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Malawi: Energy Development Plan to Decarbonise the Economy

prepared for Power Shift Africa

By The University of Technology Sydney
Institute for Sustainable Futures

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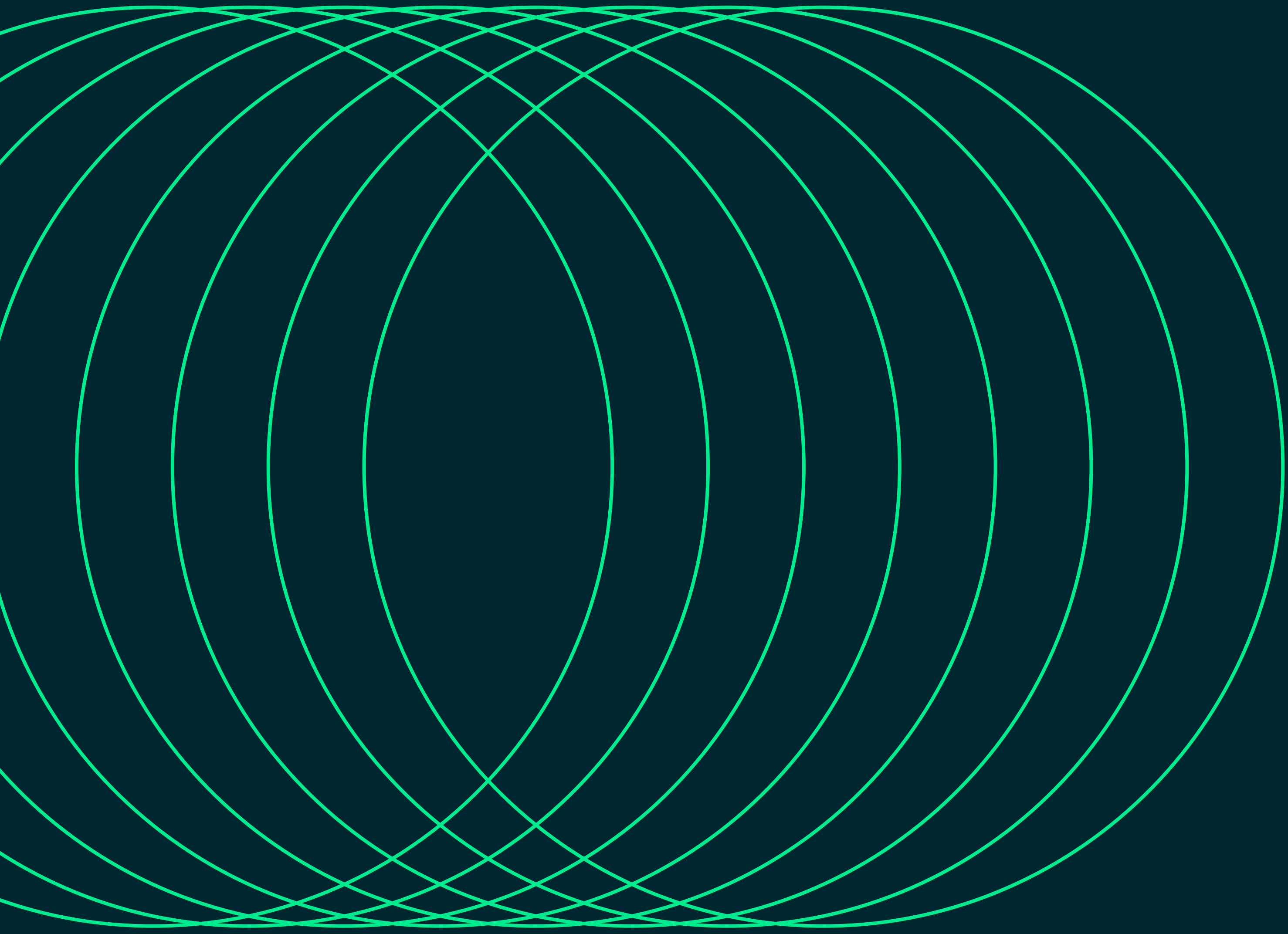

About the authors

The Institute for Sustainable Futures (ISF) was established by the University of Technology Sydney in 1996 to work with industry, government, and the community to develop sustainable futures through research and consultancy. Our mission is to create change toward sustainable futures that protect and enhance the environment, human well-being, and social equity. We seek to adopt an inter-disciplinary approach to our work and engage our partner organisations in a collaborative process that emphasises strategic decision-making.

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This project has been conducted in co-operation with Power Shift Africa, located at No. 5, Waridi Court, Rose Avenue, Kilimani.

The energy scenario software – the One Earth Climate Model – for the long-term projections and economic parameters is based on the development of the German Aerospace Centre (DLR), Institute for Technical Thermodynamics, Pfaffenwaldring 38-40, 70569 Stuttgart/Germany, and has been applied to over 100 energy scenario simulations for global, regional, and national energy analysis.

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All conclusions and any errors that remain are the authors own.

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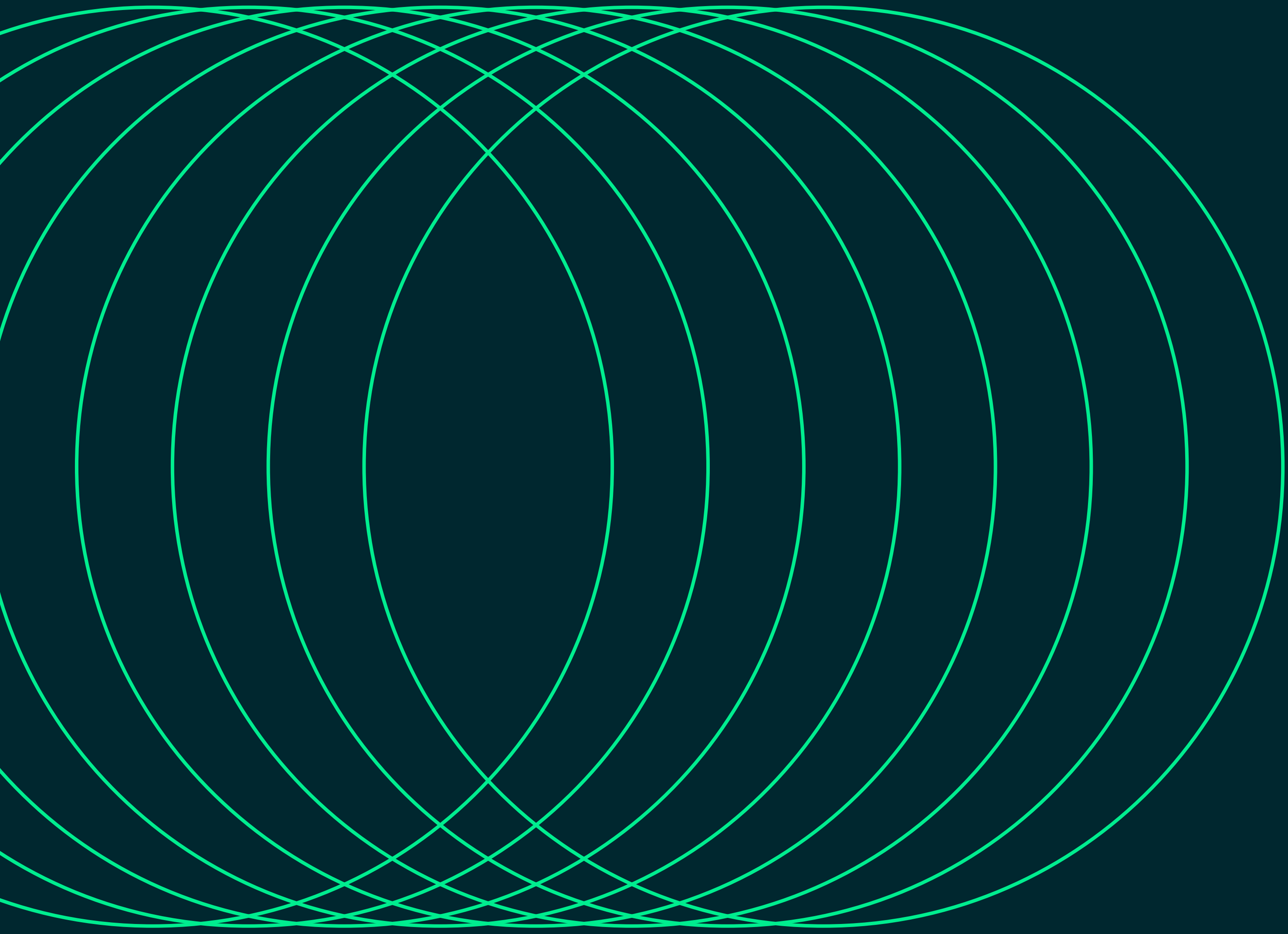
Executive Summary



Malawi submitted an updated Nation Determined Contribution (NDC) report to the United Nations Framework Convention on Climate Change (UNFCCC) in July 2021[1]. The new NDC sets a target to reduce greenhouse gas (GHG) emissions by 2030 by 2030 compared with the 'business-as-usual' (BAU) scenario.

The NDC provided a detailed assessment of the identified GHG mitigation options for Malawi, and estimated the total emissions reduction potential of around 17.7 million tonnes of CO_2 equivalents (tCO_2e) in 2040 against the BAU scenario emissions in the same year (34.6 million tCO_2e), a reduction of 51%.

Based on this analysis, mitigation measures have been grouped according to two different contributions:

- **Unconditional contributions:** A reduction of 6% relative to BAU in the year 2040; equivalent to an estimated mitigation level of 2.1 million tCO_2e in that year. This is an unconditional target, based on domestically supported and implemented mitigation measures and policies.
- **Conditional contributions:** An additional reduction of 45% relative to BAU in the year 2040; equivalent to an estimated mitigation level of 15.6 million tCO_2e in that year. This represents an additional targeted contribution, **based on the provision of international support and funding.**

Malawi is one of the very few countries that are not covered by the International Energy Agency's Statistical assessment (World Energy Balances). Therefore, the statistical data for this analysis is based on information from the Government of Malawi, the NDC, and data from the International Renewable Energy Agency (IRENA).

According to the World Bank, Malawi has achieved respectable gross domestic product (GDP) growth in the past, averaging 5% between 2004 and 2019 (World Band 2024)[2] However, Malawi faces significant difficulties in achieving inclusive and sustainable growth. The on-going global disruptions caused by the COVID-19 pandemic have been compounded by structural constraints in Africa, such as slow domestic job creation, high vulnerability to natural disasters, climate change, environmental degradation, and large infrastructure gaps. Furthermore, the pandemic has recently triggered a surge in debt levels, which must be addressed. However, strong economic growth is assumed for the development of the energy scenario.

Malawi's electricity demand is currently 100 kWh per capita (IRENA 2024), one of the lowest in the world, whereas the average global consumption is over 3,000 kWh/capita per annum (World Bank 2019)[3].

Biomass for cooking dominates Malawi's energy demand. However, industry and transport – usually large energy consumers – have only minor shares in the country's energy demand. Only 1% of Malawi's population has access to clean cooking technologies, although 14% has access to electricity services. Malawi's is among the lowest electricity access rates globally.

Power Shift Africa and the University of Technology Sydney-Institute for Sustainable Futures (UTS-ISF) have developed a comprehensive energy pathway for Malawi that is aligned with the goals of the Paris Climate Agreement.

The following sections provides an overview of the key results of the energy scenario.

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[1] Republic of Malawi, Minister of Forestry and Natural Resources, Malawi's Updated Nationally Determined Contribution (NDC), July 2021, https://unfccc.int/sites/default/files/NDC/2022-06/Malawi%20Updated%20NDC%20July%202021%20submitted.pdf?download

[2] World Bank 2024, online database, accessed September 2024 https://data.worldbank.org/indicator/NY.GDP.MKTP.KD?locations=MW

[3] World Bank Database 2019, https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?end=2019&name_desc=true&start=1960&view=chart

Development of the electricity demand

To develop a projection of the residential electricity demand in Malawi that will allow it to achieve the 1.5°C (M-1.5°C) scenario over the coming 30 years, a bottom-up electricity demand analysis was undertaken. The M-1.5°C aims to increase the access to energy – especially electricity – for all by 2050, while increasing electrification and comfort standards to the levels of the OECD countries. The growing economy will require a reliable power supply for small and medium businesses, industry, and the transport sector. It is assumed that households will use modern energy-efficient applications, based on the highest efficiency standards, to slow the growth of the power demand and to allow the parallel expansion of the energy infrastructure and the construction of renewable power plants. Electrification will be organised from the 'bottom up' in a new and innovative approach developed by the University of Technology Sydney-Institute for Sustainable Future (UTS-ISF).

It is assumed that households with an annual consumption indicated under the household type in 'phase 1' will increase their demand to 'phase 2' or 'phase 3' values over time. There are currently three household types, distinguished according to their annual electricity demand: rural households, which have an average annual electricity demand of just under 340 kWh; semi-rural households, which consume around 500 kWh per year; and urban households, with annual consumption of 840 kWh.

The electricity demand will gradually increase as the electric applications for each of the three household types progress from households with very basic needs, such as light and mobile phone charging, to a household standard equivalent to that of industrialised countries. The different levels of electrification and the utilisation of appliances are described with the affixes 'phase 1', 'phase 2', and 'phase 3' for rural households. In contrast, semi-urban and urban households are assigned to two groups: one for the basic level and one for the more-advanced stage of electrification. These households will develop over time, from the basic group towards the more advanced group.

The third phase of a rural household includes an electric oven, refrigerator, washing machine, air-conditioning, and entertainment technologies, and aims to provide the same level of comfort as are experienced by households in urban areas in industrialised countries. Adjustments will be made to the levels of comfort available in households in city and rural areas to discourage residents – especially young people – from leaving their home regions and moving to big cities. The phase-out of unsustainable biomass, such as liquefied pressurised gas (LPG) and paraffin, for cooking is particularly important in decarbonising Malawi's household energy supply. A staged transition towards electrical cooking is assumed.

Energy for cooking

The main energy demand in Malawi's households is for cooking. Firewood is the main energy source for rural households, whereas cylinders of LPG are the main source of energy for cooking in semi-urban and urban households[4]. Malawi's households also use charcoal. Based on the current usage of energy for cooking, a transition scenario from fuel-based cooking to electric cooking (e-cooking) has been developed for the M-1.5°C scenario. However, with an increasing population and a growing number of households, the overall fuel demand is likely to remain high, and a phase-out of emissions and fuel demand cannot be achieved with this measure alone. Fuel-based cooking applications will be gradually phased-out and replaced with electric cooking appliances.

The total phase-out of fuel-based systems will be for environmental and economic reasons. Fuel-based cooking requires fuel that generates emissions, and the fuel supply is, in most cases, not sustainable. Collecting fuel wood puts forests under pressure, is time-consuming, and has a negative economic impact on the country's productivity. Burning LPG causes CO_2 emissions, and its production is based on fossil gas, which must be phased-out by 2050 to remain within the global carbon budget to limit the global mean temperature rise to a maximum of +1.5°C. The remaining wood- and bio-energy-based cooking in 2050 will be sustainable charcoal. Electric cooking can be 'fueled' by renewable energy sources and will be emissions-free.

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[4] IEA (2020) Senegal fuels and technologies used for cooking by scenario, 2018–2030, 15th of August 2024, Online retrieved from: https://www.iea.org/data-and-statistics/charts/senegal-fuels-and-technologies-used-for-cooking-by-scenario-2018-2030

However, there are some challenges to the introduction of electric cooking stoves:

- Firewood remains freely available.
- In relative terms, the initial investment and monthly costs are high.
- Concerns exist about the safety of the technology. However, there are safety benefits compared with more-combustible energy sources, such as LPG.
- (Initial) concerns exist around the learnability of new appliances.
- In the cold climate of mountainous regions, fire from cooking also heats rooms.
- The use of e-cooking is perceived to be expensive.
- There are quality concerns about the appliances.
- It is a new technology that requires education to operate it.
- The current business models of distribution are not well suited to low-income households. Most vendors use an upfront model of payment rather than other innovative models, such as pay as you go, which have proven beneficial for many other technologies.
- Perceived and/or actual differences in the taste and quality of food prepared with biomass or e-cooking.

Projection of the transport energy demand

Malawi's transport sector is currently dominated by passenger cars, which account for 59% of all registered vehicles, whereas motorcycles represent 11% of the vehicle fleet. Other vehicles, such as light commercial vehicles (LCVs) account for 13% and buses and motor coaches 5%, together constituting 18% of the vehicle fleet. The remaining 12% of the vehicle fleet includes construction and industry vehicles, such as tractors, cranes, and excavators.

The total numbers of passenger-kilometres (pkm) and freight-kilometres (tonne-kilometres, tkm) are the basis for the projection of the future transport demand. The contraction of the transport demand in 2020 due to COVID is expected to end. It is anticipated that the pre-COVID transport demand of 2019 will be reached by 2023, and will then increase with population growth and GDP. It is assumed that the annual passenger kilometres will then increase by 10% annually until 2050, whereas the freight transport demand will increase by around 10% annually. The energy intensities for all vehicles are assumed to decrease over time with the implementation of more-efficient engines, the phase-out of fossil-fuel-based drives, and their replacement with electric drives. To achieve the terms of the Paris Climate Agreement, all energy-related CO_2 emissions must be phased-out by 2050. Therefore, all fossil-fuel-based vehicles must be phased-out, and electric drives will dominate, supplemented with a limited number of biofuel-based vehicles.

However, it is assumed that the share of cars will grow at the expense of two-wheeler vehicles – which will increase the average energy intensity per kilometre. Although electric drives are significantly more efficient, the increased vehicle size combined with more public transport options – mainly buses – will limit the increase in the energy demand. On average – across all passenger vehicle types – energy intensity will decrease from around 1.5 MJ per passenger kilometre to 1.07 MJ in 2030 and to 0.54 MJ in 2050.

The energy required by freight vehicles to move 1 tonne for 1 kilometre will decrease from around 1.5 MJ to 1.11 MJ by 2030 and to 0.68 MJ by 2050. Both reductions will only be possible with high shares of electric drives. The electrification of large parts of these fleets is unavoidable if the transport sector is to be decarbonised.

The supply of – sustainably produced – biofuels will be limited and will be directed to large commercial vehicles, buses, and the large trucks used in remote rural areas, where the required charging infrastructure for electric vehicles is unlikely to be developed in the next two decades.

The NDC does not include a detailed transport pathway but highlights the following priority mitigation activity for the transport sector: **'modal shifts to public transport and a shift from road to rail for freight as well as the importance of efficient transportation systems'**.

Based on the lifespans of motorcycles and cars, a country-wide overall market share of electric drives for the entire existing car fleet may not exceed 4% by 2030 for passenger and freight cars. Furthermore, it is assumed that the railway system will not be expanded beyond the current plans after 2030.

