify a range of options that would satisfy the needs of the distribution system as identified in Task 2. These options included the creation of new assets, upgrading of existing assets, and non-network solutions such as DSM measures.

Creating new assets involved proposals for new distribution circuits, additional substations and the installation of new switchgear and voltage regulators. Upgrading existing assets included replacing grid transformers with higher rated units at a substation, reconductoring of existing circuits with higher rated conductors, and voltage upgrades of existing distribution circuits from 11 kV to 33 kV.

During the options assessment, lifetime costs were taken into account to evaluate the expenses and benefits associated with each option compared to others.

Load flow studies were conducted for the peak demand years of 2026, 2030, 2040 and 2050 scenarios by taking into account the substation forecasts. The objective of the studies was to identify necessary distribution system reinforcement projects between each peak demand year (i.e. 2027 – 2030, 2031 – 2040, 2041 – 2050) to ensure sufficient capacity within the distribution system to meet the projected demand.

Task 4: Least cost investment plan: The objective of this task was to develop a least cost investment plan for the distribution system, encompassing the entire IRP period. This plan identified and prioritised necessary investments in the Zambian distribution network over the planning years of 2026, 2030, 2040 and 2050.

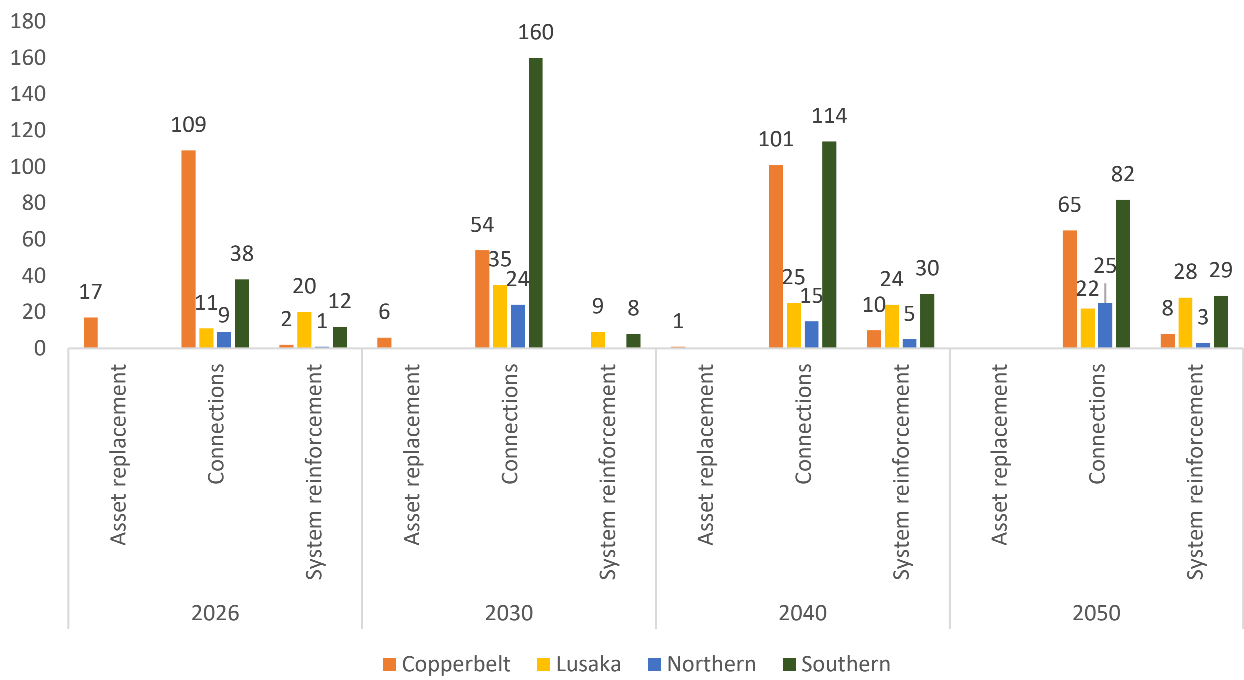
Capital investment in the distribution system was primarily driven by two factors: load related expenditure (LRE) and non-load related expenditure (NLRE). LRE covered investments required for connecting new customers, along with system reinforcements to increase capacity for these connections. NLRE encompassed investments for replacing distribution assets due to increased maintenance costs, safety risks or asset lifespan expiration. NLRE also covered investments for grid modernisation and system reliability requirements, such as the installation of auto-reclosers or sectionalisers.

Selection criteria for inclusion in the least cost distribution investment plan included synergy with transmission and generation projects, reduction of energy losses, and contribution to reducing greenhouse gas emissions.

Distribution modelling results

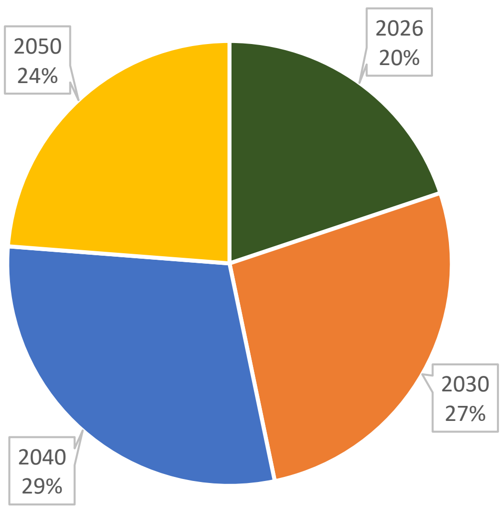
The figures below show the distribution network enhancements required for each peak demand year – 2026, 2030, 2040 and 2050 – across different regions.

Figure 6.3: Required Distribution Network Enhancements by Year and Region



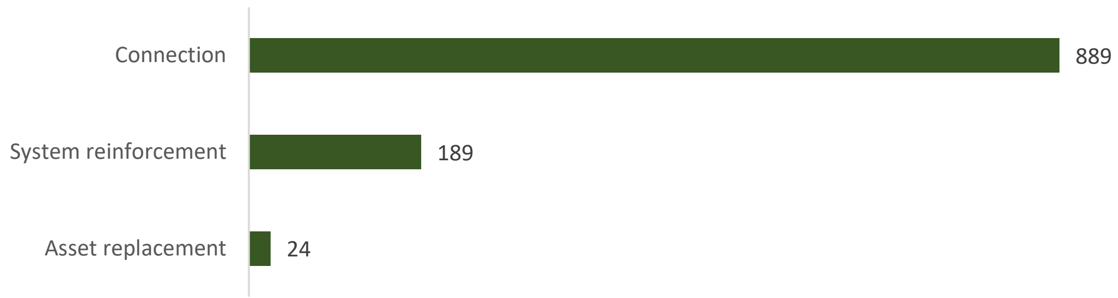
The required distribution network enhancements are quite evenly spread throughout the peak demand years, as shown in Figure 6.4 below.

Figure 6.4: Required Distribution Network Enhancements by Year



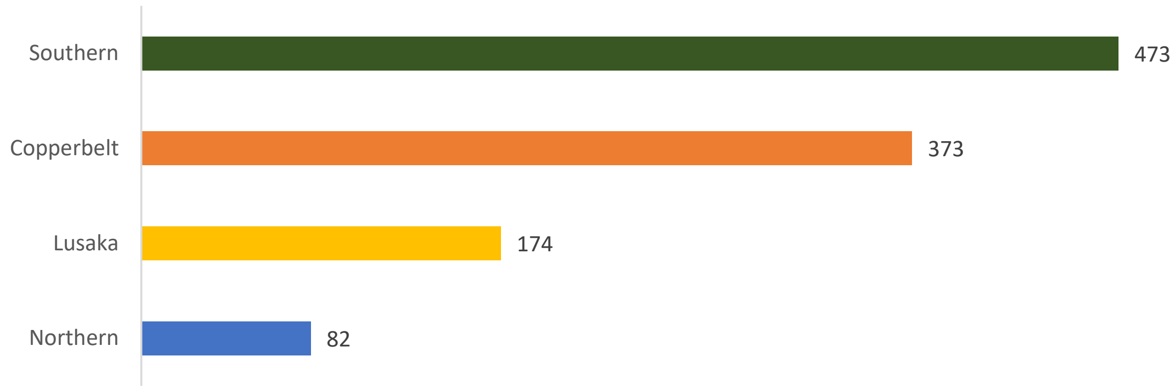
The vast majority (79%) of proposed distribution network enhancements to be made are connections, with only 2% asset replacement changes.