Projections of electricity supply: Assessment of solar and wind energy potential

The average annual solar irradiation (DNI) level in Malawi is 60–1,888 kWh/m^2 per day, and the higher end of that range is in the western part of the country. The overall onshore wind resources on land are significantly lower than the solar potential in Malawi. The wind speeds in Malawi range from 0.8 to 14 m/s at 100 m height, and high-wind-speed areas are predominantly located in the mid-northern region (Global Wind Atlas). In this analysis, we have included only areas with an average annual wind speed of ≥ 5 m/s. Malawi's solar and wind potential has been mapped under two different scenarios.

- **Scenario 1:** Available land – excluding protected areas (PA), extreme topography (slope > 30% (mountainous areas, S30), and certain land-cover classes, including closed forests, wetlands, moss and lichen, snow and ice, and water (permanent water bodies) (LU).
- **Scenario 2:** See 1, with an additional restriction that excludes areas ≤ 10 km from existing transmission lines (PT10).

Malawi is blessed with huge solar and wind energy resources. Scenario 1 provides 68,619 km^2 of areas with solar potential and a total potential for solar photovoltaic (PV) capacity of 1,715 GW. The solar potential under Scenario 2, when the land area is restricted by its proximity to power lines (£ 10 km), decreases to 32,413 km^2, which will allow utility-scale solar farms of 810 GW in Malawi. The overall wind potential under all restrictions is 195 GW from 39,036 km^2 for Scenario 1 and 83 GW from 16,521 km^2 under Scenario 2.

Malawi's total solar and onshore wind potential exceeds the projected electricity demand in 2050 – with full electrification of all households, industry, and the entire transport sector – by an order of magnitude. The potential is so large that Malawi could also export electricity to all neighbouring countries.

Assumptions for energy scenario development

Malawi must build up and expand its power generation system to increase the energy access rate to 100%. Building new power plants – no matter the technology – will require new infrastructure (including power grids), spatial planning, a stable policy framework, and access to finance. With lower solar PV and onshore wind prices, renewables have become an economic alternative to building new hydro and gas power plants. Consequently, renewables achieved a global market share of over 80% of all newly built power plants in 2021. Malawi has significant solar resources and large wind potential. The costs of renewable energy generation are generally lower with stronger solar radiation and stronger wind speeds. However, constantly shifting policy frameworks often lead to high investment risks and higher project development and installation costs for solar and wind projects relative to those in countries with more stable policies.

The scenario-building process for all scenarios includes assumptions about policy stability, the role of future energy utilities, centralised fossil-fuel-based power generation, population and GDP, firm capacity, and future costs.

- **Policy stability:** In this research, we assume that Malawi will establish a secure and stable framework for deploying renewable power generation. Financing a gas power plant or a wind farm is quite similar. In both cases, a power purchase agreement that ensures a relatively stable price for a specific quantity of electricity is required to finance the project. Daily spot market prices for electricity and/or renewable energy or carbon are insufficient for long-term investment decisions for any power plant with a technical lifetime of 20 years or longer.
- **Strengthened energy efficiency policies:** Existing policy settings – energy efficiency standards for electrical applications, buildings, and vehicles – must be strengthened to maximise the cost-efficient use of renewable energy and to achieve high energy productivity by 2030.
- **Role of future energy utilities:** With 'grid parity' of roof-top solar PV under most current retail tariffs, this modelling assumes that the energy utilities of the future will take up the challenge of increased local generation and develop new business models that focus on energy services, rather than simply on selling kilowatt-hours.
- **Population and GDP:** Projections of population and GDP are based on historical growth rates. Projections of population growth are taken from the World Bank Development Indicators.

- **Firm capacity:** The scale of each technology deployed and the combination of technologies in the three scenarios target the firm capacity. Firm capacity is the "proportion of the maximum possible power that can reliably contribute towards meeting the peak power demand when needed. Firm capacity is important to ensure a reliable and secure energy system. Note that variable renewable energy systems still have a firm capacity rating, and the combination of technology options increases the firm capacity of the portfolio of options.

Assumptions for the Malawi 1.5°C scenario

The Malawi 1.5°C (M-1.5°C) scenario is built on a framework of targets and assumptions that strongly influence the development of individual technological and structural pathways for each sector. The main assumptions considered in this scenario-building process are detailed below.

- **Emissions reductions:** The main measures taken to meet the CO_2 emissions reductions in the M-1.5°C scenario include strong improvements in energy efficiency, which will double energy productivity over the next 10–15 years, and the dynamic expansion of renewable energy across all sectors.
- **Growth of the renewables industry:** The dynamic growth of new capacities for renewable heat and power generation is assumed, based on current knowledge of the potential, costs, and recent trends in renewable energy deployment. Communities will play a significant role in the expanded use of renewables, particularly in terms of project development, the inclusion of the local population, and the operation of regional and/or community-owned renewable power projects.
- **Fossil-fuel phase-out:** The operational lifetime of gas power plants is approximately 30 years. In both scenarios (M-1.5°C and REFERENCE), coal power plants will be phased-out early, followed by gas power plants**.**
- **Future power supply:** The capacity of large hydro power plants will remain relatively flat in Malawi over the entire scenario period, whereas the quantities of bio-energy will increase within the nation's potential for sustainable biomass (see below). Solar PV is expected to be the main pillar of the future power supply, complemented by the contributions of bio-energy and wind energy. The figures for solar PV combine those for roof-top and utility-scale PV plants, including floating solar plants.
- **Security of energy supply:** The scenarios limit the share of variable power generation and maintain a sufficient share of controllable, secured capacity. Power generation from biomass and gas-fired back-up capacities and storage are considered important for the security of supply in a future energy system and are related to the output of firm capacity discussed above. Storage technologies will increase after 2030, including battery electric systems, dispatchable hydro power, and hydro pump storage.
- **Sustainable biomass levels:** No data on Malawi's sustainable level of biomass are available. However, low-tech biomass use, such as in inefficient household wood burners, is largely replaced in the M-1.5°C scenario by state-of-the-art technologies, primarily highly efficient heat pumps and solar collectors. This will result in a significant overall lowering of the total biomass use.
- **Electrification of transport:** Efficiency savings in the transport sector will result from fleet penetration by new, highly efficient vehicles, such as electric vehicles, but also from assumed changes in mobility patterns and the implementation of efficiency measures for combustion engines. The scenarios assume the limited use of biofuels for transportation, given the limited supply of sustainable biofuels.
- **Hydrogen and synthetic fuels:** Hydrogen and synthetic fuels generated by electrolysis using renewable electricity will be introduced as a third renewable fuel in the transportation sector, complementing biofuels, the direct use of renewable electricity, and battery storage. Hydrogen generation can have high energy losses. However, the limited potential of biofuels, and probably of battery storage, for electric mobility means it will be necessary to have a third renewable option in the transport sector. Alternatively, this renewable hydrogen could be converted into synthetic methane or liquid fuels, depending on the economic benefits (storage costs versus additional losses) and the technological and market development in the transport sector (combustion engines versus fuel cells). Because Malawi's hydrogen generation potential is limited, it is assumed that hydrogen and synthetic fuels will be imported. Furthermore, hydrogen utilisation will be limited to the industry sector only and is not expected to contribute more than 5% of industry's energy supply by 2050.

Malawi's 1.5°C scenario (M-1.5°C) takes an ambitious approach to transitioning the country's entire energy system to an accelerated new renewable energy supply. However, under the M-1.5°C scenario, the much faster introduction of new technologies will lead to the complete decarbonisation of energy for stationary energy (electricity), heating (including process heat for industry), and transportation. In the transport sector, there will be a strong role for storage technologies, such as batteries, synthetic fuels, and hydrogen.

Assumptions for the Malawi REFERENCE scenario

The REFERENCE scenario for Malawi has been developed based on the Malawi 1.5°C scenario, but assumes an implementation delay of 15 years. The energy-related CO_2 emissions of the REFERENCE scenario are similar to those of the BAU scenario in Malawi's NDC submission in 2021. However, the NDC does not contain any information about the actual energy supply pathway. Therefore, a detailed comparison is not possible.

The key differences between the REFERENCE case and the M-1.5°C scenario are:

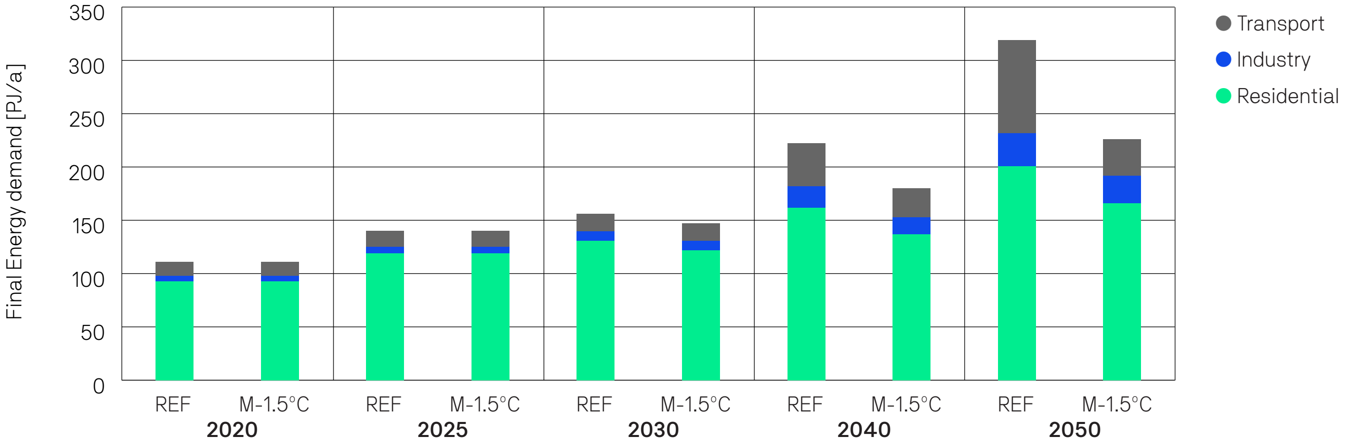
1. **Heating a sector:** In the REFERENCE scenario, the phase-out of coal, oil, and gas is delayed by 15 years for the residential, service, and industry sectors. Accordingly, electric heat pumps and solar collector systems will remain niche technologies until 2040, but will grow thereafter and increase their shares by 2050.
2. **Transport sector:** In the REFERENCE scenario, electric mobility will experience significant delays, whereas transport demand will increase as projected in the M-1.5°C scenario. Vehicles with internal combustion engines (ICEs) will remain dominant until 2040. Market shares for electric vehicles will start to grow significantly from 2040 onwards. Furthermore, biofuels will increase in the road transport sector.
3. **Power supply:** In the REFERENCE scenario, the delayed electrification in the heating and transport sectors will lead to the slower growth of the power demand than in the M-1.5°C scenario. Moreover, it is assumed that renewable power generation will not meet the increased electricity demand that arises from its delayed implementation. Therefore, fossil-fuel-based power generation will increase.

Malawi – Final Energy Demand

The projections for population development, GDP growth, and energy intensity are combined to project the future development pathways for Malawi's final energy demand. As a result of the projected continued annual growth in GDP of 8% on average until 2035 and 4.5% thereafter until 2050, the overall energy demand is expected to grow under both scenarios. The residential sector will remain the dominant player in Malawi's energy demand, but the energy demand of the industry sector will increase continuously. By 2050, industry will consume at least five times more energy than in 2020, making this sector the second highest consumer after transport under both scenarios. The energy demand of the transport sector will increase by 640% by 2050 under the REFERENCE scenario, whereas it will increase by 250% in the M-1.5°C scenario. The main reason for this significant difference in growth projections is the high rates of electrification in the M-1.5°C pathway.

The large efficiency gains achieved in the M-1.5°C scenario are attributable to high electrification rates, mainly in the cooking and transport sectors, because combustion processes with high losses will be significantly reduced.

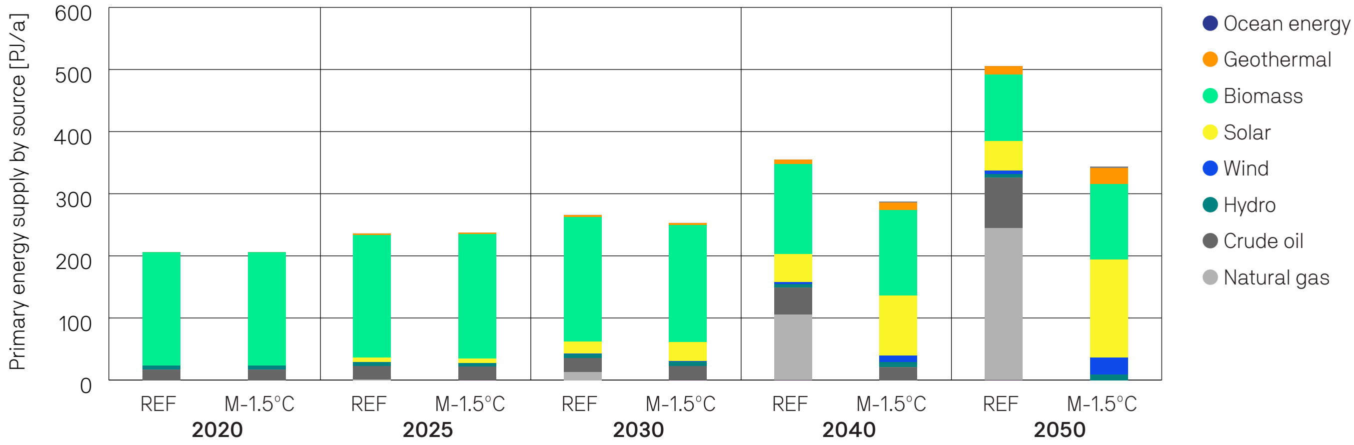
Figure E1. Projection of the total final energy demand by sector (excluding non-energy use and heat from combined heat and power (CHP))



Primary Energy Consumption

The M-1.5°C scenario aims to phase-out oil in the transport sector and oil for industrial use as fast as is technically and economically possible, through the expansion of renewable energies. The fast introduction of very efficient vehicle concepts in the road transport sector will replace oil-based combustion engines. This will lead to an overall renewable primary energy share of 100% in 2050 in the M-1.5°C scenario (when non-energy consumption is included).

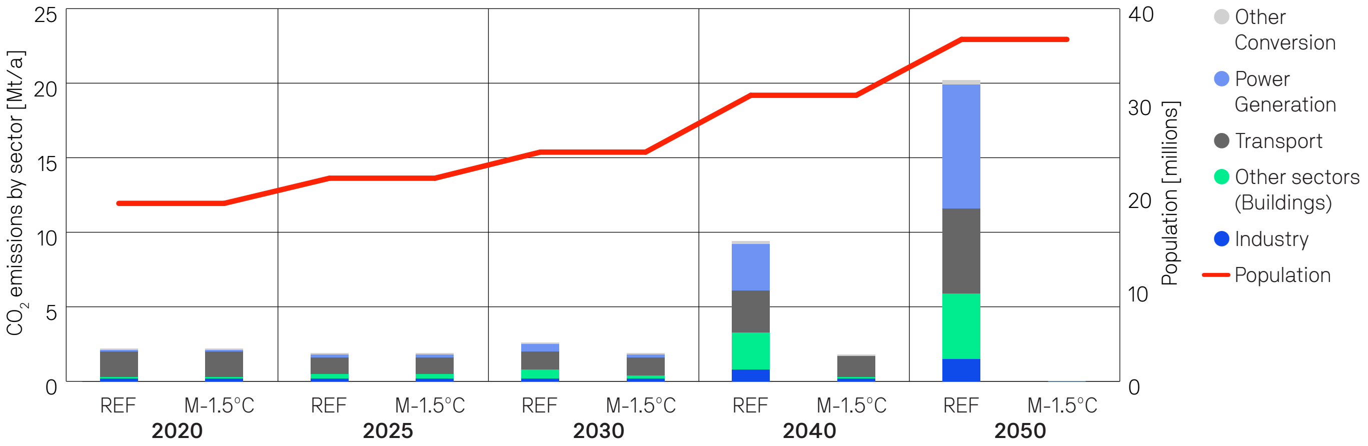
Figure E2. Projection of total primary energy demand by energy carrier (including the electricity import balance)



CO_2 Emissions Trajectories

The M-1.5°C scenario will reverse the trend of increasing energy-related CO_2 emissions after 2025, leading to a reduction of about 20% relative to 2020 by 2030 and of about 28% by 2040. In 2050, the full decarbonisation of Malawi's energy sector will be achieved under the M-1.5°C scenario. The REFERENCE scenario will lead to annual emissions of 19.8 $MtCO_2$ – identical to those in the BAU scenario of Malawi's updated NDC of 2021. In the M-1.5°C scenario, the cumulative emissions will sum to 50.3 Mt in 2020–2050 compared with 438.8 Mt CO_2 in the REFERENCE scenario.

Figure E3. Development of CO_2 emissions by sector



Cost Analysis

All three sectors will reduce their fuel costs over time because electricity generation will be based on renewables – with significant shares of solar, but also wind power. However, increased electrification will lead to higher investment costs in power generation and higher overall electricity supply costs for Malawi.

The M-1.5°C scenario requires an investment of 57 trillion Malawian kwacha (MWK; US$33.5 billion) in power generation and 29 trillion MWK (US$41 billion) in heat generation. Therefore, the total investment in power and heat generation capacities will add up to MWK 86 trillion (US$74 billion) (Figure E4).

Figure E4 shows all the accumulated fuel costs by sector and scenario and the calculated fuel cost savings in 10-year intervals between 2020 and 2050 in Malawian kwacha and US dollars. Additional power generation investments will be compensated by fuel cost savings in the decade in which they are made. Across the entire scenario period, fuel cost savings under the M-1.5°C scenario – relative to the REFERENCE case – will be MWK 322.4 trillion (US$189.7 billion).

Additional investment in power and heat generation (including cooking) under the M-1.5°C scenario will pay-off the entire investment in comparison of the M-1.5°C pathway.

In countries with a high level of energy access, fuel cost savings almost always refinance the investment in renewable energy. Malawi, however, has a low energy access rate in therefore, additional investment in energy infrastructure are required.