Figure 6.5: Proposed Distribution Network Enhancements by Type



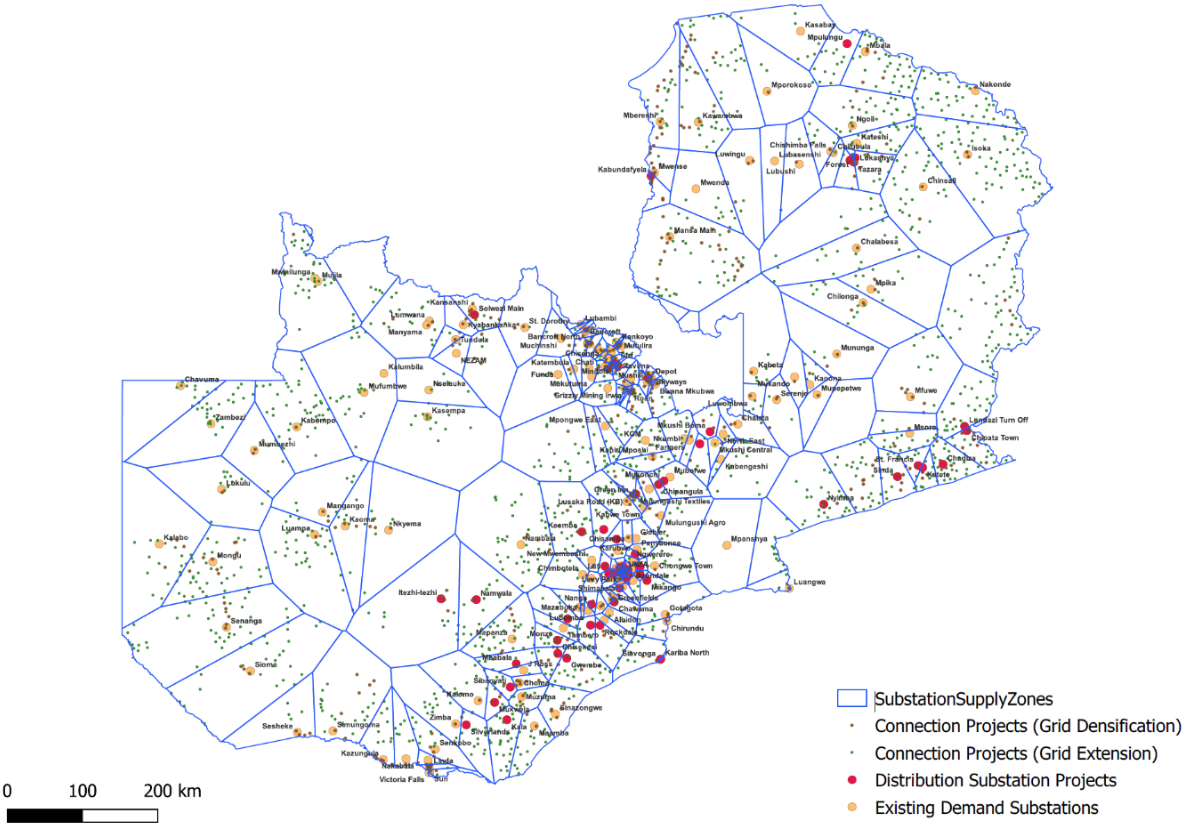
Of the total required distribution network enhancements, 76% are in the Southern and Copperbelt regions.

Figure 6.6: Required Distribution Network Enhancements by Region



Map 6.11 shows the geographical locations of some of the proposed distribution projects across the country. The projects shown on the map are the proposed connection and substation reinforcement projects illustrated by the aforementioned peak demand scenarios. These are indicated within a supply zone of the nearest existing demand substation. The names on the map represent the existing demand substations which are either transmission or distribution connected.

Map 6.11: Locations for Connection and Substation Reinforcement Projects



Impact of consumer trends on distribution/access planning

Table 6.5 below provides an overview of key consumer interventions and technologies that will impact distribution and access planning covered in the IRP. By considering energy efficiency measures, clean cooking alternatives, renewable energy sources and emerging technologies like EVs and green hydrogen, the IRP helps reduce greenhouse gas emissions, mitigate climate change impacts, and improve air quality. It enables the transition towards a more sustainable and low-carbon energy system, aligning with global commitments and national goals for sustainable development.

Table 6.5: Key Consumer Technologies that will Impact Distribution Planning

Type of Intervention/Technology Development	Key Factors Affecting Level of Impact	Treatment in the IRP
Energy Efficiency (EE)	• Government policy • EE technology development • EE awareness and capacity building • EE auditing capacity • Tariff levels and savings realised from EE interventions • Supportive regulations	The Energy Efficiency Strategy in Zambia is captured in the Energy Efficiency Strategy and Action Plan (EESAP) which was published in 2022. The IRP has taken note of the plans and recommendations of the EESAP with respect to EE auditing and capacity building and the implementation of initiatives to improve EE in the areas of heavy industry, light industry, transport, construction, building design and energy management, clean cooking, distribution of LPG and lighting. The IRP has factored these interventions into the demand forecast where appropriate, through both top-down and econometric forecasting models, as appropriate.

Demand Side Management (DSM)	• Government policy • Technology development (e.g. Smart metering) • Regulatory incentives and frameworks • Implementation of customer contracts incorporating DSM • Customer awareness	A formal and structured approach to DSM is yet to be fully explored in Zambia. Load shedding has been implemented by ZESCO for the residential and small business sectors and times of power shortages, and the mining sector has been advised to secure power from sources within SAPP at times when ZESCO is unable to supply. Potential future investments in smart metering and proposals for interruptible power contracts will be explored further in future iterations of the IRP.
Clean Cooking	• Government policy • Clean cooking resource and technology development • Clean cooking awareness and capacity building • Regulations, taxation, penalties and incentives that incentivise use of clean cooking fuels and technologies	The promotion of clean cooking alternatives to the use of charcoal, particularly in Zambia's cities, remains a critical component of Zambia's emerging Green Growth Strategy, and a significant contributory factor to Zambia achieving its NDCs over future years. The IRP has assumed that some displacement of charcoal will be achieved through an increase in cooking with electricity, particularly through efficient cook stoves and this has been incorporated in the residential demand forecast. Other alternatives to charcoal include LPG, biogas and renewable cooking fuels.
Electric Vehicles (EVs)	• Government policy • Regulations supporting EV rollout • EV affordability and availability (possibly from local production plants) • Fiscal incentives for EVs • Availability of EV charging points and associated infrastructure	EVs are anticipated to become widely available in all countries in future years, and GRZ policy it to support the future electrification of transport. The speed of deployment in Zambia will be impacted by the cost and affordability of EVs, the availability of EV charging points and the capacity of the grid/distribution network to supply sufficient energy to charge EVs on a daily basis. The impact of EVs is anticipated to have a low impact on demand on the first few years of the IRP. The anticipated growth trajectory will be modelled in more detail for future iterations of the IRP.
Rooftop/Customer Owned Solar and Net Metering	• Government policy • Regulations supporting net metering • Awareness and capacity building of rooftop systems and net metering	ERB has developed regulations that will permit net metering for both residential and commercial consumers. The regulations are expected to be approved and enacted within 18 months of the date of publication of the IRP. These regulations are expected to accelerate the deployment of rooftop solar for grid-connected customers. The generation will be considered as counting towards the recommendation for solar generation in the IRP.
Embedded Energy Storage (Distribution or Customer Owned)	• Government policy • Regulations • Technology development • Awareness and capacity building • Fiscal incentives	Embedded energy storage installations in the distribution network can prove effective, particularly in combination with VRES, in meeting peak demand and enhancing quality and security of supply. Investments in some locations may reduce or delay the need for expansion of the transmission or distribution

		network. The IRP has not modelled energy storage as part of the base case, although it has taken cognisance of energy storage capacities and Kariba North Bank, Kafue Gorge and ITT power stations. Future iterations of the IRP will undertake more detailed modelling of technical and commercial options for energy storage.
Green Hydrogen	• Government policy • Regulations • Technology development • Awareness and capacity building • Fiscal incentives	Green hydrogen technology in combination with VRES such as solar is anticipated to provide viable clean energy solutions for transport and electricity generation in future years. However, the technology is at a nascent stage in terms of technology development and the availability of commercially viable solutions. It has therefore not been incorporated into the energy modelling and recommendations of the IRP at this stage. This will be reviewed for future iterations of the IRP.