Figure E4. Accumulated fuel costs under the REFERENCE and M-1.5°C scenarios in billion USD and trillion MWK

		2020–2030		2031–2040		2041–2050		2020–2050		2020–2050 average per year	
REFERENCE		[Trillion MWK]	Billion USD	[Trillion MWK]	Billion USD	[Trillion MWK]	Billion USD	[Trillion MWK]	Billion USD	[Trillion MWK]	Billion USD
Power	Total	55.5	32.6	58.3	34.3	45.4	26.7	170.5	100.3	5.7	3.3
Heat	Total	3.5	2.0	15.3	9.0	36.1	21.2	55.6	32.7	1.9	1.1
Transport	Total	60.2	35.4	79.7	46.9	97.2	57.2	249.3	146.6	8.3	4.9
Summed Costs		**119.2**	**70.1**	**153.3**	**90.2**	**178.7**	**105.1**	**475.4**	**279.6**	**15.8**	**9.3**
		2020–2030		**2031–2040**		**2041–2050**		**2020–2050**		**2020–2050 average per year**	
M-1.5°C		**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**
Power	Total	1.2	0.7	2.3	1.3	3.1	1.8	6.5	3.8	0.2	0.1
Heat	Total	54.0	31.8	48.6	28.6	34.2	20.1	136.8	80.5	4.9	2.9
Transport	Total	2.8	1.6	4.1	2.4	2.7	1.6	9.5	5.6	0.3	0.2
Summed Costs		58.0	34.1	55.0	32.4	39.9	23.5	152.9	90.0	5.5	3.2
Difference REFERENCE versus M-1.5°C		**61.2**	**36**	**98.3**	**57.8**	**138.8**	**81.7**	**322.4**	**189.7**	**10.3**	**6.1**

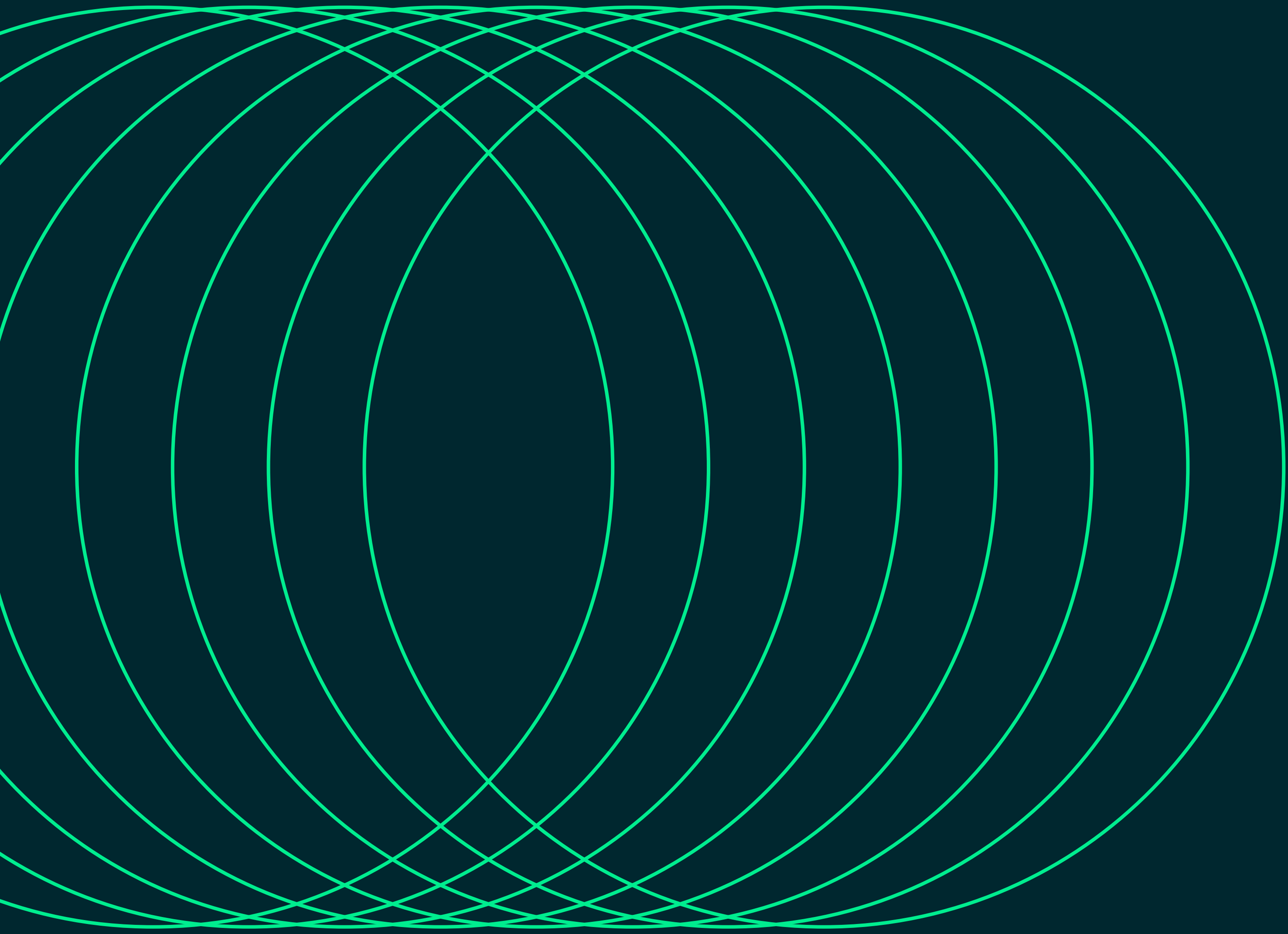
Power Sector Analysis

In a last step, after the assessment of the solar and wind potential and the projection of the future electricity demand for households, industry, and the transport sector, the power sector was analysed. The electricity demand projections and resulting load curves were calculated as important factors, especially for power supply concepts with high shares of variable renewable power generation. Furthermore, calculation of the required dispatch and storage capacities is vital to the development of energy electricity supply concepts that lead to high security of supply. A detailed bottom-up projection of the future power demand, based on the applications used, demand patterns, and household types, allows a detailed forecast of the demand to be made. The energy sector analysis was conducted for Malawi's projected electricity demand and supply for 2030 and 2050 under the M-1.5°C pathway.

Conclusion

In this study, we found that Malawi can cost-effectively build a reliable electricity supply based on local power generation with a high proportion of solar and wind power. The potential for solar and wind power will not only reliably cover all future electricity needs, but will also allow renewable electricity to be exported to neighbouring countries.

1 Introduction



This report focuses on the development of a 100% renewable energy pathway for Malawi. Here, the 100% renewable energy scenario is constructed to be robust and technically and financially feasible. The 100% renewable energy pathway will also be a clear demonstration of the security of supply for Malawi's industry, transport, and residential sectors.

The scenarios for the energy pathways do not claim to predict the future, but provide useful tools with which to describe and compare potential development pathways from the broad range of possible 'futures.' The Malawi 1.5°C (M-1.5°C) scenario is designed to calculate the efforts and actions required to achieve the ambitious objective of a 100% renewable energy system and to illustrate the options available to change Malawi's energy supply system into a truly sustainable one. It can be used as a reliable basis for further analysis of the possible ideas and actions required to implement pathways to achieve the desired results.

100% renewable energy scenarios for electricity generation, energy demand, energy supply, and transport are included. The investments required to achieve these scenarios and the policies that will facilitate them are described for the specific scenarios.

Finally, the report includes simulations of the national grid capacity required now and, in the future, and the necessary linkages between different parts of the country's power grid. The simulations support the assessment of the grid expansion requirements, the power trade balance, and the investments required to strengthen the backbone of Malawi's electricity infrastructure to ensure its reliability and resilience.

In this report, we aim to inform policy makers, researchers, and practitioners of the extent of the interventions required for Malawi to reach its target of 100% renewable energy by 2050. The decade-by-decade scenarios identify important milestones, which will allow further sector-wise energy-related targets to be defined and tracked.

1.1 Research Scope

Since 2017, the University of Technology Sydney Institute for Sustainable Futures (UTS-ISF) has undertaken detailed country-specific energy analyses (see reference list) ranging from the global south, including Malawi, to industrialised countries, including all the G20 countries and Switzerland.

All UTS-ISF energy analyses include the following components:

- A renewable energy resource analysis based on spatial GIS data under constrained land availability conditions (excluding protected areas, areas with a steep slope, and certain land-cover classes, such as closed forests, wetlands, snow and ice, and permanent water).
- The development of future energy demands for 2025, 2030, 2035, 2040, 2045, and 2050 based on the latest available statistics – the base year for energy demand is 2019 – broken down into the main energy sectors (power, buildings, industry, and transport).
- The sectoral energy demands (see above) are broken down to the level of provinces.
- The development of the following scenarios:
  - 1.5°C scenario[5] – 100% renewable energy plan to decarbonise the energy sector by 2050 within the global carbon budget required to achieve a temperature rise of 1.5°C with 66% certainty (based on IPCC AR6 2021).
  - A REFERENCE scenario for comparison
- These scenarios are combined with renewable energy scenarios with different shares of variable power generation (solar PV, wind, bio-energy, and hydro power).
- Based on the different power demand-and-supply scenarios, a projection of the required loads from the industry, commercial, and residential demands is compared with the available power generation capacity – to stress-test the security of supply.

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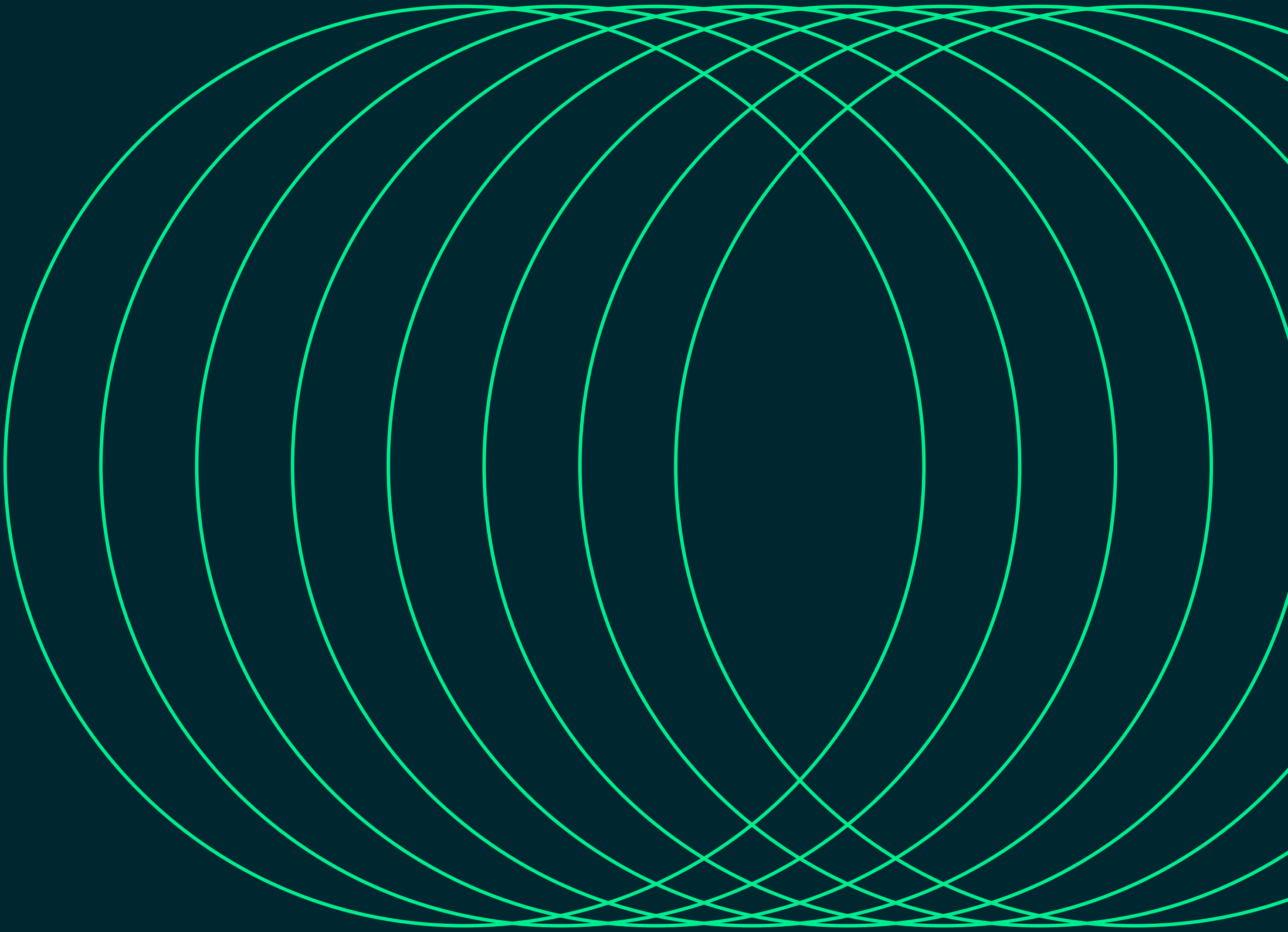
[5] 1.5 °C scenario: Series of scenarios with total global carbon budget of 400 $GtCO_2$ to limit the global mean temperature rise to a maximum of 1.5°C with 67% likelihood, as defined in IPCC AR6.

- The power generation capacity is simulated at 1-hourly resolution for seven provinces with regional long-term average meteorological data for solar radiation and onshore wind.
- The current and future required national grid capacities are simulated, together with the required linkages between different parts of the country's national power grid and import/export transactions with neighbouring countries.

This simulation is particularly important in terms of the role of 24/7 power generation and power flows between regions and neighbouring countries. Included are the:

- Grid expansion and storage requirements;
- Visualisation of the hourly demand and supply curves;
- Carbon emissions (annual and cumulative);
- Investment required in additional power generation capacity – including fuel costs and fuel cost savings, and operation and maintenance costs for all power generation capacities;
- The power sector trade balance (electricity and fuel) with neighbouring countries;
- A cost comparison of all scenarios.

2 Scenario Assumptions



2.1 Malawi: Country overview

Malawi is a landlocked country in south-east Africa, with borders to Mozambique, Zambia, and Tanzania. Lake Malawi, also known as Lake Nyasa in Malawi and Lago Niassa in Mozambique, forms a significant part of the eastern border of Malawi and is the southernmost lake in the East African Rift (Britannica 2024)[6]. The official language is English, although local languages such as Chewa (dominant), Lambya, Lomwe, Ngoni, Nkhonde, Nyakyusa, Nyanja, Sena, Tonga, Tumbuka, and Yao are still commonly used (CIA 2024)[7]. Since gaining independence in 1964, Malawi has maintained peace and a stable government. The capital Lilongwe is one of the fastest-growing cities in Africa, with a population that has doubled over the past 20 years. Lilongwe's major industry is tobacco processing, and it is a hub for the large agriculture industry in Malawi (UN-Habitat 2024)[8].

2.1.1 Political Context

Malawi is a democracy and multi-party presidential and parliamentary elections are held every 5 years. In January 2021, the Government launched the Malawi 2063 Vision, which aims to transform Malawi into a wealthy, self-reliant, industrialised upper-middle-income country, through a focus on agricultural commercialisation, industrialisation, and urbanisation. The first 10-year implementation plan is anchored to the World Bank's Country Partnership Framework (CPF) (FY21–FY25) (World Bank 2024)[9]. Malawi is part of the Least Developed Countries (LDC) Group and Evans Njewa, Chief Environmental Officer of the Government of Malawi, is chairing the LDC Group in 2024. The LDC comprises 45 nations that are especially vulnerable to climate change but have done the least to cause the problem. Through the co-ordination of the LDC Group on Climate Change, the least developed countries work together at intergovernmental negotiations under the UN Framework Convention on Climate Change (LDC-Climate 2024)[10].

2.1.2 Economic Context

Malawi remains one of the poorest countries in the world, despite making significant economic and structural reforms to sustain its economic growth. The economy is heavily dependent on agriculture, which employs over 80% of the population, and it is vulnerable to external shocks, particularly climatic shocks[11].

According to the World Bank, Malawi has achieved respectable GDP growth in the past, averaging 5% between 2004 and 2019 (World Band 2024)[12]. However, Malawi faces significant difficulties in achieving inclusive and sustainable growth. The on-going global disruptions caused by the COVID-19 pandemic have been compounded by structural constraints in Africa, such as slow domestic job creation, high vulnerability to natural disasters, climate change, environmental degradation, and large infrastructure gaps. Furthermore, the pandemic has recently triggered a surge in debt levels, which must be addressed. However, strong economic growth is assumed for the development of the energy scenario.

Population and economic development projections until 2050

The population and GDP shown in Table 2 are based on projections of the Malawi Government, and have been used for the NDC and the long-term energy plan.

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[6] Britannica, online version, accessed September 2024, https://www.britannica.com/place/Lake-Nyasa

[7] CIA, The World Factbook, online version, accessed September 2024, https://www.cia.gov/the-world-factbook/countries/malawi/#geography

[8] UN-Habitat, online database, accessed September 2024, https://unhabitat.org/malawi-lilongwe-urban-profile

[9] World Bank Country Profile, Malawi, online database, accessed September 2024, https://www.worldbank.org/en/country/malawi/overview

[10] LDC-Climate, online information, accessed September 2024, https://www.ldc-climate.org/about-us/overview/

[11] World Bank Country Profile, Malawi, online database, accessed September 2024, https://www.worldbank.org/en/country/malawi/overview

[12] World Bank (2024) online database, accessed September 2024, https://data.worldbank.org/indicator/NY.GDP.MKTP.KD?locations=MW

Table 1: Malawi's population and GDP projections until 2050

Malawi	Units	2020	2025	2030	2035	2040	2045	2050
Population	[individuals]	19,129,955	21,228,394	24,626,142	27,618,382	30,663,457	33,690,961	36,685,426
Annual Population Growth	[%/a]	2.69%	2.47%	2.39%	2.21%	2.03%	1.83%	1.66%
GDP	[US$ billion]	10.9	15.9	23.8	36.2	51.8	70.6	86.7
Annual Economic Growth	[%/a]	0.80%	6.00%	10.00%	8.00%	7.00%	6.00%	3.00%
GDP/Person (calculated)	[US$/ capita]	570	748	965	1312	1688	2095	2364

2.1.3 population development

Table 2: Overview – three modelling regions of Malawi (source: Malawi National Statistical Office)[13]

Scenario Region	Region	Counties	Population [2018]	Area [km²]	Population Density
1	Northern Region	Chitipa	234,927	4,027	58
		Karonga	365,028	8,968	41
		Likoma	14,527	21	678
		Mzimba & Muzuzu	1,161,460	10,465	111
		Nkhata Bay	284,681	10,586	27
		Rumphi	229,161	7,284	31
	Northern Region Total		**2,289,784**	**41,351**	**55**
2	Central Region	Dedza	830,512	3,900	213
		Dowa	772,569	2,625	294
		Kasungu	842,953	8,187	103
		Lilongwe & City	2,626,900	6,064	433
		Mchinji	602,305	3,121	193
		Nkhotakota	393,077	8,091	49
		Ntcheu	659,608	3,343	197
		Ntchisi	317,069	1,973	161
		Salima	478,346	4,873	98
	Central Region Total		**7,523,339**	**42,177**	**178**
3	Southern Region	Balaka	438,379	1,937	226
		Blantyre & City	1,251,480	1,948	643
		Chikwawa	564,684	4,706	120
		Chiradzulu	356,875	650	549
		Machinga	735,438	4,095	180
		Mangochi	1,148,610	9,010	127
		Mulanje	684,107	2,149	318
		Mwanza	130,949	1,400	94
		Neno	138,291	1,015	136
		Nsanje	299,168	1,878	159
		Phalombe	429,450	1,111	387
		Thyolo	721,456	1,828	395
		Zomba & City	851,737	3,226	264
	Southern Region Total		**7,750,624**	**34,953**	**222**