7 Access to Electricity

The GRZ's Vision 2030 was first adopted in 2006 and envisaged that Zambia would attain 51% access to electricity by 2030[29]. In 2015, universal standards were adopted through the SDGs. SDG7 seeks to provide "affordable, reliable, sustainable and modern energy for all[30]" by 2030. All UN member states adopted SDGs and multilateral development banks have designated funding towards developing countries attaining SDG7 and the other SDGs. The IRP has adopted a target of full electrification by 2030, consistent with SDG7.

Zambia developed a Least Cost Geospatial Electrification Plan (LCGEP) in 2022, which was funded by the World Bank and delivered by an international consulting firm on behalf of the MoE. The plan aimed to establish least cost pathways for universal electrification in Zambia by 2030. This was achieved using geo-spatial technology and available inputs, including the location of existing grid networks and costing algorithms. The process of developing the LCGEP afforded very limited time for site visits and community consultations, which are discussed further below.

The LCGEP considered three potential modes of electrification based on the principles of least cost connection per household and the service level required, namely through:

- grid access through densification or extension, or
- mini-grids (localised grids and generation sources typically located at rural growth centres, usually using solar with batteries as a generation source), or
- SHSs designed to provide a service at household level.

The LCGEP distinguishes the service level available from these systems based on proximity to the grid and level of demand, linked to ability to pay, in each area of the country.

Access levels have been defined by the World Bank's ESMAP which include tier-level definitions for cooking as well as electricity. For example, Tier 1 electricity access provides for basic consumer services (lighting and phone charging) and Tier 5 for comprehensive services (unlimited household appliances). The recommendations from the LCGEP using a baseline year of 2020 are summarised in Table 7.1.

Table 7.1: Tier Levels for Electricity Service Provision[31]

Mode of Electrification	Generic Location Description	Number of People Connected by 2030	Cost per Connection[32]
Grid Access – Extension Tier 5	Compacted grouped households in high demand density areas	0.3 million	$360
Grid Access – Densification Tier 5	Unconnected households in grid connected localities	4.7 million	$850
Mini-Grids Tier 3, Tier 4	Compacted grouped households in low demand density areas	4.8 million	$2,420
SHSs Tier 1, Tier 2	Scattered households in low demand density areas	8.9 million	$120

[29] GRZ, 2006, GRZ National Long Term Vision 2030. www.moe.gov.zm/irp/?wpdmpro=grz-national-long-term-vision-2030

[30] UN, 2020, Affordable and Clean Energy: Why it Matters. www.un.org/sustainabledevelopment/wp-content/uploads/2016/08/7_Why-It-Matters-2020.pdf

[31] Definitions are from World Bank ESMAP programme

[32] Cost per connection assumed based on recommendations of LCGEP.

The following assumptions have been made in developing the energy access plan under the IRP:

- population growth rate of 2.8% through the plan period;
- average of 5.5 people per household connection through plan period;
- full access electricity to all households by 2030;
- grid electrification based on the modelling undertaken under the IRP Demand Workstream which envisages 3.4 million grid connections (serving 18.5 million people) by 2050;
- split of off-grid electrification between mini-grids and SHSs based on LCGEP recommendation by year 2030, extrapolated on the same basis to 2050.

Based on the above assumptions, the projected electrification of Zambia's population through the three modes of electrification is summarised in Figure 7.1 and Table 7.2 below.

Figure 7.1: Projections for Mode of Electrification of Zambia's Population, 2023 – 2050

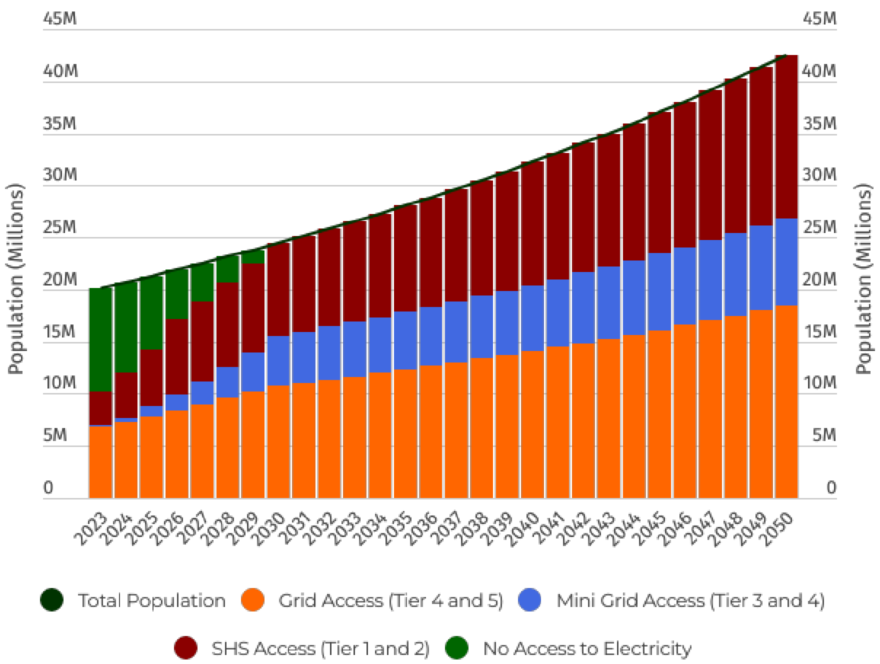


Table 7.2: Enhanced Access to Electricity through Grid Access, Mini-Grids and Solar Home Systems

Trends in Electricity Access over Plan Period	2020	2023	2026	2030	2040	2050
% of Population with Access	44.5%	51%	78%	100%	100%	100%
% of Population with Grid Access	31%	34%	38%	44%	44%	43%
% of Population with Off-Grid Access	13%	17%	40%	56%	56%	57%
Number of People with Grid Access (Tier 4 and 5) (Million)	5.9	6.8	8.4	10.8	14.1	18.5
Number of People with Mini Grid Access (Tier 3 and 4) (Million)	0.1	0.1	1.5	4.8	6.4	8.4
Number of People with SHS Access (Tier 1 and 2) (Million)	2.4	3.3	7.3	8.9	11.8	15.6
Number of People with No Access (Million)	10.5	9.9	4.7	-	-	-
Total (Million)	**18.93**	**20.15**	**21.89**	**24.45**	**3222**	**42.47**

The REA has the overall responsibility for planning and implementation of rural electrification in Zambia. It will play a crucial role in supporting Zambia's commitment to achieving universal electricity access for all citizens by 2030. REA's Rural Electrification Master Plan (REMP) was first developed in 2007[33] as a guiding document to electrify Zambia covering the period from 2008 to 2030, setting a target to attain 51% access in rural areas by 2030. REA has commenced a process to update the REMP taking account of revised electrification targets, social and demographic changes and the currently available technology and resources to facilitate rural off-grid electrification. The updated REMP will take cognisance of the grid expansion plans developed in the IRP and the least cost investment pathways recommended through the LCGEP. The process of updating the REMP will involve community, district and provincial consultations to ensure that recommendations are supported by target communities and accurately capture their development plans, which in turn will facilitate a more granular approach to electrification planning than was possible with the LCGEP methodology.

[33] With the support of the Japan International Cooperation Agency (JICA).