Source: Malawi National Statistical Office (2018)

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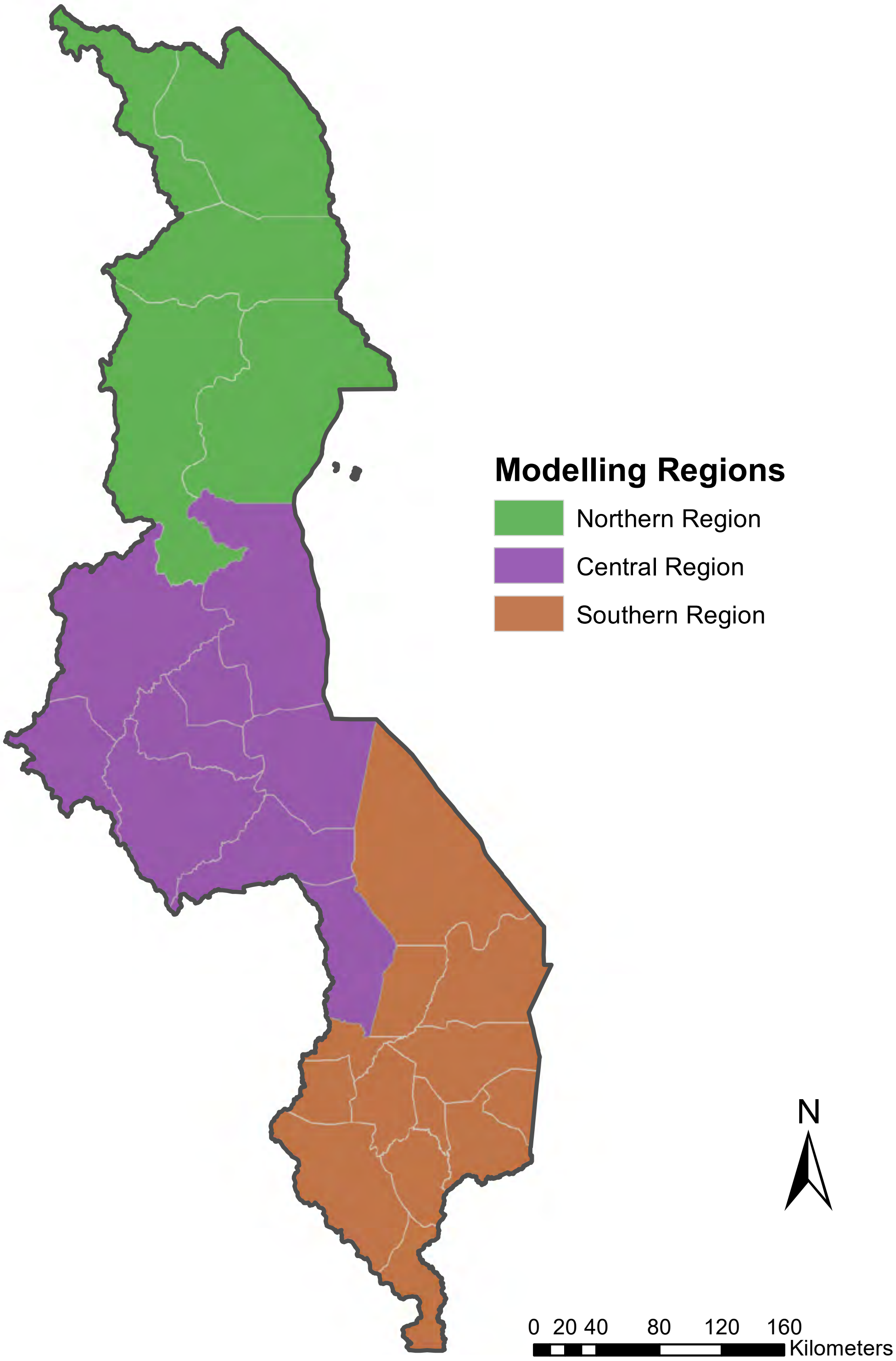
[13] Malawi National Statistical Office (https://www.nsomalawi.mw/census/2018)

Figure 1: Malawi – Modelling Regions



Source: generated by ISF from World Administrative Divisions[14]

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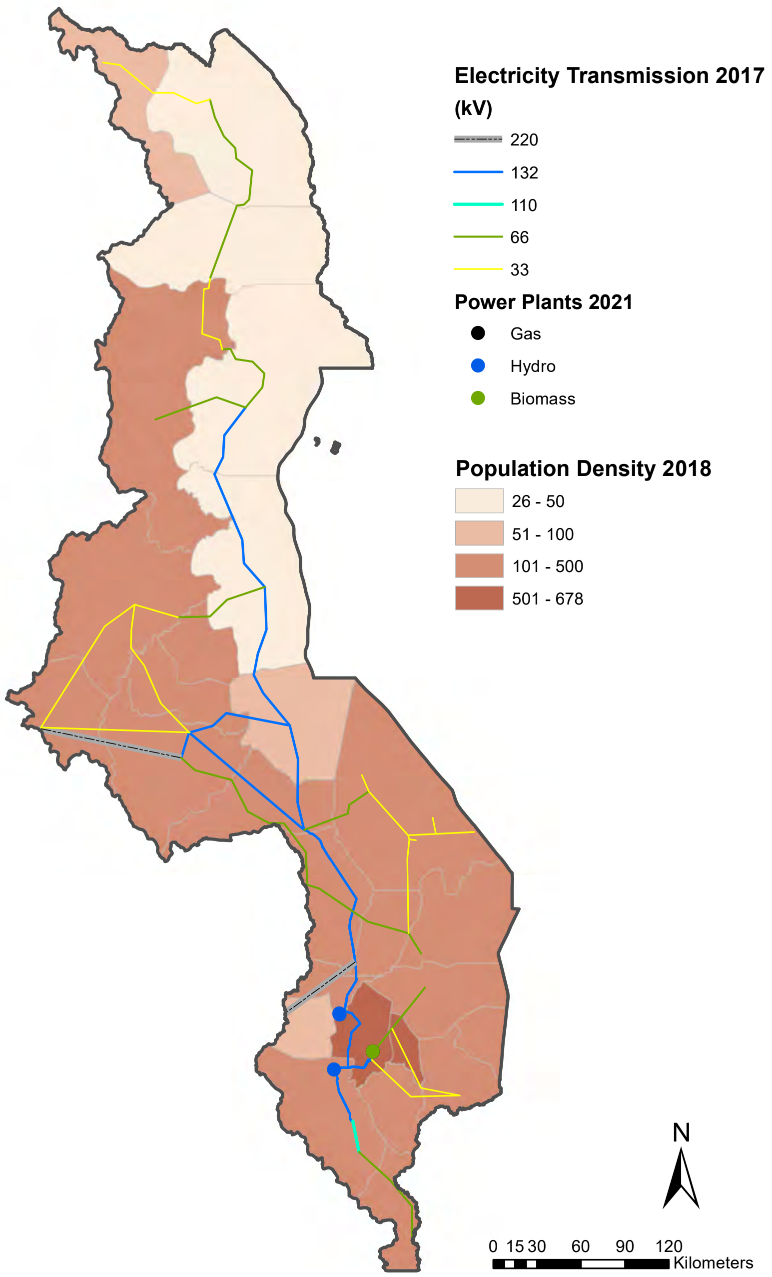
[14] World Administrative Divisions, https://hub.arcgis.com/datasets/esri::world-administrative-divisions/explore

2.2 Electricity infrastructure and energy access

For this analysis, Malawi's power sector is divided into three modelling regions. The regional distribution of the population and the availability of the energy infrastructure correlate with the socio-economic situation in all regions. The following map provides an overview of the locations of power lines and power plants, a regional breakdown of energy pathways, and a power sector analysis (Chapter 6).

Figure 2: Distribution of population and the existing electricity infrastructure in Malawi



Source: Malawi Electricity Transmission Network (2017)[15]; power stations – Global Power Plant Database (v1.3.0)[16]; the population density is based on Malawi population and housing census (2018)[17]

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[15] World Bank Group: https://kurma-monitor-prod.stanford.edu/catalog/stanford-xy243hj1082

[16] World Resources Institute, https://datasets.wri.org/dataset/globalpowerplantdatabase

[17] Government of Malawi: https://malawi.unfpa.org/sites/default/files/resource-pdf/2018%20Malawi%20Population%20and%20Housing%20Census%20Main%20Report%20%281%29.pdf

Figure 2 shows the population density of Malawi. The highest population concentrations are shown in dark red and the lowest in white. The map clearly shows the high population densities in the metropolitan areas of Lilongwe, Blantyre and Mzuzu in the west and south-west of Malawi. The existing constructed electricity infrastructure (power lines, power plants, and sub-stations), with their different types of grids, are shown as lines, and the differently coloured dots mark grid-connected power plants – each colour represents a specific technology, identified in the legend. The lines represent power transmission lines with different voltage levels. The figure visualises the distribution of the grid, power plants, and population density, but does not claim to be complete. The energy access rate of the local population in Malawi is around 14.2%[18], although access to energy services does not necessarily mean that the supply is always available.

2.3 Energy access – development in 2005–2023

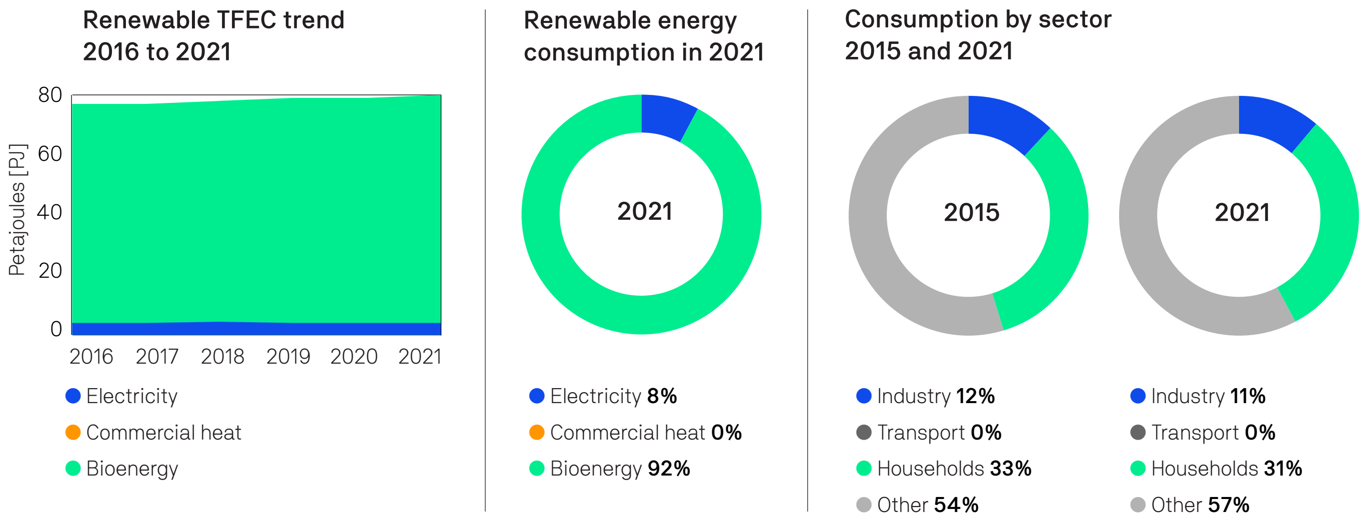
It is necessary to analyse the development of the past energy demand to project that of the future. Unfortunately, Malawi is one the very few countries not represented at the International Energy Agencies energy statistics services. Therefore, the reporting format differs from that of other country reports in the One Earth Climate Model series, because not all historical energy consumption and supply data are available.

Instead, the ‘energy profile’ reporting format published by the International Renewable Energy Agency (IRENA) has been used as a basis for this section (IRENA 2024)[19].

Figure 3 shows Malawi’s final energy demand development between 2016 and 2021. The overall energy demand remained stable in this period, whereas economic activity measured in GDP stalled, especially due to COVID-19 around 2020.

Biomass for cooking dominates Malawi’s energy demand. Industry and transport–usually large energy consumers–have minor shares in the countries energy demand. Only 1% of Malawi’s population has access to clean cooking technologies, whereas 14% have access to electricity services. Malawi has among the lowest electricity access rates globally.

Figure 3: Final energy demand development in Malawi from 2005 to 2019



Renewable TFEC trend 2016 to 2021

Renewable energy consumption in 2021

Consumption by sector 2015 and 2021

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[18] World Bank: https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=MW

[19] IRENA 2024, online database, Malawi Energy Profile, accessed September 2024, https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Malawi_Africa_RE_SP.pdf

The power generation capacity has increased since 2018 with the installation of solar PV systems. Of the 180 MW of newly installed solar PV capacity, 56% was on-grid and 44% off-grid. The total installed capacity in 2023 was 724 MW, 615 MW of which was on-grid and the remaining 110 MW off-grid. Over the past decade, solar PV has been the fastest growing power generation technology in Malawi (Figure 4). Solar PV dominates off-grid power generation, whereas hydro dominates the on-grid sector (Figure 5). However, on-grid solar PV is growing significantly faster than any other grid-connected power generation technology.

Malawi's electricity demand is currently 100 kWh per capita (IRENA 2024), one of the lowest in the world, whereas the global average consumption exceeds 3,000 kWh/capita per annum (World Bank 2019)[20].

Figure 4: Development of power generation capacity (on-grid and off-grid) in Malawi from 2005 to 2020

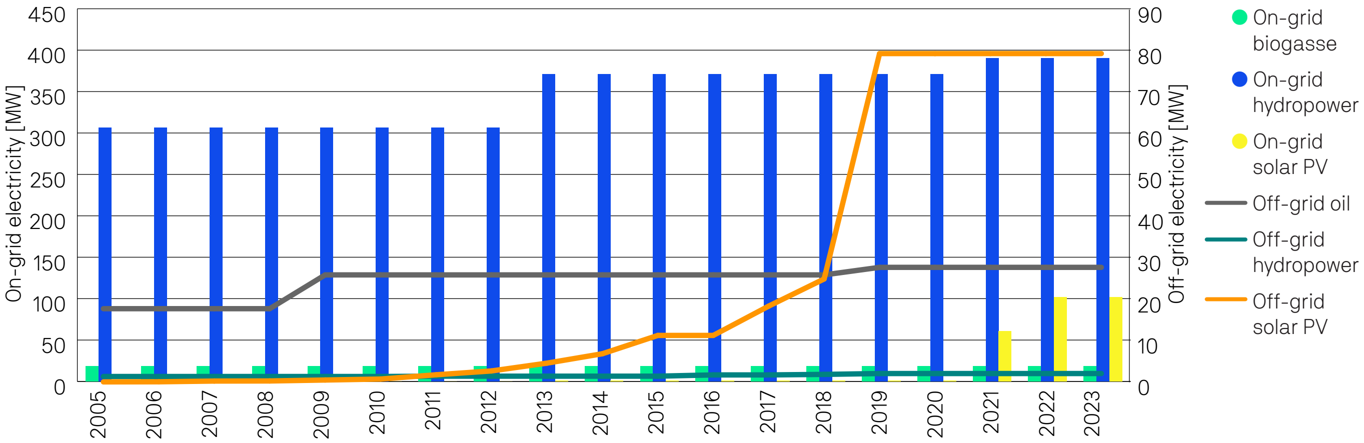
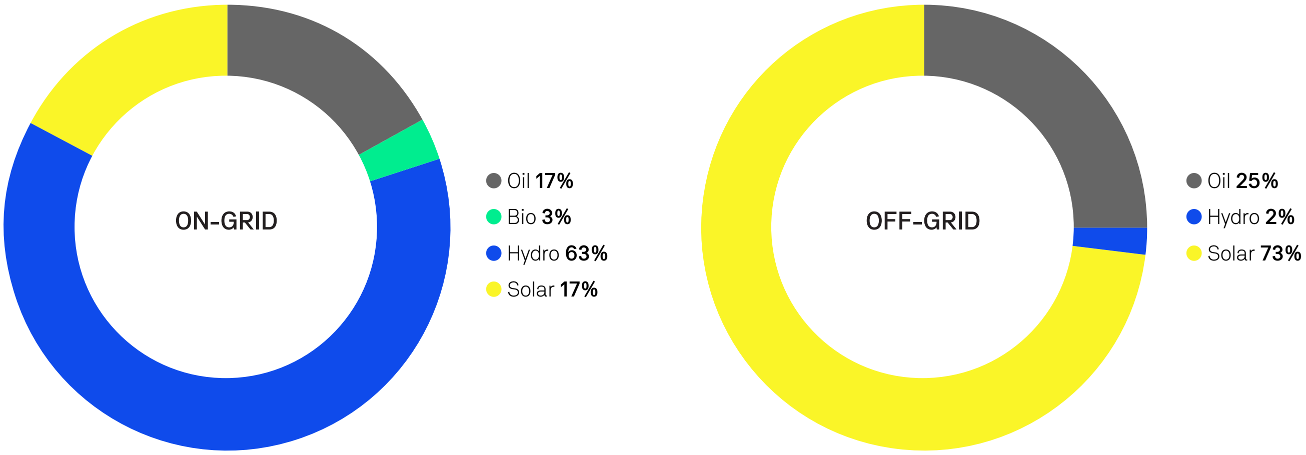


Figure 5: Power generation capacity (on-grid and off-grid) by technology in 2023



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[20] World Bank Database 2019, https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?end=2019&name_desc=true&start=1960&view=chart

2.3.1 Definition of renewable energy

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body assessing climate change. In its Special Report on Renewable Energy Sources and Climate Change Mitigation,[21] the IPCC defines the term ‘renewable energy’ as follows:

‘RE is any form of energy from solar, geophysical or biological sources that is replenished by natural processes at a rate that equals or exceeds its rate of use. RE is obtained from the continuing or repetitive flows of energy occurring in the natural environment and includes resources such as biomass, solar energy, geothermal heat, hydro power, tide and waves, ocean thermal energy and wind energy. However, it is possible to utilise biomass at a greater rate than it can grow or to draw heat from a geothermal field at a faster rate than heat flows can replenish it. On the other hand, the rate of utilisation of direct solar energy has no bearing on the rate at which it reaches the Earth. Fossil fuels (coal, oil, natural gas) do not fall under this definition, as they are not replenished within a time frame that is short relative to their rate of utilisation.’

2.4 Development of the Residentlal energy demand

To project the residential electricity demand in Malawi over the coming 30 years to achieve the Malawi 1.5°C (M-1.5°C) scenario, a bottom-up electricity demand analysis was performed. The M-1.5°C aims to increase the access to energy – especially electricity – for all by 2050, while increasing the electrification and comfort standards to the levels of OECD countries. The growing economy requires a reliable power supply for small and medium businesses, industry, and the transport sector. It is assumed that households will use modern energy-efficient applications, based on the highest efficiency standards, to slow the growth of the power demand and to allow the parallel expansion of the energy infrastructure and the construction of renewable power plants. Electrification will be organised from the ‘bottom up’ in a new and innovative approach developed by UTS-ISF.