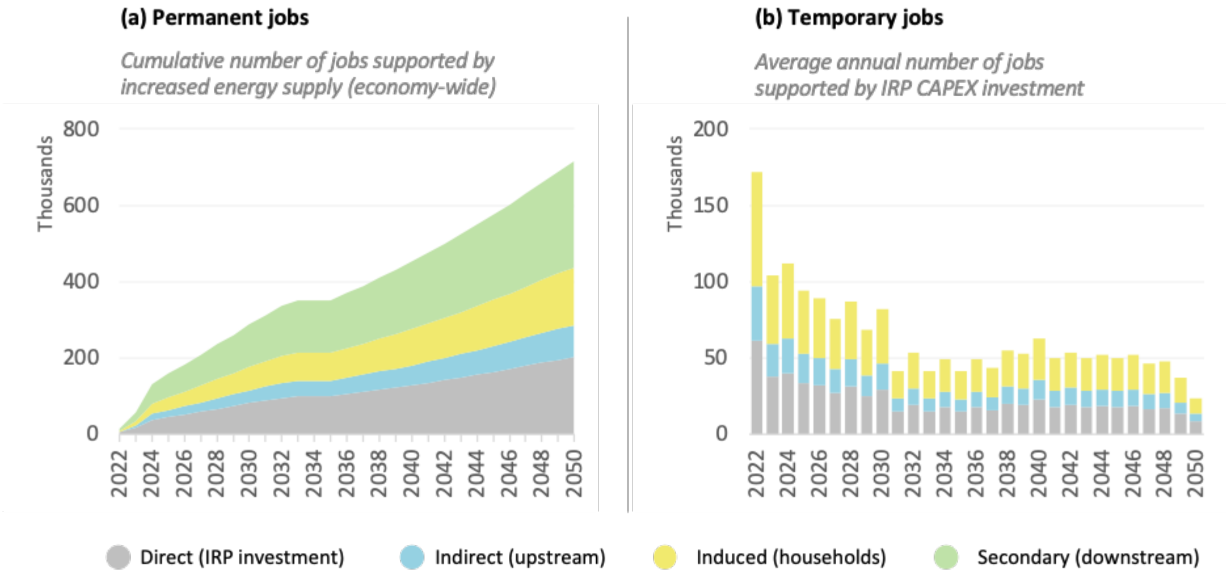
8 THE HUMAN DIMENSION OF THE INTEGRATED RESOURCE PLAN

Energy and access to energy have profound impacts on human lives and the well-being of society. The human value of energy lies in its ability to address basic needs, drive economic development, improve healthcare and education, enhance quality of life and empower individuals and communities, among other factors. Equally, if implemented without adequate planning and consideration of social and environmental factors, projects in the energy sector can have negative impacts on people and communities and fail to take full advantage of available social and economic empowerment opportunities. The successful development and implementation of the IRP thus extends beyond the technical requisites and physical infrastructure needed to meet energy demand to highlight the strategies required to ensure a sustainable energy future for the rapidly growing population of Zambia. By considering the human aspects alongside technical parameters, the IRP aims to create an inclusive and equitable energy transition that benefits and protects all segments of society. This section of the IRP Summary Report delves into the IRP's key findings and recommendations concerning the areas of job creation, social safeguarding, social inclusion and economic empowerment in the context of the IRP.

8.1 Job Creation

Job creation is an integral part of the energy transition and a consequential by-product of the IRP's implementation. To quantify employment opportunities that can be harnessed as the energy system evolves, the IRP captures the potential for direct job generation in the energy sector in line with the IRP's investment recommendations, as well as the potential for indirect job generation through the economic stimulus associated with increased energy supply.

Figure 8.1 Projected Jobs Supported by IRP investments, 2022 – 2050



	2022-30	2031-50	Total	%
Direct	81,165	121,130	202,295	*28%*
Indirect	33,541	50,057	83,598	*12%*
Induced	60,794	90,729	151,523	*21%*
Secondary	111,415	166,275	277,689	*39%*
Total	286,915	428,190	715,105	*100%*

	2022-30	2031-50	Average	%
Direct	35,229	17,055	22,695	*36%*
Indirect	20,090	9,726	12,943	*20%*
Induced	42,813	20,726	27,581	*44%*
Secondary	-	-	-	-
Total	98,133	47,507	63,218	*100%*

The increased energy supply resulting from the IRP is expected to support over 700,000 new permanent jobs in the Zambian economy by 2050, with the largest share of beneficiaries (39%) being downstream energy consumers. Over 200,000 jobs are expected in the energy sector alone, plus a further 84,000 jobs in upstream suppliers and over 150,000 jobs supported by household spending resulting from increased wages and salaries (represented in Figure 8.1).

These permanent jobs are expected to be complemented by an annual average of over 60,000 temporary jobs relating to IRP CAPEX investments and associated construction projects. Temporary job creation will be higher in the earlier years of the IRP implementation, with an average of almost 100,000 jobs per year being supported between now and 2030. The largest portion of this (44%) will come from the induced spending effects of households receiving higher incomes from construction work.

IRP Impact Model

The job creation impacts of the IRP are estimated using economic multipliers derived from the Zambian government's latest input-output tables, which describe how goods and services are traded within the economy[34].

IRP impacts are divided between 1) short-term economic stimulus associated with CAPEX investments and associated construction projects, and 2) long-term economic stimulus associated with increased energy supply. Impacts are further subdivided between a) direct effects (e.g. jobs at energy companies), b) indirect effects (jobs at upstream suppliers, e.g. manufacturing firms or financial services providers), c) secondary effects (jobs at downstream users of the increased energy supply), and d) induced effects (the impact of wages paid as a result of IRP being recirculated through the economy via household spending)[35].

8.2 Gender and Social Inclusion

The MoE is highly committed to advancing gender equality in the energy sector as demonstrated through the 2022 Gender Equality Strategy and Action Plan (GESAP) for the energy sector and the re-launch of the Zambia Gender and Energy Network (ZGEN). Through its Gender and Social Inclusion report, the IRP tailors actions and social inclusion guidance provided in the GESAP to the IRP recommendations, identifies opportunities to enhance women's representation, empowerment and access to energy-related opportunities and develops social safeguard standards to help operationalise the key GESAP objective of increasing social and gender integration in energy infrastructure projects.

Gender and social inclusion recommendations

The IRP gender and social inclusion report offers an overview of the challenges faced by women, young people and persons with disabilities in the energy sector and provides recommendations for the mainstreaming of gender equality and social inclusion in upcoming generation, transmission and distribution projects prescribed under the IRP. Gender and social inclusion aspects are considered on the consumer level as well as in employment and participation in the IRP value chain. The gender and social inclusion report has taken a more holistic approach to energy than other sections of the IRP to include cooking, since it is a critical gender aspect.

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[34] Zambia Statistics Agency (2017). Supply, use, and input output tables – 2010. Zambia Central Statistical Office, Lusaka. November 2017.

[35] Note that the temporary job creation estimates do not include any downstream effects, as these are all assumed to be captured by the permanent job creation effects of the energy sector.

The key recommendations are summarised below.