2.4.1 Household electricity demand

The current and future developments of the electricity demand for Malawi’s households were analysed from the second half of 2024 onwards under the leadership of Power Shift Africa. The future development of the household demand has been discussed in a multiple-stakeholder dialogue with representatives of Malawi’s academia, civil society, and government.

Figure 6 shows the breakdown of Malawi’s households by size(UN-ES 2022)[22]. The current average electricity demands of Malawi’s households are significantly lower than those of OECD countries.

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[21] Arvisu D, Bruckner T, Chum H, Edenhofer O, Estefen S, Faaij A, Fischedick M, Hansen G, Hiriart G, Hohmeyer O, Hollands KGT, Huckerby J, Kadner S, Killingtveit Å., Kumar A, Lewis A, Lucon O, Matschoss P, Maurice L, Mirza M, Mitchell C, Moomaw W, Moreira J, Nilsson LJ, Nyboer J, Pichs-Madruga R, Sathaye J, Sawin J, Schaeffer R, Schei T, Schlömer S, Seyboth K, Sims R, Sinden G, Sokona Y, von Stechow C, Steckel J, Verbruggen A, Wiser R, Yamba F, Zwickel T (2011) Technical Summary. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation,(O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds), Cambridge University Press, Cambridge, UK and New York, NY, USA.

[22] UN-ES (2019) United Nations, Department of Economic and Social Affairs, Population Division (2022). Database of Household Size and Composition 2019, https://www.un.org/development/desa/pd/data/household-size-and-composition

Figure 6: Households by size – Malawi

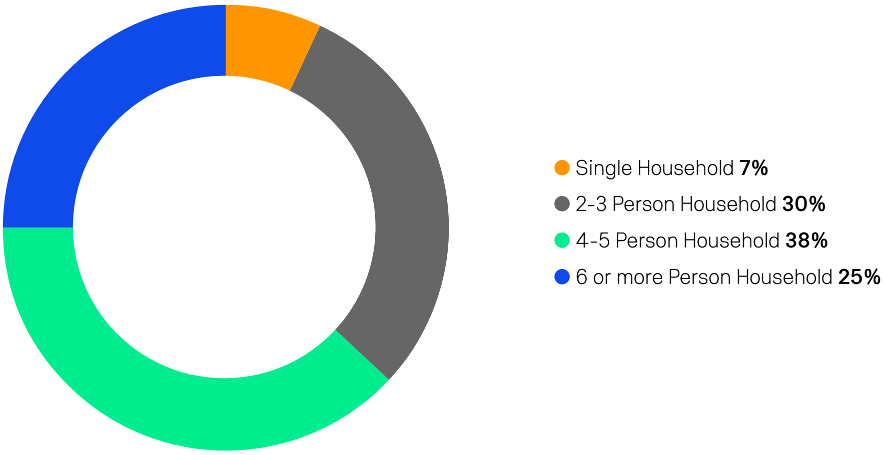

Table 3 shows the electricity demand and the electrical appliances used by households in Malawi in 2020 and the projected '*phases*', with increased demand when electrification is increased. It is assumed that households with an annual consumption indicated under the household type in 'phase 1' will increase their demand to 'phase 2' or 'phase 3' values over time. There are currently three household types, separated according to their annual electricity demand: rural households, which have an average annual electricity demand of just under 340 kWh; semi-rural households, which consume around 500 kWh per year; and urban households, with an annual consumption of 840 kWh.

The electricity demand will gradually increase as the electric applications for each of the three household types progress from households with very basic needs, such as light and mobile phone charging, to a household standard equivalent to that of industrialised countries. The different levels of electrification and the utilisation of appliances are described with the affixes 'phase 1', 'phase 2', and 'phase 3' for rural households. In contrast, semi-urban and urban households are assigned to two groups: one with the basic level of electrification and one for the more-advanced stage. The households will develop over time, from the basic group towards the more advanced group.

The third phase of a rural household includes an electric oven, refrigerator, washing machine, air-conditioning, and entertainment technologies, and aims to provide the same level of comfort as households in urban areas in industrialised countries. Adjustments will be made to the levels of comfort in households in city and rural areas to discourage residents – especially young people – from leaving their home regions and moving to big cities. The phase-out of unsustainable biomass, such as LPG and paraffin, for cooking is particularly important in decarbonising Malawi's household energy supply. A staged transition towards electrical cooking is assumed (see Section 2.1.8.2).

Table 3: Household types used in all scenarios and their assumed annual electricity demands

Malawi			**Annual Household Electricity Demands**
Household Type	**Group**		**Annual electricity demand [kWh/a]**
Rural	Phase 1	– Very-low-income rural household	250
		– Low-income rural household	
	Phase 2	– Lower-middle-income rural household	1,447
	Phase 3	– Upper-middle-income rural household	3,603
Semi-Urban	Basic	– Low-to-middle-income semi-urban household	2,303
	Advanced	– Middle-income semi-urban household	3,632
Urban – Apartment	Basic	– Low-to-middle-income urban household (apartment)	3,243
	Advanced	– Middle-income urban household (apartment)	4,256
Urban House	Basic	– Low-to-middle-income urban household (house)	2,495
	Advanced	– Middle-to-high-income urban household (house)	3,424

The typical household electricity demands are compared with:

1. Regional countries in East Africa;
2. Representative OECD country. The authors have chosen Switzerland for its well-documented electricity demands and good representation of energy-efficient but highly electrified households among the OECD countries.

OECD household: Switzerland

Table 4 shows an example of the electricity demands of different household types in the OECD country of Switzerland. Switzerland was chosen as the example because of its well-documented electricity demands and its good exemplification of the energy-efficient and highly electrified households among OECD countries. In predicting the future development of Malawi's electricity demand, we assume that the level of electrification and household appliances used will ultimately be similar to those in industrialised countries. Although the electricity demand of households in industrialised countries – excluding electric mobility – can be reduced through technical efficiency measures and more-efficient appliances by improving technical standards, the current demand provides an orientation for the future demands in developing countries.

Table 4: Standard household demands in an industrialised country (Switzerland)

Standard Household – OECD	**Apartment**			**Separate House**			
Category	**2 People [kWh/a]**	**Additional person [kWh/a]**	**4 People [kWh/a]**	**2 People [kWh/a]**	**Any additional person/s [kWh/a]**	**4 People [kWh/a]**	**Calculated Urban Family 2 [kWh/a]**
Cooking/baking including special equipment, e.g., coffee maker	300	80	460	300	80	460	0
Dishwasher	250	25	300	250	25	300	
Refrigerator with or without freezer compartment	275	40	355	325	60	445	340
Separate freezer	275	25	325	350	25	400	
Lighting	350	90	530	450	125	700	198
Consumer electronics (TV, video, hi-fi, various players, etc.)	250	60	370	275	80	435	110
Home office (PC, printer, modem, comfort phone, etc.)	200	60	320	200	80	360	
Div. Nursing and small appliances including humidifier	250	45	340	325	60	445	272
Washing machine	225	65	355	250	78	405	127
Laundry dryer (about 2/3 of the laundry, with a tumbler)	250	85	420	275	88	450	
General (building services)	400		400+	900	150	1200	
Total	**3025**	**575**	**4175**	**3900**	**850**	**5600**	**1047**
Climatisation							1,013
Total, including climatisation	**3025**	**575**	**4175**	**3900**	**850**	**5600**	**2060**

Source: Der typische Haushalt-Stromverbrauch Energieverbrauch von Haushalten in Ein- und Mehrfamilienhäusern/Schweis, https://www.energieschweiz.ch/stories/energieeffiziente-elektrogeraete/

The development of the country-wide shares of the electricity demand in Malawi according to the various household types is presented in Table 5. Electrification starts with basic household types, such as rural, semi-urban, and urban (apartments or houses) and moves to better-equipped households. Therefore, the proportion of fully equipped households will grow constantly, whereas the proportion of basic households increases in the early years and decreases towards the end of the modelling period. By 2050, most households will have a medium-to-high level of comfort equipment. The authors of this report have deliberately chosen a high standard for Malawi's households to close the gap between households in OECD countries and countries in the global south, to achieve greater equity.

Table 5: Household types – development of household shares of the electricity demand country-wide in Malawi

Household type	Country-wide electricity shares [%] (rounded)				
	2020	**2025**	**2030**	**2040**	**2050**
No access to electricity	86.20%	77.77%	62.22%	31.11%	0.00%
Rural – phase 1	1.40%	2.25%	3.25%	5.25%	7.25%
Rural – phase 2	4.00%	6.44%	8.44%	12.44%	16.44%
Rural – phase 3	0.40%	0.64%	2.64%	6.64%	10.64%
Semi-Urban – basic	1.00%	1.61%	2.61%	4.61%	6.61%
Semi-Urban – advanced	0.40%	0.64%	2.64%	6.64%	10.64%
Urban Apartment – basic	0.40%	0.64%	2.64%	6.64%	10.64%
Urban Apartment – advanced	0.20%	0.32%	2.32%	6.32%	10.32%
Urban House – basic	3.00%	4.83%	6.83%	10.83%	14.83%
Urban House – advanced	3.00%	4.83%	6.39%	9.50%	12.61%
Total	**100%**	**100%**	**100%**	**100%**	**100%**

Source: UTS-ISF research

According to the most recent data in ***The Energy Progress Report*** published in June 2024 (EPR 2024)[23], only 14% of Malawi's households have access to electricity. This is the fourth lowest level globally, behind South Sudan, Burundi, and Chad.

However, these households might not have access to reliable and uninterrupted electricity. Here, rapidly expanding cities are problematic because the infrastructure for transport and energy supply and the requirements of residential apartment buildings cannot match the demand, often leading to social tensions. Mini-grids for remote areas have proven a successful technology option for bringing energy services to remote communities, helping villages develop local economies, and providing alternative opportunities for young people to establish careers outside metropolitan areas.

2.4.2 Household Fuel demand – cooking

The main energy demand for Malawi's households is for cooking. In Malawi households, firewood and charcoal are the main fuels used for cooking, with a higher proportion (90.9%) of households in rural areas using firewood as a cooking fuel than in urban areas (18.9%). In urban areas, about 75% of households use charcoal as their main fuel for cooking, compared with 7.5% of households in rural areas. The demand for charcoal and firewood is driving deforestation and forest degradation in Malawi, and is also undermining agricultural productivity and food security, water security, and the hydroelectricity-generating capacity – leaving the country more vulnerable to climate shocks. The use of these fuels also causes household air pollution, which in turn affects health and causes time poverty and loss of productivity among its primary users – women (ESMAP 2022)[24].

Table 6 provides an overview of the most important cooking technologies and their key technical and economic parameters (WFC 2019).[25] The data are taken from a comprehensive analysis of cooking technologies and the sustainability and cost-effectiveness of electric cooking. One key finding of this analysis was that cooking with electricity (whether with solar home systems [SHSs] or in a mini-grid context) using high-efficiency appliances could make cooking even cheaper than it is many households that currently use firewood or charcoal. The World Bank's bottom-up research from across sub-Saharan Africa indicated that households spend US$1–31 per month, on average, on cooking fuels (World Bank 2014)[26]. Because slow cookers and pressure cookers allow household cooking costs of between US$15–21/month for SHSs and US$3.56–9.53/month for mini-grids, the economics of cooking with high-efficiency cooking appliances is becoming increasingly compelling (WFC 2019).

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[23] (EPR 2021), IEA, IRENA, UNSD, World Bank, WHO (2024) Tracking SDG 7: The Energy Progress Report. World Bank, Washington DC; World Bank. License: Creative Commons Attribution – Non-Commercial 3.0 IGO (CC BYNC 3.0 IGO). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Jun/IRENA_Tracking_SDG7_energy_progress_2024.pdf

[24] ESMAP (2022) MALAWI CCDR, Clean Cooking Sector Background Note, Energy Sector Management Assistance Program, June 2022, The World Bank Group. 1818 H Street NW, Washington, DC 20433, https://documents1.worldbank.org/curated/en/099545210272215738/pdf/P1772200f17fda0aa0b22c04835f7a20cfa.pdf

[25] WFC 2019, Beyond fire – How to achieve electric cooking; Toby D. Couture (E3 Analytics); Dr. David Jacobs (IET– International Energy Transition GmbH), Eco Matser and Harry Clemens (Hivos), Anna Skowron (WFC) and Joseph Thomas (E3 Analytics), World Future Council, Lilienstrasse 5–9, 22095 Hamburg, Germany, May 2019–costs are converted from Euro to US$ with the exchange rate of 25th August 2022: 1 Euro = US$1

[26] World Bank 2014, Clean and Improved Cooking in Sub-Saharan Africa: Second Edition. World Bank, Washington, DC. Available at: http://documents.worldbank.org/curated/en/164241468178757464/pdf/98664-REVISED-WP-P146621-PUBLIC-Box393185B.pdf

Table 6: Basic data on technologies for cooking and energy use

Appliance	Cost Range [EUR]	Median Cost [EUR]	Watts (range)	Approximate Daily Household Consumption (in Wh/day for electric options or in kg/day for solid and gas-based fuels)	Approximate Daily Household Consumption [MJ/day]
Three Stones (Wood)	0	0	N/A	4.15–20.76 kg/day	68.48–342.54
Traditional Cooking Stove (Wood)	0–5	2.5	N/A	3.32–8.3 kg/day	54.78–136.95
Improved Cooking Stove (Wood)	5–65	35	N/A	2.08–5.53 kg/day	34.32–91.25
Three Stones (Charcoal)	0	0	N/A	1.92–4.81 kg/day	54.72–137.09
Traditional Cooking Stove (Charcoal)	0–10	5	N/A	1.6–4.01 kg/day	45.60–114.29
Improved Cooking Stove (Charcoal)	5–65	35	N/A	1.2–2.4 kg /day	34.20–68.40
Improved Cooking Stove (Wood-based Biomass Pellets)	16–80	48	N/A	1.76–3.96 kg/day	30.41–68.43
Improved Cooking Stove (Agricultural waste pellets)	16–80	48	N/A	2.42–5.44 kg/day	30.49–68.54
Single Burner Hot Plate	8–35	21.5	600–2000	1200–4000 Wh/day	4.32–14.40
Induction Hot Plate	45–95	67.5	1000–2300	2000–4600 Wh/day	7.20–16.56
Slow Cooker/Rice Cooker/Crock Pot	10–130	70	120–300	175–700 Wh/day	0.63–2.52
Electric Pressure Cooker	19–140	79.5	500–1000	160–340 Wh/day	0.58–1.22
Microwave Oven	50–100	75	600–1200	100–1200 Wh/day	0.36–4.32
Gas Stove (single burner)	20–60	40	N/A	0.3 kg/day	13.7
Gas Stove (double burner)	30–90	60	N/A	0.3 kg/day	13.7
Gas Stove (four burners)	40–100	70	N/A	0.3 kg/day	13.7

The daily and annual energy demands for the three main fuel-based cooking technologies are shown in Table 9.

Table 7: Cooking energy demand in Malawi2021 by technology and household type

	Demand per Household per Day [MJ/day]	Demand per Household and Year [MJ/year HH]								
		Rural – Phase 1	Rural – Phase 2	Rural – Phase 3	Semi-Urban 1	Semi-Urban 2	Urban Apartment 1	Urban Apartment 2	Urban House 1	Urban House 2
Wood + Bio-energy-fuel-based Cooking	96	4,380	5,840	5,840	17,520	5,840	5,840	5,840	5,840	8,760
Gas/liquefied-natural-gas-based cooking	13.7	625	833	833	2,500	833	833	833	833	1,250
Electric cooking	3.3	151	201	201	602	201	201	201	201	301

A transition scenario from fuel-based cooking to electric cooking (e-cooking) has been developed for the M-1.5°C scenario based on current cooking energy usage (Table 8). However, with an increasing population and a growing number of households, the overall fuel demand is likely to remain high, and the phase-out of emissions and fuel demand cannot be achieved with this measure.

Fuel-based cooking applications will be gradually phased-out and replaced with electric cooking appliances. The total phase-out of fuel-based systems will be for environmental and economic reasons. Fuel-based cooking requires fuel that generates emissions, and the fuel supply is, in most cases, unsustainable. Collecting fuel wood puts forests under pressure, is time-consuming, and has a negative economic impact on the country's productivity. Burning LPG causes CO_2 emissions, and its production is based on fossil gas, which must be phased-out by 2050 to remain within the global carbon budget to limit the global mean temperature rise to a maximum of +1.5°C. The remaining wood and bio-energy-based cooking in 2050 will be with sustainable charcoal.

Electric-cooking can be supplied by renewable energy sources and will be emissions-free.

Table 8: Transition scenario from fuel-based to electricity-based cooking in Malawi under the M-1.5°C pathway

Share of Households with Wood + Bio-energy-fuel-based Cooking			**Rural – Phase 1**	**Rural – Phase 2**	**Rural – Phase 3**	**Semi-Urban 1**	**Semi-Urban 2**	**Urban Apartment 1**	**Urban Apartment 2**	**Urban House 1**	**Urban House 2**
Average Energy Demand by Household (HH; based on World Future Council 2019)			**4,380**	**5,840**	**5,840**	**17,520**	**5,840**	**5,840**	**5,840**	**5,840**	**8,760**
2020	98%	[MJ/a HH]	4,292	5,723	5,723	17,170	5,723	5,723	5,723	5,723	8,585
2025	96%	[MJ/a HH]	4,205	5,606	5,606	16,819	5,606	5,606	5,606	5,606	8,410
2030	80%	[MJ/a HH]	3,504	4,672	4,672	14,016	4,672	4,672	4,672	4,672	7,008
2035	70%	[MJ/a HH]	3,066	4,088	4,088	12,264	4,088	4,088	4,088	4,088	6,132
2040	30%	[MJ/a HH]	1,314	1,752	1,752	5,256	1,752	1,752	1,752	1,752	2,628
2045	10%	[MJ/a HH]	438	584	584	1,752	584	584	584	584	876
2050	5%	[MJ/a HH]	219	292	292	876	292	292	292	292	438
Share of Household with Gas/ Liquid-natural-gas-based Cooking			**Rural – Phase 1**	**Rural – Phase 2**	**Rural – Phase 3**	**Semi-Urban 1**	**Semi-Urban 2**	**Urban Apartment 1**	**Urban Apartment 2**	**Urban House 1**	**Urban House 2**
Average Energy Demand by Household (HH; based on World Future Council 2019)			**625**	**833**	**833**	**2,500**	**833**	**833**	**833**	**833**	**1,250**
2020	1%	[MJ/a HH]	7	9	9	28	9	9	9	9	14
2025	1%	[MJ/a HH]	8	10	10	31	10	10	10	10	16
2030	2%	[MJ/a HH]	0	0	0	1	0	0	0	0	0
2035	2%	[MJ/a HH]	13	17	17	50	17	17	17	17	25
2040	2%	[MJ/a HH]	13	17	17	50	17	17	17	17	25
2045	2%	[MJ/a HH]	13	17	17	50	17	17	17	17	25
2050	0%	[MJ/a HH]	0	0	0	0	0	0	0	0	0
Phase-in of Electric Cooking 2020–2050											
Share of Households with Electric Cooking			**Rural – Phase 1**	**Rural – Phase 2**	**Rural – Phase 3**	**Semi-Urban 1**	**Semi-Urban 2**	**Urban Apartment 1**	**Urban Apartment 2**	**Urban House 1**	**Urban House 2**
Average Energy Demand by Household (HH; based on World Future Council 2019)			**151**	**201**	**201**	**602**	**201**	**201**	**201**	**201**	**301**
2020	1%	[$\text{kWh}_{\text{electric}}$/a HH]	1	2	2	5	2	2	2	2	3
2025	3%	[$\text{kWh}_{\text{electric}}$/a HH]	4	6	6	17	6	6	6	6	8
2030	18%	[$\text{kWh}_{\text{electric}}$/a HH]	27	36	36	108	36	36	36	36	54
2035	28%	[$\text{kWh}_{\text{electric}}$/a HH]	42	56	56	169	56	56	56	56	84
2040	68%	[$\text{kWh}_{\text{electric}}$/a HH]	102	137	137	410	137	137	137	137	205
2045	88%	[$\text{kWh}_{\text{electric}}$/a HH]	132	177	177	530	177	177	177	177	265
2050	95%	[$\text{kWh}_{\text{electric}}$/a HH]	143	191	191	572	191	191	191	191	286

However, there will be some challenges to the introduction of electric cooking stoves:

- Firewood remains freely available.
- In relative terms, the initial investment and monthly costs are high.
- Concerns exist about the safety of the technology.
- (Initial) concerns exist around the learnability of new appliances.
- In the cold climate of mountainous regions, fire from cooking also heats rooms.
- The use of e-cooking is perceived to be expensive.
- There are concerns about the quality or the appliances.
- It is a new technology that requires education to operate.
- The current business models of distribution are not well suited to low-income households. Most vendors use an upfront model of payment rather than other innovative models, such as pay as you go, which have proven beneficial for many other technologies.
- Perceived and/or actual differences in the taste and quality of food prepared with biomass or e-cooking.