1. **Set a minimum level of access to clean cooking.** The National Electrification Strategy (NES) and the LCGEP have adopted Tier 1 of the multi-tier framework as the minimum level of access to electricity. It is recommended that the MoE provides similar policy guidance on the minimum level of service for clean cooking, which should include setting targets for electric cooking. The demand assessment of the IRP highlights that transitioning to electric cooking would not result in significant energy demand increases as previously anticipated. Furthermore, it is the most cost-effective clean energy solution for households. Switching to clean energy for cooking is associated with numerous benefits, including increased employment and income generation for women, as well as reduced health hazards.
2. **Make clean cooking an integral part of rural electrification.** The revised REMP should adopt a comprehensive approach to rural electrification by considering the use of electricity for both domestic and productive purposes. In many remote rural areas, SHSs are likely the most cost-effective alternative. However, most SHSs available in the market are unable to power high-load appliances such as electric stoves or hotplates. This limitation fails to address a critical energy need for rural women. To address this gap, it is recommended that the implementation of SHSs be complemented by clean cooking technologies, such as pellet stoves and biogas digesters. These technologies can provide a solution for cooking needs in rural areas. Alternatively, consideration should be given to high-powered SHSs that are compatible with electric pressure cookers. By incorporating these options, the revised REMP can ensure that the energy needs of rural women are effectively met while promoting cleaner and more efficient cooking practices.
3. **Integrate 'complementary services' to optimise the positive impact of electrification.** To optimise the positive impact of electrification projects, it is crucial to integrate complementary services alongside the provision of electricity. These services may include credit facilities, entrepreneurship training, establishment of savings groups, social marketing of electric appliances and other related initiatives. Such measures serve multiple purposes: they assist poorer households in overcoming prohibitive initial connection charges, and they encourage greater adoption of energy services for both productive and domestic purposes, ultimately leading to improved livelihoods.
4. **Incorporate social and gender requirements in procurement documents.** Clear definitions outlining risk management and opportunities for women, persons with disabilities and young people must be established upfront and included as contractual obligations for energy infrastructure projects. Procurement documents should incorporate social safeguards and require the inclusion of gender and social inclusion specialists as key personnel to ensure necessary expertise.
5. **Develop an equal employment opportunity policy.** The Implementation Plan for National Energy Policy 2019 and the GESAP emphasise affirmative action in employment and boards to enhance gender representation. The IRP provides an excellent opportunity to implement these measures and extend them to young people and persons with disabilities. To ensure effectiveness, an equal employment opportunity policy is necessary to guide the practical implementation of affirmative action measures in the sector. This goes beyond setting quotas and targets for employment and should aim to cover recruitment, training and capacity building, mentorship, work environment, institutional collaborations and professional development and advancement.

Social safeguard standards

To increase social and gender integration in energy infrastructure projects, the MoE, with the support of CIGZambia, has developed social safeguard standards targeting developers and contractors. These standards aim to prevent or mitigate social risks and negative impacts of energy projects, while promoting opportunities and positive impacts. They are underpinned by a strong gender equality and social inclusion perspective, with a particular focus on women, young people and persons with disabilities. The standards establish minimum requirements across six areas, primarily addressing country-specific social risks considered to be of medium to high risk, making them applicable to all energy infrastructure projects.

Table 8.1: Social Safeguard Standards and Examples of Key Requirements

Social Safeguard Standards	Examples of Key Requirements
Social Safeguard Standard 1: Labour and Working Conditions	• Include a clearance letter certified by the Ministry of Labour as part of the qualification and evaluation criteria in the procurement process. • Submit employment contracts of project staff to the Labour Office for review and approval.
Social Safeguard Standard 2: Non-Discrimination and Equal Opportunity	• Adopt minimum employment quotas to promote equal opportunity. The following quotas are recommended: ▪ At least 80% of the total workforce should be Zambian nationals. Of this number, at least 70% should be community members from the project area (communities within 10 km radius of the project site). ▪ At least 30% of the total workforce should be women. ▪ At least 30% of the total workforce should be youth (aged 19 to 35). ▪ At least 5% of the total workforce should be persons with disabilities.
Social Safeguard Standard 3: Sexual Exploitation, Abuse and Sexual Harassment (SEAH)	• Develop a SEAH Action Plan which outlines the necessary measures to address the SEAH risks and how to handle allegations of SEAH. • Ensure that all workers are sensitised on and sign a code of conduct, which sets out acceptable behaviour in the workplace and out of hours. • Identify gender-based violence service providers in the project area. This can be done through the online Gender-based Violence Dashboard managed by the Gender Division.
Social Safeguard Standard 4: Community Protection and Empowerment	• Implement a workplace and community health programme focused on HIV/AIDS and other diseases, alcohol abuse, SEAH, sexual and reproductive health and rights, and gender equality among other things. • Identify goods and services which could be provided by local businesses in the community, including businesses owned by women, youth and persons with disabilities.
Social Safeguard Standard 5: Resettlement and Land Acquisition	• Conduct gender analysis to assess impact of resettlement or land acquisition for different groups (e.g. women, older people and persons with disabilities). • Develop resettlement action plan and/or livelihood restoration plan (if applicable).
Social Safeguard Standard 6: Stakeholder Engagement and Information Disclosure	• Establish electrification community committees in project-affected communities comprising 5–15 members from various community structures within the area, including traditional leaders and the ward development committees. • Develop and implement a stakeholder engagement plan. • Establish a project grievance redress mechanism.

8.3 Economic Empowerment

To increase the participation of Zambian companies and companies owned by targeted citizens and promote knowledge and skills transfer, the MoE will develop a Citizen Empowerment Policy tailored for the energy sector, in cooperation with the Citizens Economic Empowerment Commission, Zambia Public Procurement Authority and the Zambia Development Agency. As part of procurement, developers will be categorised based on the level of citizen ownership, as proposed in Figure 8.2 below. This categorisation can help apply shareholding requirements and prioritise or reserve contracts for companies owned by Zambians and/or targeted citizens (including women, youth and persons with disabilities) during the bid evaluation process. Based on the developer status, there are three main bidding strategies to foster local participation:

- minimum shareholding requirement based on developer status;
- application of reservation scheme based on developer status;
- application of preference schemes based on developer status.

All power projects must apply one of the three bidding strategies. The selected bidding strategy would vary depending on the project and capacity of local developers and contractors. The development of the Citizen Empowerment Policy will include a careful analysis of the bidding strategies. It must balance the ambition to economically empower citizens with other factors such as quality, capacity, cost effectiveness and attractiveness of foreign investors and developers. If implemented adequately, such bidding strategies have the potential to ensure that future investments in energy infrastructure projects go hand in hand with the government's ambition to empower its citizens. Evidence from South Africa, Botswana, Nigeria and China shows that such strategies can be highly effective at empowering citizens, increasing capacity and skills transfer and ultimately propelling economic growth.

Figure 8.2 Proposed Developer Categories and Applicable Margin of Preference

A. Company that has been registered in Zambia by a foreign investor for the purpose of participating in a bidding process
B. Company that is foreign owned and has been registered in Zambia for a period of 3 years undertaking economic activities (-4%)
C. Company that has had a presence in Zambia for at least 3 years and has significant equity participation (>30%) by Zambian citizens (-6%)
D. Company wholly owned by Zambian citizens (-8%)
E. Company wholly owned by Zambian citizens, with significant equity participation by targeted citizens (women, young people, persons with disabilities) (-10%)
F. Company wholly owned by targeted citizens (-12%)

9 POWER SECTOR FINANCIAL SUSTAINABILITY

The investments made in Zambia's power sector underpin the growth of all other sectors of the economy. Most power sector projects are highly capital intensive and incorporate long-term competitively priced debt or concessional finance as the largest component of the financing structure. The IRP has been developed at a time when Zambia has entered into an arrangement with the International Monetary Fund (IMF) that places restrictions on future borrowing by the GRZ and publicly owned institutions including ZESCO.

There was a decrease in the rate of investment commitments for new on-grid power infrastructure from 2019 to 2022 as a result of rapidly growing sector arrears, resulting in an increase in sector credit risk and a contraction of the availability of debt financing sources for new projects. The situation was exacerbated by increased country risk, resulting in Zambia entering into an Extended Credit Facility Arrangement with the IMF on 31 August 2022 for $1.3 billion. This agreement includes conditions that restrict the GRZ and its various agencies entering into new credit facilities, and in the case of ZESCO, only permit ZESCO to secure concessional financing facilities from named multilateral lenders for a period of 39 months from the date of signature of the agreement.

Through the IRP, a six-point framework to support sector bankability is proposed that seeks to demonstrate to investors that investment-related risk factors are being addressed. The key focus areas and related actions and interventions are shown in the diagram and tables below.

Figure 9.1: Six-Point Framework for Power Sector Bankability

Each of these six points is presented further below.

Cost Reflective Tariffs	Status
Cost of Service Study completed and published	Completed and published by ERB in August 2022
New tariffs implemented	Approved by ERB Board and published on 21 April 2023
Multi-Year Tariff Framework	Framework in place and 5-year tariff projections published on 21 April 2023
Use of system/ancillary services tariffs finalised	Tariff framework still in development
Risk Mitigation	**Status**
Solution identified for non-paying customers (mining, Government)	Government is taking appropriate action to ensure re-capitalisation of mines that have accrued arrears for power supplies, so that operations will be financially sustainable going forward Financial discipline with Government departments is improving to reduce arrears in payments for power supplies
Accrued sector arrears are paid off to normalise power trading arrangements/contracts	Quantum of IPP arrears reduced through tariff re-negotiation process ZESCO has secured a local financing facility to restructure some arrears with IPPs in accordance with available future cashflow
Concessionary/grant finance secured for projects with non-commercial returns	Reflected in new ZESCO Investment Policy approved in 2022 (for Government-led projects)
Multilateral credit guarantee secured to support future Government-driven power procurement from IPPs	To be requested from multilateral institutions by Ministry of Finance and incorporated in the IRP Investment Plan for Generation issued by December 2023
Long-term/concessional finance sourced for priority transmission projects	To be incorporated in the IRP Investment Plan for Transmission by December 2023
Energy sector categorised as priority sector within country debt renegotiations	Agreement between Zambia and IMF carves out certain permitted finance sources and financial institutions to fund essential power sector projects despite the general moratorium on acquiring new long-term debt for ZESCO and the Zambian Government
Integrated Least Cost System Planning	**Status**
IRP finalised and approved by Minister of Energy/Cabinet	Finalised in July 2023
Least cost generation plan used to procure new generation plants by capacity/energy/technology mix	Government Statement on Generation Procurement and IRP Investment Plan for Generation issued by December 2023
Transmission and distribution investments matched to Demand Growth and Generation Plan	Prioritised Transmission and Distribution Investment Plan will be incorporated into the IRP Investment Plan for Transmission and the IRP Investment Plan for Distribution both by December 2023
Financing sources for IRP finalised and project implementation tracked through Energy Planning Centre	Energy Planning Centre Terms of Reference and Reporting Framework finalised by June 2024
Open Access and Market Development	**Status**

Open access framework, rules, regulations, charging framework and contracts are approved for transmission use of system	Target date for final approval is June 2024
Charging framework, rules and regulations agreed for system operator/ancillary services and energy storage	Target date for final approval is June 2024
Roadmap for Establishment of Independent System Operator approved by Minister of Energy/Cabinet	Target date for approval of roadmap is December 2023
Market design strategy and rules agreed by Minister of Energy/Cabinet	Target date for final approval is June 2024
Effective and Transparent Regulation	**Status**
Non-discriminatory grid access for new connections	To be facilitated through the grid codes for transmission and distribution, and the operational processes of ERB and ZESCO
Non-discriminatory access to grid and grid services for licensed operators	To be provided for through open access regulations under development, consistent with the Electricity Act of 2019
Efficiency measures implemented for key sector actors	Implemented by ERB through annual performance reviews of all licensed operators
Transparency maintained over costs of different segments of value chain, including balancing energy and system operations services	To be reflected in the tariff determination process by ERB for use of system charges, ancillary services, balancing energy and energy storage
Grid Connectivity and Interconnectors	**Status**
Transmission grid development plan provides strong connectivity for generation plants/off-takers in all provinces to reduce grid connection costs	Plans captured in the IRP Transmission Report published in July 2023 and will be incorporated into the IRP Transmission Investment Plan by December 2023
Investment in grid stability projects ensures grid stability and quality of supply	Plans captured in the IRP Transmission Report published in July 2023 and will be incorporated into the IRP Transmission Investment Plan by December 2023
Enhancement of interconnector capacity with existing and new markets in SAPP and EAPP provides additional power trading opportunities for market actors	Design for Zambia – Tanzania Interconnector has been completed and financing sources identified Further interconnector projects to be developed in accordance with SAPP Plan (currently being updated) reflecting national priorities
Revised grid code and standard grid connection assessments and connection agreements make connection of new renewable energy generation plan efficient	Updated grid code for both transmission and distribution to be approved and issued by July 2024

The implementation of appropriate interventions and continued monitoring of the different factors and risks affecting sector bankability will assist in rebuilding investor confidence, so that the required funds to implement projects recommended in the IRP can be raised from public and private sources.

10 SUMMARY OF THE IRP INVESTMENTS

This section details the financial investments required for the implementation of the IRP, as well as recommendations on procurement.

10.1 Generation Investments

Table 10.1 below presents the aggregate investments needed for on-grid generation projects up to 2050. These investments are determined in constant prices for 2021 US$ (i.e. without projected inflation) and exclude grid connection and transmission costs as well as other project development costs.

Table 10.1: Investment profile for on-grid generation expansion for 2023 – 2050

Investment by Generation Technology	**Annuity by Technology (Million USD / MW)**	**Generation Investments (Million USD)**				
		2026	**2030**	**2040**	**2050**	**2021 – 2050**
Hydro Storage (H_STOR)	3.80	-	-	-	-	-
Hydro (Run-of-River)	1.28	833	1,994	1,897	1,820	6,545
Thermal - Steam (Coal/other fuels)	1.07	-	643	643	643	1,930
Geothermal	1.60	-	48	768	768	1,584
Biomass	0.63	32	170	189	378	769
Solar PV	1.01	1,563	407	1,380	1,447	4,797
Wind	1.29	515	1,019	2,924	2,748	7,206
Nuclear	6.40	-	-	-	-	-
Solar CSP	3.83	-	-	-	-	-
Total Investment (Million USD)		**2,943**	**4,281**	**7,801**	**7,805**	**22,830**
Hydro Storage (H_STOR) %		0%	0%	0%	0%	0%
Hydro (Run-of-River) %		28%	47%	24%	23%	29%
Thermal - Steam (Coal/other fuels) %		0%	15%	8%	8%	8%
Geothermal %		0%	1%	10%	10%	7%
Biomass %		1%	4%	2%	5%	3%
Solar PV %		53%	10%	18%	19%	21%
Wind %		17%	24%	37%	35%	32%
Nuclear %		0%	0%	0%	0%	0%
Solar CSP %		0%	0%	0%	0%	0%
Total %		**100%**	**100%**	**100%**	**100%**	**100%**

Source: IRP Generation Workstream – Antares base model.
CSP: concentrated solar power

The immediate investment requirements up to 2026 are in solar (53%), hydro (28%) and wind (17%), reflecting the ability of the Zambian grid to absorb a relatively high proportion of solar generation in the early years of the plan. The largest investment requirements over the plan period to 2050 are in wind (32%), hydro (29%) and solar (21%), which reflects a more representative allocation of the relative investment required in different generation sources following least cost development principles. The

Antares model did not recommend nuclear or concentrated solar power during the plan period, as these technologies are not competitive in terms of cost and performance against available alternatives.

10.2 Transmission Investments

IRP transmission investments to 2050 are summarised in Table 10.2 below. It is notable that 59% of the total required investment is scheduled to be delivered by 2030, in advance of the significant investments in generation, distribution and access planned through to 2050. The relative "front loading" of transmission investment within the context of the overall IRP emphasises the extent to which transmission investment will unlock growth in the economy (connecting new industries, mines and agricultural centres), enhance access (connecting underserved provinces and reinforcing supplies to Zambia's cities), facilitate connection of new climate resilient renewable energy sources and de-risk the sector by enhancing connectivity with neighbouring countries.

Table 10.2: Investment Profile for Transmission Expansion for 2023 – 2050

Transmission Investments (Million USD)					
Time Period	2023 - 2026	2027 - 2030	2031 - 2040	2041 - 2050	2021 - 2050
Investment (Million USD)	**953**	**457**	**745**	**231**	**2,386**

10.3 Distribution Investments

IRP transmission distribution investments at the 33 kV voltage level to 2050 are summarised in Table 10.3 below. It is notable that 52% of the total required investment is scheduled to be delivered by 2030 which will facilitate grid connectivity for a further 4.0 million people, as well as supporting the growth of commercial, industrial and agricultural customers who receive power at 33 kV voltage and below. The investments in later years will facilitate grid connectivity for a further 7.7 million people.