There are already numerous electric cooking devices on Malawi's market, including:

- Induction stoves
- Electric pressure cookers
- Electric ovens
- Hot plates
- Microwave ovens
- Electric and gas hobs
- Roti makers
- Infrared stoves
- Rice cookers
- Slow cookers
- Electric frying pans
- Air fryers
- Electric kettles

Among these, the most viable energy-efficient appliances are:

- Induction stoves
- Infrared stoves
- Rice cookers
- Electric pressure cookers

The supply-side barriers to e-cooking are:

- Electric cooking stoves do not seem to be manufactured locally;
- After-sales service is poor (i.e., poor access to repairs and maintenance);
- Concerns exist about the quality and stability of the electricity supply.

Technical challenges posed by e-cooking to electric utilities and energy service companies

The increase in the peak load during meal times will require an upgrade of the electricity distribution grid in terms of load management and the ability of the power grid to supply higher loads. The introduction of electric vehicles to replace fossil fuels will further increase the electric load and require grid expansion and reinforcement to be implemented by electric grid operators. Furthermore, current household electricity connections are often limited to 5-ampere meters, which significantly limits the load for each household, and the parallel operation of multiple appliances is not possible when electric stoves are used. The technical standard of household wiring is also low; cables are often not properly installed, or a lack of protective earthing compromises electrical safety.

Policy and social challenges in promoting electric cooking

Local-level governments must introduce policy frameworks, such as specific energy policies, acts, procedures, and/or guidelines, to support the increased utilisation of electric cooking devices. These policies include support for additional renewable electricity generation to supply stoves.

However, the implementation of sustainable cooking technologies is challenging for rural households in terms of getting access to those technologies, technology standards, and financing.

Therefore, the development of clean cooking programs is lagging behind the actual targets. Finally, the general awareness of the benefits of e-cooking – particularly in rural areas – is still low because access to the necessary information is lacking. Finally, this lack of information means that the acceptance of e-cooking devices in the supply chain – specialised kitchenware and hardware shops – is low. Therefore, awareness programs for retail staff are required.

2.5 Industry and business demands

The analysis of Malawi's economic development is based on a breakdown of the fiscal year 2020 and assumes that the overall structure of the economy will not change, and that all sectors will grow at a rate equal to that of the GDP over the entire modelling period.

Figure 7 shows that in the fiscal year 2020/21, food, beverage, and tobacco services contributed most strongly to the growth of GDP (in the basic price), whereas machinery and transport equipment contributed the least. For the largest sectors, the contribution of the food, beverages, and tobacco industry to the economic growth rate in that fiscal year (FY) was 38%, and the contribution of agriculture, forestry, and fishing was 19%. Figure 8 presents the annual GDP growth rate from 2005 to 2020 by sub-sector.

Figure 7: Contributions of sub-sectors to GDP growth

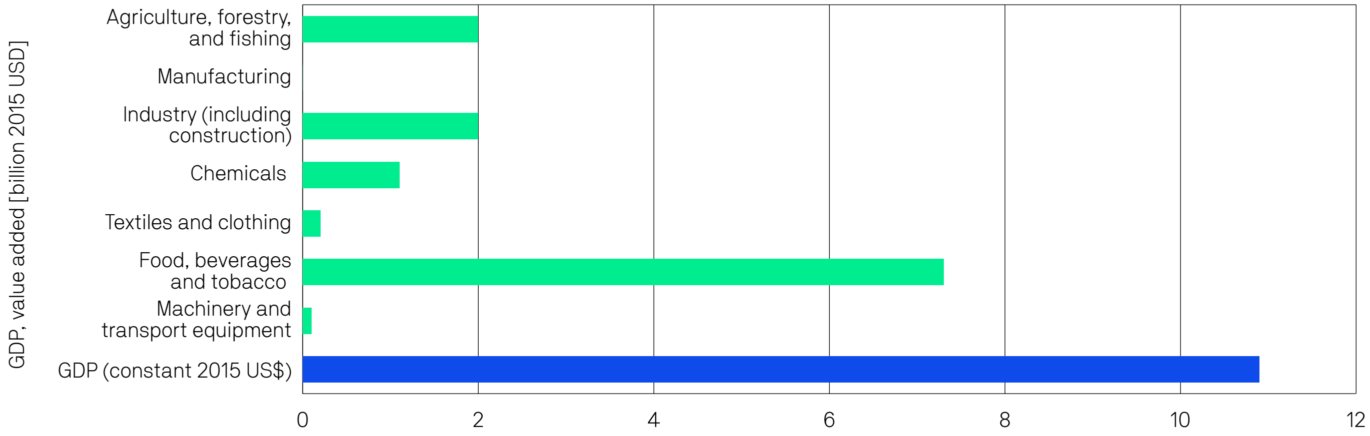
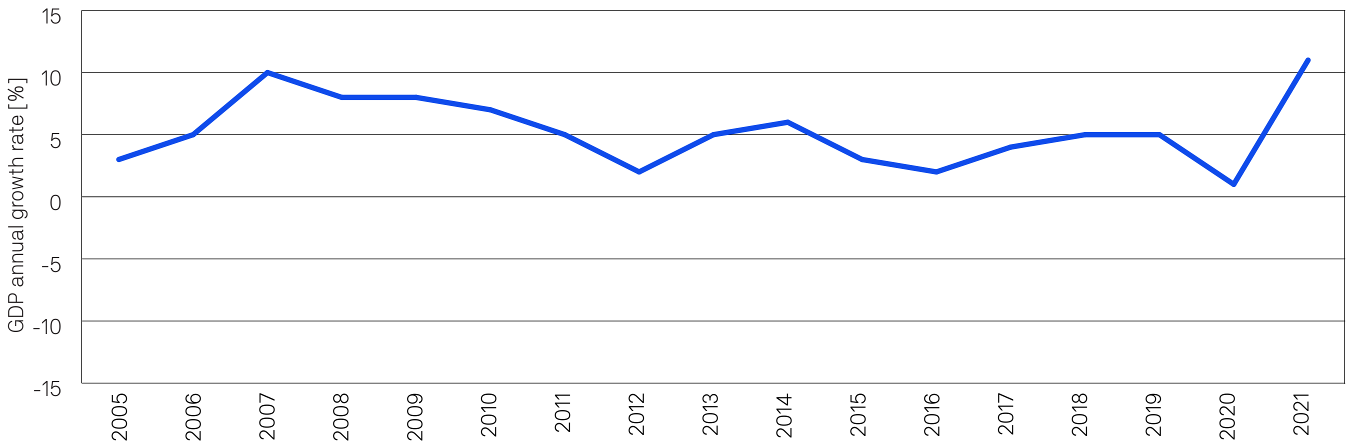


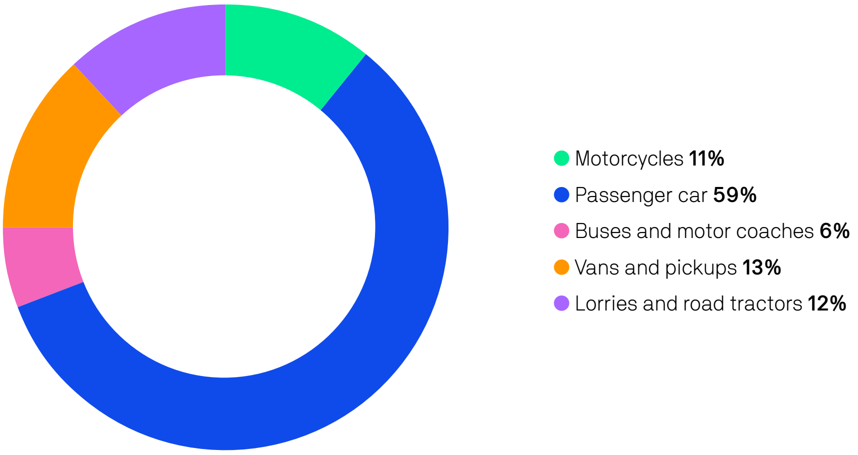
Figure 8: Growth rate of gross domestic product (GDP)



2.6 Transport Demand

Malawi's transport sector is currently dominated by passenger cars, which account for 59% of all registered vehicles, whereas motorcycles represent 11% of the vehicle fleet. Other vehicles make-up 18% of the vehicle fleet, such as light commercial vehicles (LCVs; 13%) and buses and motor coaches (5%). The remaining 12% of the vehicle fleet includes construction and industry vehicles, such as tractors, cranes, and excavators. The latest statistics available at the time of writing (September 2024) were from 2014 (Tan et al. 2023).[27]

Figure 9: Categories of registered vehicles, with the percentages of the total number of registered vehicles (2014/2022) (Tan et al. 2023)



To develop a future transport scenario, the technical parameters of all vehicle options are required to project the energy demands. The following section provides an overview of the vehicular energy intensities for passenger and freight transport. Based on these, the actual utilisation – in terms of annual kilometres per vehicle – was estimated, to calculate the energy demand over time until 2050.

The energy intensities for the different vehicle types and each available drive train play important roles in the calibration of transport modes and projections. Each transport mode has different vehicular options. Each of the vehicles has different drive-train and efficiency options. The technical variety of passenger vehicles, for example, is extremely large. The engine sizes for five-seater cars range from 20 kW to > 200 kW.

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[27] Tan N, Ambunda R, Medimorec N, Cortez A, Krapp A, Maxwell E (2023) Transport Starter Data Kit: Historical socio-transport data for Malawi (2.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.10410191

Furthermore, drive trains can use a range of fuels, from gasoline, diesel, and bio-diesel to hydrogen and electricity. Each vehicle has a different energy intensity in megajoules per passenger-kilometre (MJ/pkm). Therefore, the energy intensities provided in the following tables are average values.

2.6.1 Technical Parameters – Passenger Transport

Passenger transport by road is the commonest and most important form of travel (TUMI 2021)[28]. There are numerous technical options to 'move people with vehicles': bicycles, motorcycles, tricycles, city cars, and four-wheel-drive SUVs. Each vehicle has a very different energy intensity per km. Although this research project aims for high technological resolution, simplifications are required. Table 9 shows the energy intensities for the main vehicle types (electric or with ICEs), and forms the basis of the energy scenario calculations.

Table 9: Energy intensities for passenger transport – road transport

			Passengers		Vehicle Demand	Consumption per Passenger	Energy Demand
Passenger Transport			**Average Passengers per Vehicle**	**Assumed Occupation Rate**	**Average**	**Average**	**Assumption for Scenario Calculation**
		Fuel			**litre/100 km**	**litre/100 pkm**	**[MJ/pkm]**
Scooters & motorbikes	2-wheeler	Gasoline	1	1	3.0	3.0	1.21
E-bikes Scooters Motorbikes Rickshaw		**Electricity**			**kWh_{el}/100 km**	**kWh_{el}/100 pkm**	**[MJ/pkm]**
	2-wheeler	Battery	1	1	1.0	1.0	0.04
	2-wheeler	Battery	1	1	1.8	1.9	0.06
	2-wheeler	Battery	1	1	4.8	4.8	0.17
	3-wheels	Battery	3	2	8.0	4.0	0.14
Cars		**Fuels**	**0**	**0**	**litre/100 km**	**litre/100 pkm**	**[MJ/pkm]**
	Small	ICE-oil	2	1.8	5.0	2.8	1.12
	Medium	ICE-oil	4	2	7.5	3.8	1.51
	Large	ICE-oil	5	2	10.5	5.3	2.11
	Small	ICE-gas	2	1.8	4.5	2.5	0.63
	Medium	ICE-gas	4	2	7.0	3.5	1.41
	Large	ICE-gas	5	2	10.0	5.0	1.25
	Small	ICE-bio	2	1.8	5.0	2.8	0.91
	Medium	ICE-bio	4	2	7.5	3.8	1.51
	Large	ICE-bio	5	2	10.5	5.3	1.72
	Small	Hybrid-oil	2	1.8	4.0	2.2	0.89
	Medium	Hybrid-oil	4	2.5	6.0	2.4	0.96
	Large	Hybrid-oil	5	2.5	8.5	3.4	1.37
		Electricity			**kWh_{el}/100 km**	**kWh_{el}/100 pkm**	**[MJ/pkm]**
	Small	Battery	2	1.8	16.0	8.9	0.32
	Medium	Battery	4	2	25.0	12.5	0.45
	Large	Battery	5	2	32.5	16.3	0.59
	Large	Fuel Cell	4	2	37.5	18.8	1.36

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[28] TUMI (2021), Teske S, Niklas S, Langdon R, (2021) TUMI Transport Outlook 1.5 °C – A global scenario to decarbonise transport; Report prepared by the University of Technology Sydney for the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIS) GmbH; Published by TUMI Management, Deutsche Gesellschaft für International Zusammenarbeit (GIS) GmbH, Friedrich-Ebert-Allee 36 + 40, 53113 Bonn, Germany; https://www.transformative-mobility.org/assets/publications/TUMI-Transport-Outlook.pdf

2.6.2 Technical Parameters – Public Transport

There is a huge variety of public transport vehicles – from rickshaws to taxis and mini-buses to long-distance trains. The occupation rates for those vehicles are key factors in calculating the energy intensity per passenger per kilometre. For example, a diesel-powered city bus transporting 75 passengers uses, on average, about 27.5 litres per 100 kilometres. If the bus operates at full capacity during peak hour, the energy demand per passenger is as low as 400 mL per kilometre, lower than almost all fossil-fuel-based road transport vehicles. However, if the occupancy drops to 10% – e.g., for a night bus – the energy intensity increases to 3.7 litres, equal to that of a small energy-efficient car. Occupation rates vary significantly and depend on the time of day, day of the week, and season.

There are also significant regional differences, even within a province. Again, the parameters shown in Table 10 are simplified averages and are further condensed for the scenario calculations. Although high technical resolution is possible for the scenario model, it would pretend an accuracy that does not exist because the statistical data required for this resolution are not available at the regional level.

Table 10: Energy intensities for public transport – road and rail transport

Public Transport			Passengers		Vehicle Demand	Consumption per Passenger	Energy Demand
			Average Passengers per Vehicle	**Assumed Occupation Rate**	**Average litre/100 km**	**Average litre/100 km**	**Assumption for Scenario Calculation MJ/pkm**
Buses	Small	Diesel	12	40%	8.8	1.8	0.73
	Small	Bio	12	40%	8.8	1.8	0.60
	12 m	Diesel	75	40%	27.5	0.9	0.37
	12 m	Bio	75	40%	27.5	0.9	0.30
	Large	Diesel	135	40%	57.5	1.1	0.43
		Electricity	**0**	**0**	**kWh$_{el}$/100 km**	**kWhel/100 pkm**	**MJ/pkm**
	Small	Battery	12	40%	31	6.4	0.23
	Small	Fuel Cell	12	40%	77	15.9	0.57
	12 m	Battery	75	40%	143	4.8	0.17
	12 m	Fuel Cell	75	40%	358	11.9	0.43
	Large	Overhead Lines	135	40%	263	4.9	0.18
		Fuel	**0**	**0**	**litre/100 km**	**litre/100 pkm**	**MJ/pkm**
Trains	Metros	Diesel	400	40%	150	0.9	0.38
	Metros	Bio	400	40%	150	0.9	0.31
	Commuter Trains	Diesel	600	40%	300	1.3	0.50
	Commuter Trains	Bio	600	40%	300	1.3	0.41
		Electricity	**0**	**0**	**kWh$_{el}$/100 km**	**kWhel/100 pkm**	**MJ/pkm**
	Trams	Electric	300	40%	495	4.1	0.14
	Metros	Electric	300	40%	1,200	10.0	0.14
	Commuter Trains	Electric	600	40%	1,950	8.1	0.17

2.6.3 Technical Parameters – Freight transport

The energy intensity data for freight transport are not as diverse as those for passenger transport because the transport vehicle types are standard and the fuel demands are well known. However, the utilisation rates of the load capacities vary significantly, and consistent data are not available for the calculated regional and global levels. Therefore, the assumed utilisation rate greatly influences the calculated energy intensity per tkm. The average energy intensities per tkm used in the scenario are shown in Table 11 and are largely consistent with those from other sources in the scientific literature (EEA 2021)[29]. The assumed energy intensities for electric and fuel cell/hydrogen freight vehicles are only estimates because this technology is still in the demonstration phase. Therefore, none of the scenarios factor in large shares of electric freight transport vehicles before 2035.