Table 10.3: Investment Profile for Distribution Expansion for 2023 – 2050

Distribution Investments (Million USD)					
Time Period	2023 - 2026	2027 - 2030	2031 - 2040	2041 - 2050	2021 - 2050
Investment (Million USD)	**247**	**259**	**364**	**107**	**976**

10.4 Off-Grid Investments

The investment profile for access has been informed by the recommendations of the LCGEP. Detailed planning for enhanced access will be undertaken through the implementation of an updated REMP for off-grid access, and through localised plans for grid densification and expansion around the 33 KV distribution network expansion for on-grid access.

The investment profile in Table 10.4 below takes into consideration the number of off-grid and on-grid connections planned to attain universal access by 2030 and assumes that universal access will be maintained through the full plan period. The forecast investments have used an average cost per connection as advised under the LCGEP for both off-grid and on-grid connections. The investment required by 2030 comprises 52% of the full investment required by 2050.

Table 10.4: Investment Profile for Access 2023 – 2050

Access Investments (Million USD)					
Time Period	2023 - 2026	2027 - 2030	2031 - 2040	2041 - 2050	2021 - 2050
On-Grid Access (Million USD)	143	166	235	309	**853**
Off-Grid Access (Million USD)	698	1,488	749	991	**3,926**
Total Access (Million USD)	**841**	**1,654**	**984**	**1,300**	**4,779**

10.5 Aggregated Power Sector Investment Required

Table 10.5 below summarises the total power sector investment required in all value chains of the IRP using standard capital costs by technology type from international and local data sources. In the case of access, the cost estimates are based on the cost per connection used in the LCGEP. Figures represent standard estimates of capital costs under a competitive procurement environment and exclude project development costs (e.g. feasibility studies), financing costs and costs of environmental remediation which would need to be considered on a project-specific basis.

Table 10.5: Summary of Electricity Sector Investment Required Defined in IRP

IRP Investment Summary	Incremental Investments ($millions)				Cummulative Investments ($millions)			
Year	2023 to 2026	2027 to 2030	2031 to 2040	2041 to 2050	2026	2030	2040	(Total) 2050
Generation ($m)	2,943	4,281	7,801	7,805	2,943	7,224	15,026	**22,830**
Transmission ($m) including 66kV	953	457	745	231	953	1,410	2,156	**2,386**
Investment in Distribution - 33kv Network ($m)	247	259	364	107	247	506	870	**976**
Investment in On-Grid Access ($m)	143	166	235	309	143	308	544	**853**
Investment in Off-Grid Access ($m)	698	1,488	749	991	698	2,185	2,935	**3,926**
Total IRP Planned Investment ($m)	**4,983**	**6,650**	**9,895**	**9,442**	**4,983**	**11,634**	**21,529**	**30,971**
Generation %	59%	64%	79%	83%	59%	62%	70%	74%
Transmission %	19%	7%	8%	2%	19%	12%	10%	8%
Distribution %	5%	4%	4%	1%	5%	4%	4%	3%
On Grid Access %	3%	2%	2%	3%	3%	3%	3%	3%
Off Grid Access %	14%	22%	8%	10%	14%	19%	14%	13%
Total IRP Planned Investment ($m)	100%	100%	100%	100%	100%	100%	100%	100%

It is notable that on-grid generation is the largest cost component of the IRP, comprising 62% of the capital investment of $11.6 billion required by 2030, and 74% of the capital investment of $31.0 billion required by 2050.

The cost of off-grid energy access is the second-largest cost component, comprising 19% of the overall required capital investment by 2030 and 13% by 2050.

The cost of essential transmission investments to extend the capacity and reach of the grid across all of Zambia's provinces comprises 8% of the overall IRP investment requirement. However, investment is front-loaded comprising 19% of the overall investment required by 2026, and 12% of the total investment required by 2030, but reducing proportionately between 2030 and 2050 once the grid network has been extended.

10.6 Procurement Recommendations

Recommendations for effective procurement

The various project investments outlined in the IRP will be undertaken by licensed operators from both the public and private sector. Public sector procurement processes are governed by the Public Procurement Act of 2020, and the Public Procurement Regulations of 2022 which require principles of transparency and competition to be embedded into public sector procurement processes. It is widely acknowledged that competitive procurement processes when structured and executed well have the potential to maximise value for money for consumers. This was evident in the results from the solar energy procurement programmes implemented in Zambia, namely Scaling Solar (2016 – 2017) and GET FiT (2018 – 2019), which resulted in tariff levels from bidders at levels significantly lower than originally expected.

Conversely, when competitive procurement processes have not been followed, tariffs have often been agreed at unsustainable levels which ultimately have to be re-negotiated, and which can threaten the overall financial stability of the power sector.

While it is recognised that in certain situations, principles of competitive procurement may be difficult to apply (e.g. due to urgency, limited alternatives, extraneous factors), it is nevertheless proposed that:

- Projects are recommended/selected only if consistent with recommendations of the IRP (as may be updated from time to time.
- Principles of competitive tender are embedded in the project procurement process whenever it is possible to do so.
- When it is not practical to follow a standard competitive procurement process, measures are taken and documented to ensure that value for money for consumers is maintained.
- A standardised approach it taken with respect to contractual documentation including bidding documents, power purchase agreements, implementation agreements, financing agreements and grid connection agreements so that as far as possible, there is fair and transparent treatment between different market actors and the ability to compare proposals from different bidders under a common framework.

Generation procurement recommendation

The current IRP generation recommendations mainly point to a combination of hydro, solar, wind, coal and geothermal as being the optimal solution for Zambia. The development timescales for projects can be analysed under the three phases of project development as summarised in Table 10.6 below.

Many projects in Zambia across all technologies have completed feasibility studies, and some have also completed procurement defined as establishing a mutually agreed power purchase agreement between buyer and seller in accordance with local legislation and best practice.

Table 10.6: Typical Project Development Timescales for Generation by Technology Type

Time Taken (years) to Develop On-Grid Generation by Technology Type	Phase One: Feasibility Study/Procurement	Phase Two: Financing	Phase Three: Construction and Commissioning	Total
Hydro	2 – 3 years	2 years	3 – 5 years	7 – 10 years
Solar	1 – 2 years	1 year	1 year	3 – 4 years
Wind	1 – 2 years	1 year	1 – 2 years	3 – 5 years
Coal	1 – 2 years	1 – 2 years	2 years	3 – 5 years
Geothermal	2 – 4 years	2 – 3 years	2 – 3 years	6 – 10 years

The financing process currently represents a bottleneck insofar as on-grid generation projects require a significant component of long-term debt (between 70% and 85% of project value) that is typically provided by multinational development banks (MDBs), development finance institutions (DFIs) and to a lesser extent, commercial banks, at commercially affordable rates. Many projects also require political risk insurance coverage for the full project investment based on an external assessment of country risk through insurance schemes provided by these lending institutions, MDBs and/or DFIs.

Taking account of the development timescales of various generation project technologies, and the quantum of new generation required according to the generation modelling, the IRP recommends the following procurement is concluded as soon as possible:

Table 10.7: Generation Procurement Recommendations Based on IRP Modelling

Technology	Recommended Procurement	Rationale
Hydro (run of river)	2,205 MW	Represents recommended capacity by 2030, due to long development timescales
Solar	1,555 MW	Represents recommended capacity by 2026 due to shorter timescales for financing and construction
Wind	400 MW	Represents recommended capacity by 2026 due to shorter timescales for financing and construction
Coal	600 MW	Represents recommended capacity by 2030, but if completed earlier will compensate for potential delays in other projects. Coal generation is a base load/non-variable source and (like hydro and geothermal) makes a greater contribution to system stability than VRES
Geothermal	30 MW	Represents recommended capacity by 2030, due to long development timescales

The IRP is agnostic as to the commercial model for development of these generation projects. The Electricity Act of 2019 allows for private sector participation in project ownership (IPPs) and for private sector off-take arrangements, with power wheeling/transmission services provided by the licensed transmission and distribution network operators.

Location of generation projects

The modelling undertaken in the IRP took cognisance of the quality and quantity of generation resource in different provinces of Zambia. Map 10.1 and Table 10.8 below summarise the assumptions made in relation to the location of different generation sources in Zambia, and the 330 kV substations into which power would be injected, taking into account the IRP transmission development plan.

Map 10.1: Provincial Allocation of New Generation Development to 2030 as Modelled in the IRP

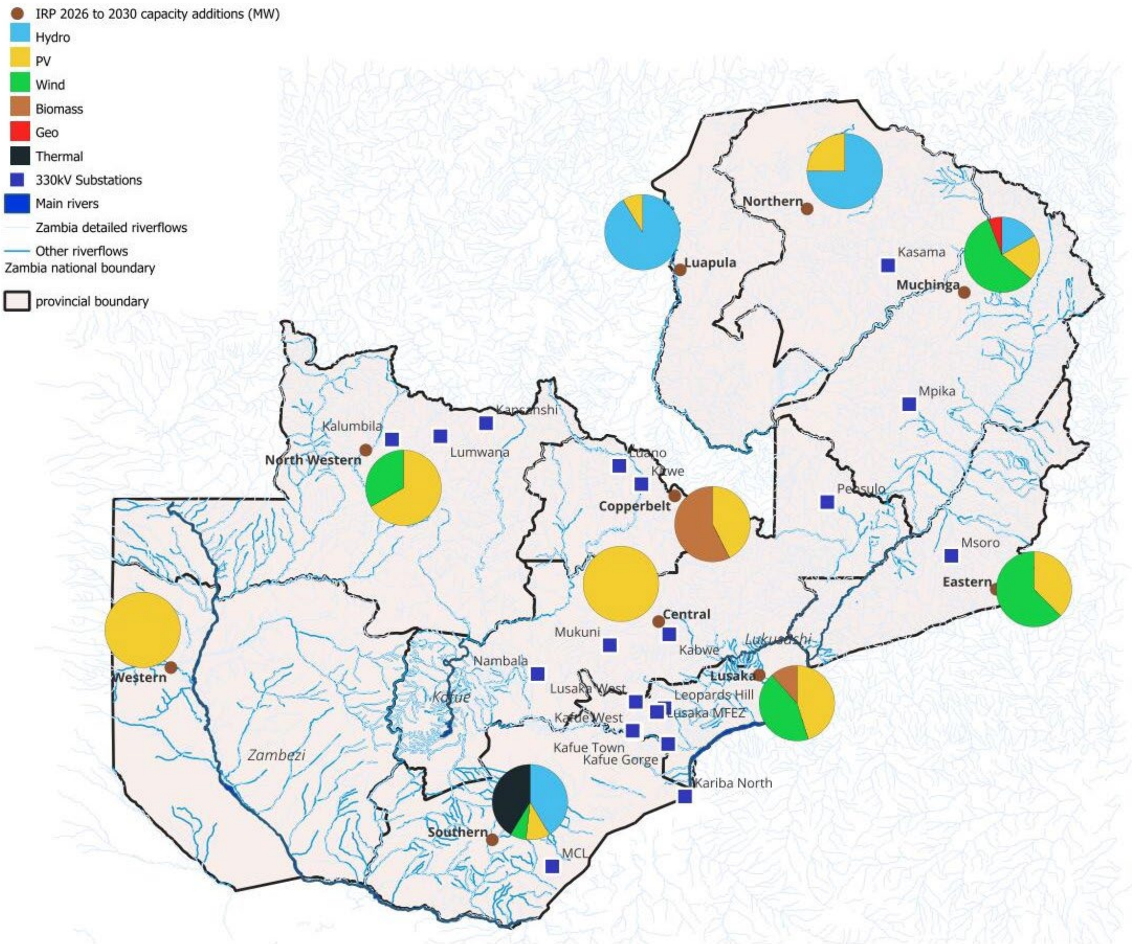

Table 10.8: Power Generation Procurement Recommendation to 2030 Broken Down by Province

Location	New Power Generation Sources (MW) by 2030
North Western	300
Northern	605
Luapula	1,164
Western	155
Eastern	800
Muchinga	516
Southern	1,450
Central	405
Copperbelt	470
Lusaka	443
Total	**6,308**

There are different spatial configurations of generation development that are possible to meet the anticipated future demand growth, but the allocation of power generation sources to be developed by province in Table 10.8 provides a guide to be used as the basis for procurement of new power generation sources in the short term. This recommendation has been aligned to the objectives of following a least cost development pathway for the integrated power system, addressing climate challenge risks, diversifying the energy mix and constructing generation capacity as close as possible to sources of demand.

Financing of generation projects

The agreement between Zambia and IMF signed in August 2022, together with accumulated sector trade arrears have placed restrictions on the extent to which ZESCO is able to invest significantly in new infrastructure and off-take power from IPPs until financial stability is re-established. There are exceptions within the IMF agreement for the World Bank and African Development Bank to provide new facilities on concessional terms. The main IRP document presents a road map for full power sector financial recovery. Key recommendations to unlock debt financing for projects listed in Table 10.7 above include:

- Leverage private sector participation in generation investment through IPPs and joint ventures/public–private partnerships (with ZESCO).
- Encourage private sector off-taker arrangements with large users (mining sector in particular) and intermediaries to limit future financing risk placed on Government.
- Where ZESCO is the off-taker:
  - Develop workable bankability structures for generation projects taking account of lender requirements for the application of cashflows received from customers (options include assignment of receivables, cash waterfalls etc.) and to address the requirement for investment insurance for political risk.
  - Restrict power purchases to the lower of: 1) the limits placed by the IRP recommendations, and 2) an assessment of the extent to which ZESCO is able to provide bankable off-take arrangements acceptable to generation project lenders.
  - Pursue external financial support from MDBs to support ZESCO off-take of power and increase the quantum of power that ZESCO can purchase from generation projects in consultation with Ministry of Finance/IMF as required.

Transmission and distribution procurement

Sections 10.2 and 10.3 above summarise the transmission and distribution requirements of the IRP up to 2030. These include:

- 4,114 km of 330 kV transmission lines and 1,094 km of transmission lines between 66 kV and 132 kV with associated high voltage transformers and substation equipment;
- 33 kV distribution lines with associated transformers and substation equipment consistent with energy access and economic growth targets;
- associated network at 11 kV and around 750,000 grid connections serving about 4 million people.

The high voltage transmission network and distribution investments are predominantly intended to be additions to the existing ZESCO transmission and distribution networks. The procurement and financing of these networks would therefore most likely be undertaken by ZESCO.

Funding for these projects is typically provided by MDBs and DFIs through long-term loan facilities with ZESCO. While the quantum of funding available is constrained due to the conditionality around the IMF agreement, some funding has been made available (e.g. $300m for Zambia – Tanzania Interconnector from World Bank) and it is recommended that the full transmission plan is prioritised and presented to the MDBs and DFIs for financing in phases over the period to 2030. The funding gap is currently around $1 billion. Climate financing may be an option for part of the plan that can be linked to a reduction in carbon emissions and growth in the regional trading of renewable energy.

A significant step towards enhancing the bankability of the transmission and distribution network would be through financially ringfencing the portion of the cashflows from customers relating to transmission and distribution. This would provide an assured revenue stream for repayment of loans which are acquired to fund transmission and distribution projects.

Off-grid procurement

Off-grid projects typically require a larger element of subsidy than on-grid projects and are developed by the REA (for Government-funded projects) or private sector investors. Output or performance-based funding structures which are competitively procured such as the Beyond the Grid Fund for Zambia[36] have been successful in leveraging private sector capital to supplement public funds to provide access to more than 1 million people in Zambia to date. It is recommended that REA and the MoE engage more deeply with the MDBs and cooperating partners to enhance funding available for off-grid electrification through such structures.

[36] Beyond the Grid Fund for Zambia, https://beyondthegrid.africa

Ministry of
Energy

info@moe.gov.zm
+260 211 230840