Table 11: Energy intensities for freight transport – road and rail transport

					Vehicle Demand	Consumption per Tonne	Energy Demand
Freight Transport			**Maximum Load Capacity (tonnes)**	**Assumed Utilisation Rate**	**Average**	**Average**	**Assumption for Scenario Calculation**
Trucks		**Fuel**			**litre/100 km**	**litre/tkm**	**[MJ/tkm]**
	3.5 tonnes	Diesel	3.5	40%	11	7.9	3.16
	3.5 tonnes	Bio	3.5	40%	11	7.9	2.57
	7.5 tonnes	Diesel	7.5	40%	20	6.5	2.61
	7.5 tonnes	Bio	7.5	40%	20	6.5	2.13
	12.5 tonnes	Diesel	12.5	40%	25	5.0	2.01
	12.5 tonnes	Bio	12.5	40%	25	5.0	1.64
		Electricity			**kWh_{el}/100 km**	**kWhel/tkm**	**[MJ/tkm]**
	3.5 tonnes	Battery	3.5	40%	19	13.6	1.34
	3.5 tonnes	Fuel Cell	3.5	40%	46	33.2	1.33
	7.5 tonnes	Battery	7.5	40%	41	13.6	0.49
	7.5 tonnes	Fuel Cell	7.5	40%	100	33.2	1.19
	12.5 tonnes	Battery	12.5	40%	68	13.6	0.49
	12.5 tonnes	Fuel Cell	12.5	40%	166	33.2	1.19
Trains		**Fuels**			**litre/100 km**	**litre/tkm**	**[MJ/tkm]**
	Freight–740 m	Diesel	1,000	40%	300	0.8	0.30
	Freight–740 m	Bio	1,000	40%	300	0.8	0.25
		Electricity			**kWh_{el}/100 km**	**kWhel/tkm**	**[MJ/tkm]**
	Freight–740 m	Electric	1,000	40%	5,840	14.6	0.53

2.6.4 Utilisation of vehicles

In the second step, the utilisation of vehicles must be analysed to develop projections into the future. No up-to-date surveys are available. The annual pkm for passenger transport and tkm for freight transport are calculated based on the current energy demand and the energy intensities of the vehicles in use. The average energy intensity across all passenger vehicles is assumed to have been 1.5 MJ per kilometre in 2020 – which reflects the current vehicle fleet of motorcycles (average of 1.2–1.3 MJ/pkm), cars (1.5 MJ/pkm), and SUVs and pick-up trucks with an energy demand (2–6 MJ/pkm). The assumed average energy intensity for freight vehicles is calculated accordingly, assuming vans and mini-vans are the main transport vehicles. It is also assumed that ICEs and not electric drives are in use.

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[29] European Environment Agency, https://www.eea.europa.eu/publications/ENVISSUENo12/page027.html

Table 12: Malawi – projected passenger and freight transport demands under the M-1.5°C scenario

		2019	2020	2025	2030	2035	2040	2045	2050
Road: Passenger Transport Demand	[PJ/a]	3	3	3	3	5	5	6	8
Annual passenger-kilometres	[million pkm]	6,082	6,246	7,585	8,116	9,334	10,267	11,294	12,423
Average energy intensity – passenger vehicles	[MJ/pkm]	2.5	2.5	2.5	1.8	1.7	1.7	1.6	1.6
Annual demand variation	[%/a]	-	-	2.0%	7.0%	15.0%	10.0%	10.0%	10.0%
Road: Freight Transport Demand	[PJ/a]	1.2	1.1	1.3	1.5	1.8	1.7	1.9	2.4
Annual freight kilometres	[million tkm]	2,655	2,666	3,919	4,115	4,321	4,537	4,764	5,002
Average energy intensity – freight vehicles	[MJ/tkm]	1.51	1.51	1.20	1.14	1.11	1.08	1.07	1.06
Annual demand Variations	[%/a]	-	-	2.00%	7.00%	15.00%	10.00%	10.00%	10.00%

The total numbers of passenger and freight kilometres are the basis for the projection of the future transport demand. The contraction of the transport demand in 2020 due to COVID is expected to end. It is anticipated that the pre-COVID transport demand of 2019 will be reached by 2023, and the transport demand will increase with population growth and GDP. It is assumed that the annual pkm will increase by 10% annually until 2050, whereas the freight transport demand will increase by around 10% annually. All assumptions and calculated energy demands are shown in Table 12. The energy intensities for all vehicles are assumed to decrease over time with the implementation of more-efficient engines, the phase-out of fossil-fuel-based drives, and their replacement with electric drives. To achieve the terms of the Paris Climate Agreement, all energy-related CO_2 emissions must be phased out by 2050. Therefore, all fossil-fuel-based vehicles must be phased out, and electric drives will dominate, supplemented with a limited number of biofuel-based vehicles.

However, it is assumed that the share of cars will grow at the expense of two-wheeler vehicles – which will increase the average energy intensity per kilometre. Although electric drives are significantly more efficient, the increased vehicle size combined with more public transport options – mainly buses – will limit the increase in the energy demand. On average – across all passenger vehicle types – the energy intensity will decrease from around 1.5 MJ per pkm to 1.07 MJ in 2030 and to 0.54 MJ in 2050.

The energy required by freight vehicles to move 1 tonne for 1 kilometre will decrease from around 1.5 MJ to 1.11 MJ by 2030 and to 0.68 MJ by 2050. Both reductions will only be possible with high shares of electric drives. Figure 10 and Figure 11 show the development of drive trains for passenger and freight transport vehicles, respectively, over time. The electrification of large parts of these fleets is unavoidable if the transport sector is to be decarbonised. The supply of – sustainably produced – biofuels will be limited and will be directed to large commercial vehicles, buses, and the large trucks used in remote rural areas, where the required charging infrastructure for electric vehicles is unlikely to be developed in the next two decades.

Figure 10: Passenger transport – drive trains by fuel

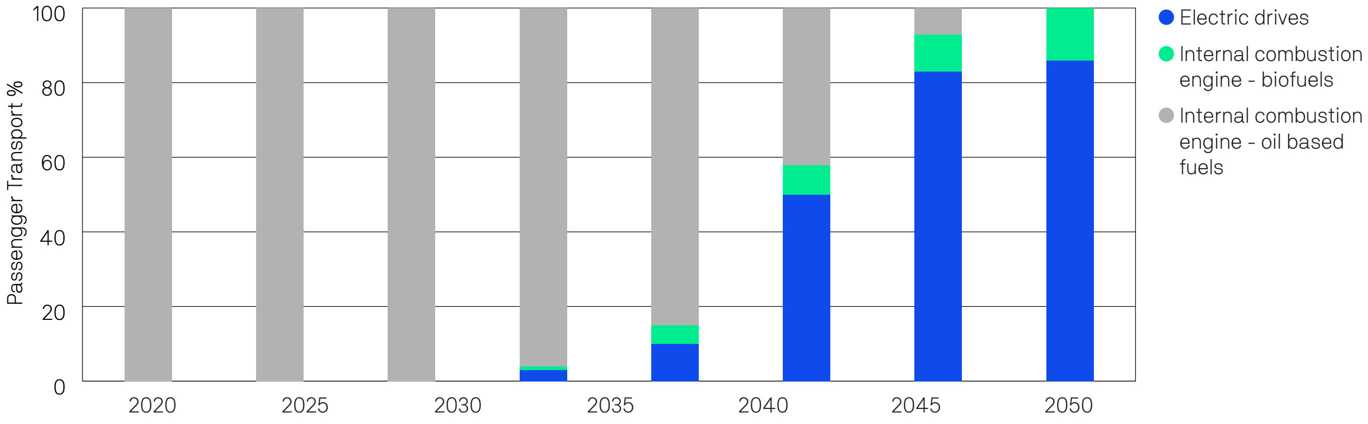
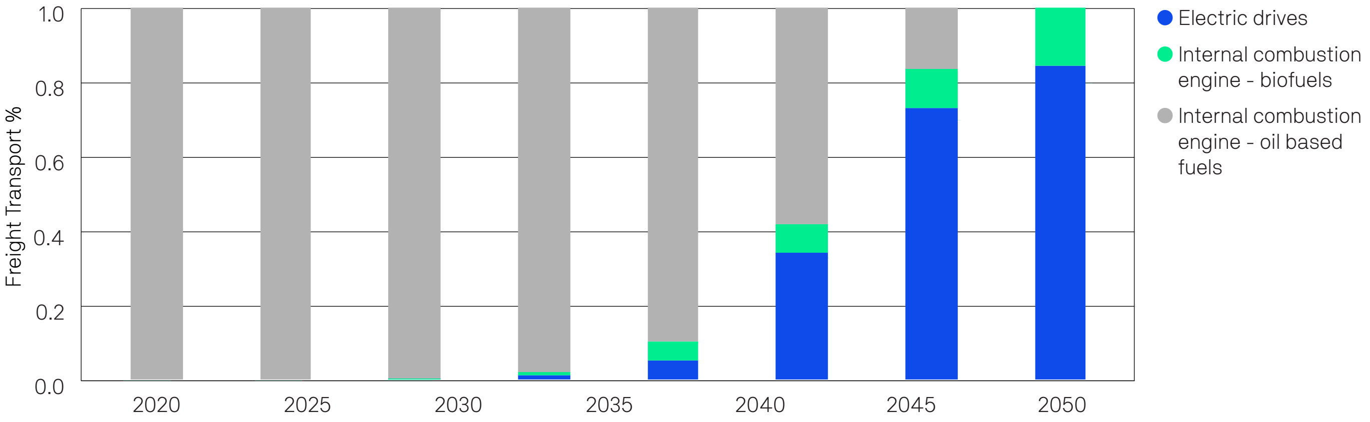


Figure 11: Freight transport – drive trains by fuel



Malawi submitted an updated NDC report to the UNFCCC in July 2021[30]. The new NDC sets a target to reduce GHG emissions by 2030 by 2030 compared with the 'business-as-usual' (BAU) scenario.

The NDC does not include a detailed transport pathway but highlights the following priority mitigation activity for the transport sector: ***'modal shifts to public transport and a shift from road to rail for freight as well as the importance of efficient transportation systems'***.

Therefore, the assumed trajectory for the transport sector (Figure 10 and Figure 11) can be used a proposal for a transport sector concept for future decarbonisation pathways.

Based on the lifespans of motorcycles and cars, a country-wide overall market share of electric drives for the entire existing car fleet may not exceed 4% by 2030 for passenger and freight cars. Furthermore, it is assumed that the railway system will not be expanded beyond the current plans after 2030.

Supply-side barriers to e-vehicles

Currently, most e-vehicles are imported. The infrastructure required for electric mobility, in terms of maintenance and service centres and charging stations across urban and rural areas, is lagging. The resilience and reliability of the electricity supply – especially in rural areas – is still under development and faces challenges. Therefore, a rapid expansion of the charging infrastructure, which will increase the load even further, will depend on the progress of electricity services. However, the decarbonisation of Malawi's energy sector will require increased electrification of the transport sector, and the expansion of a resilient power supply based on sustainable power generation technologies is essential.

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[30] Republic of Malawi, Minister of Forestry and Natural Resources, Malawi's Updated Nationally Determined Contribution (NDC), July 2021, https://unfccc.int/sites/default/files/NDC/2022-06/Malawi%20Updated%20NDC%20July%202021%20submitted.pdf?download

2.7 Technology and fuel cost projections

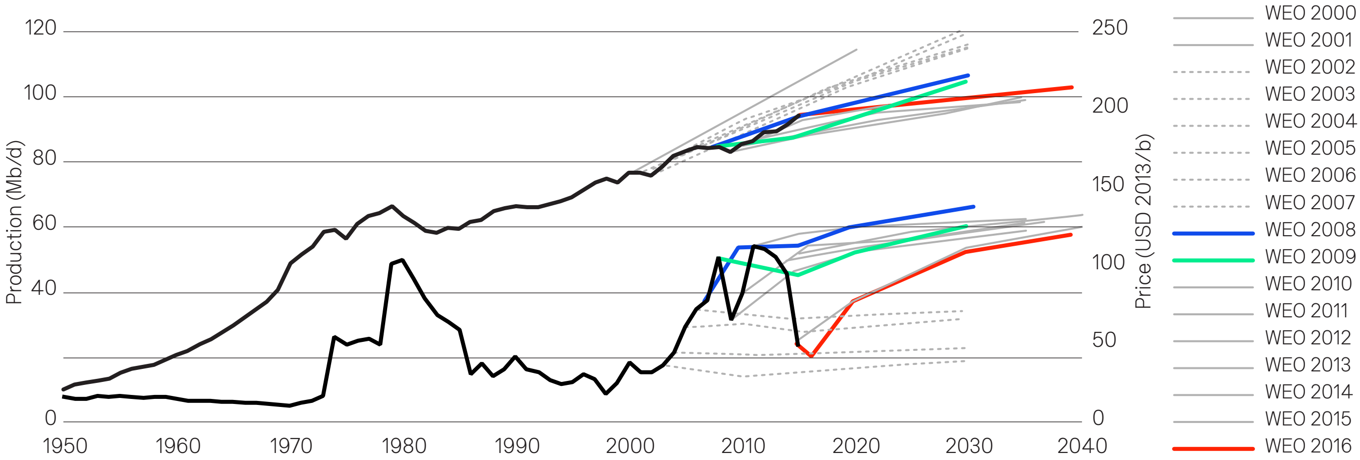
All cost projections in this analysis are based on a recent publication by Teske et al. (2019)[31]. Section 5.2 is based on Chapter 5 of that book, written by Dr. Thomas Pregger, Dr. Sonja Simon, and Dr. Tobias Naegler of the German Aerospace Center/DLR. The parameterisation of the models requires many assumptions about the development of the characteristic technologies, such as specific investments and fuel costs. Therefore, because long-term projections are highly uncertain, we must define plausible and transparent assumptions based on background information and up-to-date statistical and technical information.

The speed of an energy system transition also depends on overcoming economic barriers. These largely involve the relationships between the cost of renewable technologies and of their fossil and nuclear counterparts. For our scenarios, the projection of these costs is vital to ensure a valid comparison of energy systems. However, there have been significant limitations to these projections in the past in terms of investment and fuel costs.

Moreover, efficiency measures generate costs that are usually difficult to determine, and depend on technical, structural, and economic boundary conditions. Therefore, in the context of this study, we have assumed uniform average costs of 3 cents per kWh of electricity consumption avoided in our cost accounting.

During the last decade, fossil fuel prices have seen huge fluctuations. Figure 12 shows the oil prices since 1997. After extremely high oil prices in 2012, we are currently in a low-price phase. Gas prices saw similar fluctuations (IEA 2017)[32]. Therefore, fossil fuel price projections have also seen considerable variations (IEA 2017[33]; IEA 2013[33]) and this has influenced the scenario results.

Figure 12: Historical development and projections of oil prices (bottom lines) and historical world oil production and projections (top lines) by the World Energy Outlook (WEO), published by the International Energy Agency (IEA), according to Wachtmeister et al. (2018)



Although oil-exporting countries have provided the best oil price projections in the past, institutional price projections have become increasingly accurate, with the IEA leading the way in 2018 (Roland Berger 2018)[34]. An evaluation of the oil price projections of the IEA since 2000 by Wachtmeister et al. (2018)[35] showed that price projections have varied significantly over time. Whereas the IEA's oil production projections seem comparatively accurate, its oil price projections showed errors of 40%–60%, even when made only 10 years ahead. Between 2007 and 2017, the IEA price projections for 2030 varied from US$70 to US$140 per barrel, providing significant uncertainty regarding future costs in the scenarios. Despite this

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[31] Teske S (2019), Achieving the Paris Climate Agreement Goals – Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5 °C and +2.0 °C, ISBN 978-3-030-05842-5, Springer, Switzerland 2019.

[32] IEA (2017) World Energy Outlook 2017. International Energy Agency, Organisation for Economic Co-operation and Development, Paris.

[33] IEA (2013) World Energy Outlook 2013. International Energy Agency, Organisation for Economic Co-operation and Development, Paris.

[34] Roland Berger (2018) 2018 oil price forecast: who predicts best? Roland Berger study of oil price forecasts. https://www.rolandberger.com/en/Insights/Publications/2018-oil-price-forecast-who-predicts-best.html

[35] Wachtmeister H, Henke P, Höök M (2018) Oil projections in retrospect: Revisions, accuracy and current uncertainty. Applied Energy 220:138–153. doi: https://doi.org/10.1016/j.apenergy.2018.03.013

limitation, the IEA provides a comprehensive set of price projections. Therefore, we based our scenario assumptions on these projections, as described below.

However, because most renewable energy technologies provide energy without fuel costs, the projections of investment costs become more important than the fuel cost projections, and this limits the impact of errors in the fuel price projections. It is only for biomass that the cost of feedstock remains a crucial economic factor for renewables. These costs range from negative costs for waste wood (based on credit for the waste disposal costs avoided), through inexpensive residual materials, to comparatively expensive energy crops. Because bio-energy has significant market shares in all sectors in many regions, a detailed assessment of future price projections is provided below.

Investment cost projections also pose challenges for scenario development. Available short-term projections of investment costs depend largely on the data available for existing and planned projects. Learning curves are most commonly used to assess the future development of investment costs as a function of their future installations and markets (McDonald and Schrattenholzer 2001[36]; Rubin et al. 2015[37]). Therefore, the reliability of cost projections largely depends on the uncertainty of future markets and the availability of historical data.

Fossil fuel technologies provide a large cost dataset, featuring well-established markets and large annual installations. They are also mature technologies, so many cost-reduction potentials have already been exploited.

For conventional renewable technologies, the picture is more mixed. For example, like fossil fuels, hydro power is well established and provides reliable data on investment costs. Other technologies, such as solar PV and wind, are experiencing tremendous installation and cost-reduction developments. However, solar PV and wind are the focus of cost monitoring, and big data are already available on existing projects. Nonetheless, their future markets are not readily predictable, as seen in the evolution of IEA market projections over recent years in the World Energy Outlook series (compare, for example, IEA 2007, IEA 2014, and IEA 2017). Small differences in cost assumptions for PV and wind lead to large deviations in the overall costs, and cost assumptions must be made with particular care.

Furthermore, many technologies have only relatively small markets, such as geothermal, modern bio-energy applications, and concentrated solar power (CSP), for which costs are still high and for which future markets are insecure. The cost reduction potential is correspondingly high for these technologies. This is also true for technologies that might become important in a transformed energy system but are not yet widely available. Hydrogen production, ocean power, and synthetic fuels might deliver important technology options in the long term after 2040, but their cost reduction potential cannot be assessed with any certainty today.

Therefore, cost assumptions are a crucial factor in evaluating scenarios. Because costs are an external input into the model and are not internally calculated, we assume the same progressive cost developments for all scenarios. In the next sections, we present a detailed overview of our assumptions for power and renewable heat technologies, including the investment, fuel costs, and potential CO_2 costs in the scenarios.

2.7.1 Power technologies

The focus of cost calculations in our scenario modelling is the power sector. We compared the specific investment costs estimated in previous studies (Teske et al. 2015)[38], which were based on a variety of studies, including the European Commission-funded NEEDS project (NEEDS 2009), projections of the European Renewable Energy Council (Zervos et al. 2010)[39], investment cost projections by the IEA (IEA 2014), and current cost assumptions by IRENA and IEA (IEA 2016c). We found that investment costs generally converged, except for PV. Therefore, for consistency, the power sector's investment and operation and maintenance costs are based primarily on the investment costs within WEO 2016 (IEA 2016c) up to 2040, including their regional disaggregation. We extended the projections until 2050 based on the trends in the preceding decade.

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[36] McDonald A, Schrattenholzer L (2001) Learning rates for energy technologies. Energy Policy 29 (4):255–261. doi: https://doi.org/10.1016/S0301-4215(00)00122-1

[37] Rubin ES, Azevedo IML, Jaramillo P, Yeh S (2015) A review of learning rates for electricity supply technologies. Energy Policy 86:198–218. doi: https://doi.org/10.1016/j.enpol.2015.06.011

[38] Teske S, Sawyer S, Schäfer O, Pregger T, Simon S, Naegler T, Schmid S, Özdemir ED, Pagenkopf J, Kleiner F, Rutovitz J, Dominish E, Downes J, Ackermann T, Brown T, Boxer S, Baitelo R, Rodrigues LA (2015) Energy [R]evolution – A sustainable world energy outlook 2015. Greenpeace International.

[39] Zervos A, Lins C, Muth J (2010) RE-thinking 2050: a 100% renewable energy vision for the European Union. European Renewable Energy Council (EREC).

For renewable power production, we used investment costs from the 450 ppm scenario from IEA 2016c. For technologies not distinguished in the IEA report (such as geothermal combined heat and power [CHP]), we used cost assumptions based on our research (Teske et al. 2015). Because the cost assumptions for PV systems by the IEA do not reflect recent cost reductions, we based our assumptions on a more recent analysis by Steurer et al. (2018)[40], which projects lower investment costs for PV in 2050 than does the IEA.

The costs for onshore wind were adapted from the same source (Steurer et al. 2018) to reflect more-recent data. Table 13 summarises the cost trends for power technologies derived from the assumptions discussed above for Malawi. It is important to note that the cost reductions are not a function of time but of cumulative capacity (production of units), so dynamic market development is required to achieve a significant reduction in specific investment costs. Therefore, overall, we may underestimate the costs of renewables in the REFERENCE scenario compared with the *With the Existing Measures* (WEM) scenario and the M-1.5°C pathway (see below).

However, our approach is conservative when we compare the REFERENCE scenario with the more ambitious renewable energy scenarios under identical cost assumptions. Fossil-fuel power plants have limited potential for cost reductions because they are in advanced stages of the technology and market development. The products of gas and oil plants are relatively cheap, at around US$670/kW and US$822/kW, respectively.

In contrast, several renewable technologies have seen considerable cost reductions over the last decade. This is expected to continue if renewables are deployed extensively. Hydro power and biomass have remained stable in terms of costs. Tremendous cost reductions are still expected for solar energy and wind power, even though they have experienced significant reductions already. Whereas CSP might deliver dispatchable power at half its current cost in 2050, variable PV costs could drop to 35% of today’s costs.

Table 13: Investment cost assumptions for power generation plants in US dollars (US$) and the local currency (trillion MWK) per kW until 2050

Assumed Investment Costs for Power Generation Plants										
	2020		**2025**		**2030**		**2040**		**2050**	
Technology	**[US$/ kW]**	**[MWK /kW]**	**[US$/ kW]**	**[MWK/ kW]**	**[US$/ kW]**	**[MWK/ kW]**	**[US$/ kW]**	**[MWK/ kW]**	**[US$/ kW]**	**[MWK/ kW]**
Coal power plants	2,018	3,430,215	2,018	3,430,215	2,018	3,430,215	2,018	3,430,215	2,018	3,430,215
Diesel generators	908	1,543,597	908	1,543,597	908	1,543,597	908	1,543,597	908	1,543,597
Gas power plants	504	857,554	504	857,554	504	857,554	504	857,554	676	1,149,122
Oil power plants	938	1,595,050	918	1,560,748	898	1,526,446	865	1,470,705	827	1,406,388
Conventional Renewables										
Hydro power plants*	2,674	4,545,035	2,674	4,545,035	2,674	4,545,035	2,674	4,545,035	2,674	4,545,035
New renewables										
PV power plants	989	1,680,806	744	1,265,429	736	1,252,029	565	960,460	474	806,101
Onshore wind	1,594	2,709,870	1,559	2,649,841	1,523	2,589,813	1,463	2,486,906	1,412	2,401,151
Offshore wind	3,723	6,328,747	3,097	5,265,381	2,472	4,202,014	2,295	3,901,870	2,119	3,601,726
Bio-energy PP	2,371	4,030,503	2,346	3,987,625	2,320	3,944,748	2,220	3,773,237	2,129	3,618,877

*Values apply to both run-of-the-river and reservoir hydro power.

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[40] Steurer M, Brand H, Blesl M, Borggrefe F, Fahl U, Fuchs A-L, Gils HC, Hufendiek K, Münkel A, Rosenberg M, Scheben H, Scheel O, Scheele R, Schick C, Schmidt M, Wetzel M, Wiesmeth M (2018) Energiesystemanalyse Baden-Württemberg: Datenanhang zu techoökonomischen Kenndaten. Ministerium für Umwelt Klima und Energiewirtschaft Baden-Württemberg, STrise: Universität Stuttgart, Deutsches Zentrum für Luft- und Raumfahrt, Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Stuttgart.

2.7.2 Heating technologies

Assessing the costs in the heating sector is even more challenging than in the power sector. Costs for new installations differ significantly between regions and are interlinked with construction costs and industrial processes, which are not addressed in this study. Moreover, no data are available to allow the comprehensive calculation of the costs for existing heating appliances in all regions. Therefore, we have concentrated on the additional costs of new renewable applications in the heating sector.

Our cost assumptions are based on a previous survey of renewable heating technologies in Europe, which focused on solar collectors, geothermal energy, heat pumps, and biomass applications. Biomass and simple heating systems in the residential sector are already mature. However, more-sophisticated technologies that can provide higher shares of heat demand from renewable sources are still under development and rather expensive. Market barriers will slow the further implementation and cost reductions in renewable heating systems, especially for heating networks. Nevertheless, significant learning rates can be expected if renewable heating is increasingly implemented, as projected in all scenarios.

Table 14 presents the investment cost assumptions for heating technologies, disaggregated by sector. Geothermal heating shows the same high costs in all sectors. In Europe, deep geothermal applications are being developed for heating purposes at investment costs ranging from €500/kW$_{thermal}$ (shallow) to €3000/kW$_{thermal}$ (deep), with the costs strongly dependent on the drilling depth. The cost reduction potential is assumed to be around 30% by 2050. No data are available for the specific situation in Malawi. However, geothermal power and heating plants are not assumed to be built under any scenario.

Heat pumps typically provide hot water or space heat for heating systems with relatively low supply temperatures, or they supplement other heating technologies. Therefore, they are currently mainly used for small-scale residential applications. Costs currently cover a large bandwidth and are expected to decrease by only 20% to US$1450/kW by 2050.

We assume the appropriate differences between the sectors for biomass and solar collectors. There is a broad portfolio of modern technologies for heat production from biomass, ranging from small-scale single-room stoves for heating or CHP plants on an MW scale. Investment costs show similar variations: simple log-wood stoves can be run for US$100/kW, but more sophisticated automated heating systems that cover the whole heat demand of a building are significantly more expensive to run. The running costs of log-wood or pellet boilers range from US$500/kW to 1300/kW. Large biomass heating systems are assumed to reach their cheapest cost in 2050 at around US$480/kW for industry. For all sectors, we assume a cost reduction of 20% by 2050.

In contrast, solar collectors for households are comparatively simple and will become cheap to run, at US$680/kW, by 2050. The costs of simple solar collectors for service water heating may have been optimised already, whereas their integration into large systems is neither technologically nor economically mature. For larger applications, especially in heat-grid systems, the collectors are large and more sophisticated. Because there is not yet a mass market for such grid-connected solar systems, we assume there will be a cost reduction potential until 2050.

Table 14: Specific investment cost assumptions (in US$2015) for heating technologies in the scenarios until 2050

Investment Costs for Heat Generation Plants									
		2020		**2030**		**2040**		**2050**	
		[US$/ kW]	**[MWK/ kW]**	**[US$/ kW]**	**[MWK/ kW]**	**[US$/ kW]**	**[MWK/ kW]**	**[US$/ kW]**	**[MWK/ kW]**
Solar collectors	Industry	820	1,394,000	730	1,241,000	650	1,105,000	550	935,000
	In heat grids	970	1,649,000	970	1,649,000	970	1,649,000	970	1,649,000
	Residential	1,010	1,717,000	910	1,547,000	800	1,360,000	680	1,156,000
Geothermal		2,270	3,859,000	2,030	3,451,000	1,800	3,060,000	1,590	2,703,000
Heat pumps		1,740	2,958,000	1,640	2,788,000	1,540	2,618,000	1,450	2,465,000
Biomass heat plants		580	986,000	550	935,000	510	867,000	480	816,000
Commercial biomass heating systems	Commercial scale	810	1,377,000	760	1,292,000	720	1,224,000	680	1,156,000
Residential biomass heating stoves	Small scale/ Rural	110	187,000	110	187,000	110	187,000	110	187,000

2.7.3 Renewable Energy costs in Malawi In 2021

The following tables provide an overview of the assumed renewable energy costs in Malawi. This information is based on research by the authors and energy scenario developments for various countries of the global south. The costs may also vary from region to region.

Table 15: Solar Home Systems – estimated costs

Solar Home Systems	[MWK]	[US$]	[US$/kW$_{peak}$]
10 W	78,200	46	4,572
20 W	146,200	86	4,322
50 W	270,300	159	3,186
55 W	294,100	173	3,152
60 W	312,800	184	3,059
80 W	357,000	210	2,629
100 W	425,000	250	2,495
Institutional Solar Power Systems	**[MWK]**	**[$]**	**[US$/kW$_{peak}$]**
1000 W	3,870,900	2,277	2,277
2000 W	6,487,200	3,816	1,908

Source: UTS-ISF own research, September 2024

Table 16: Solar dryers – estimated costs

Solar Dryers [1 sq ft = 0.0929 m^2]	[MWK]	[US$]	[US$/m^2]
3–6 sq ft (household) [	438,600	258	617
10–15 sq ft (household)	996,200	586	505
> 21 sq ft (institutional)	1,540,200	906	464

Source: UTS-ISF own research, September 2024

Table 17: Solar cookers – estimated costs

Solar Cookers	[MWK]	[US$]
Parabolic – household	333,200	196
Parabolic – institutional	2,040,000	1,200

Source: UTS-ISF own research, September 2024

Table 18: Biomass stoves – estimated costs

Biomass Stoves	[MWK]	[US$]
Institutional improved stove – type 1	661,300	389
Institutional improved stove – type 2	693,600	408
Institutional improved stove – type 3	824,500	485
Natural draft stove	59,500	35
Forced draft stove	120,700	71
Improved metallic stove	164,900	97

Source: UTS-ISF own research, September 2024

2.7.4 Fuel cost projections

Fossil Fuels

Although fossil fuel price projections have seen considerable variations, as described above, we based our fuel price assumptions up to 2040 on ***World Energy Outlook 2023*** (IEA 2023). Beyond 2040, we extrapolated the price developments between 2035 and 2040 and present them in Table 19. Although these price projections are highly speculative, they provide prices consistent with our investment assumptions.

Table 19: Development projections for fossil fuel prices in US$2015 based on World Energy Outlook 2023 (STEPS) (IEA 2023)

Development Projections of Fossil Fuel Prices										
	2019		2025		2030		2040		2050	
All Scenarios	[US$/GJ]	[MWK/GJ]	[US$/GJ]	[MWK/GJ]	[US$/GJ]	[MWK/GJ]	[US$/GJ]	[MWK/GJ]	[US$/GJ]	[MWK/GJ]
Oil	8.5	14,450	12	20,400	11	18,700	10	17,000	10.5	17,850
Gas	9.8	16,660	10	17,000	10	17,000	11	18,700	12	20,400
Coal	3.2	5,440	3.5	5,950	4	6,800	3.8	6,460	3.5	5,950

2.7.5 Biomass prices

Biomass prices depend on the quality of the biomass (residues or energy crops) and the regional supply and demand. The global variability is large. Lamers et al. (2015)[41] reported a price range of €4–4.8/GJ for forest residues in Europe in 2020, whereas agricultural products might cost €8.5–12/GJ. Lamers et al.[42] modelled a range for wood pellets from €6/GJ in Malaysia to €8.8/GJ in Brazil. IRENA modelled a cost supply curve on a global level for 2030, ranging from US$3/GJ for a potential of 35 EJ/yr up to US$8–10/GJ for a potential of up to 90–100 EJ/yr (IRENA 2014) (and up to US$17/GJ for a potential extending to 147 EJ).

Bio-energy prices in Malawi in 2021

Table 20: Biogas prices – small quantities – in Malawi by region

	2 m^3		4 m^3		6 m^3		8 m^3	
Biogas	[MWK]	[US$]	[MWK]	[US$]	[MWK]	[US$]	[MWK]	[US$]
Household – low cost assumption	698,700	411	997,900	587	1,149,200	676	1,285,200	756
Household – average cost assumption	817,700	481	1,099,900	647	1,272,450	749	1,388,050	817
Household – high cost assumption	936,700	551	1,201,900	707	1,395,700	821	1,490,900	877

Source: UTS-ISF own research – September 2024

Table 21: Biogas prices – medium quantities – in Malawi by region

	12.5 m^3		40 m^3		60 m^3		100 m^3	
Biogas	[MWK]	[US$]	[MWK]	[US$]	[MWK]	[US$]	[MWK]	[US$]
Household – low cost assumption	3,690,700	2,171	10,633,500	6,255	14,116,800	8,304	20,590,400	12,112
Household – average cost assumption	4,040,050	2,377	11,289,700	6,641	16,243,500	9,555	23,666,550	13,922
Household – high cost assumption	4,389,400	2,582	11,945,900	7,027	18,370,200	10,806	26,742,700	15,731

Source: UTS-ISF own research, September 2024

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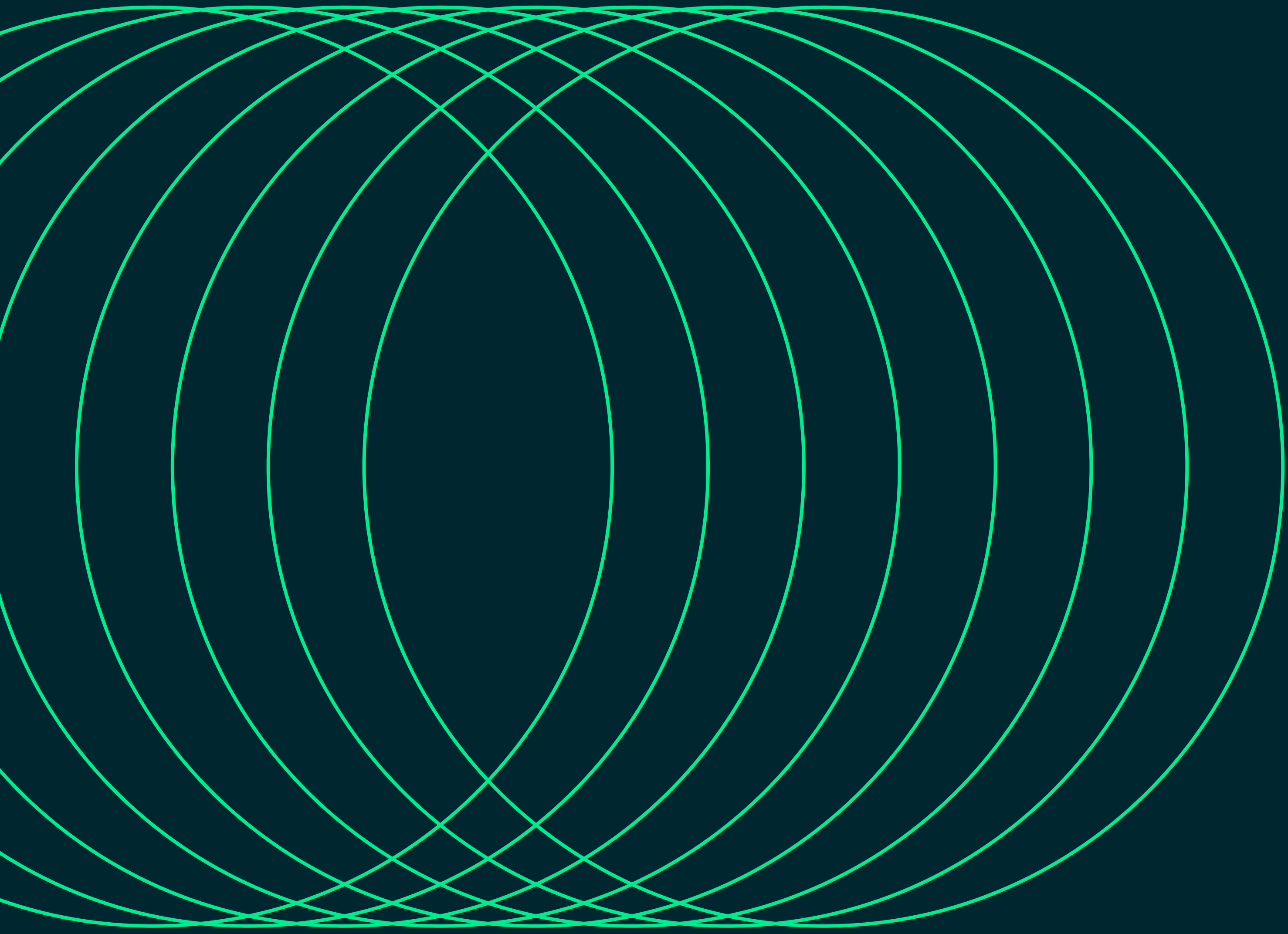
[41] Lamers P, Hoefnagels R, Junginger M, Hamelinck C, Faaij A (2015) Global solid biomass trade for energy by 2020: an assessment of potential import streams and supply costs to North-West Europe under different sustainability constraints. GCB Bioenergy 7(4):618–634. doi: https://onlinelibrary.wiley.com/doi/10.1111/gcbb.12162

3

Malawi: Renewable Energy Potential



Malawi's solar and wind potential was assessed as an input for energy scenario development. In this section, we assess the technical potential under space-constrained conditions.

3.1 The [R]E SPACE Methodology

The [R]E Space methodology is part of the One Earth Climate Model (OECM) methodology. GIS mapping was used to ascertain Malawi's renewable energy resources (solar and wind). It was also used in the regional analysis of geographic and demographic parameters and the available infrastructure that could be leveraged in developing the scenarios. Mapping was performed with the software ESRI ArcGIS10.6.1, which allows spatial analyses and maps the results. It was used to allocate solar and wind resources and for the demand projections for the three modelling regions. Population density, access to electricity infrastructure, and economic development projections are key input parameters in a region-specific analysis of Malawi's future energy situation, to clarify the requirements for additional power grid capacities and/or micro-grids.

The [R]E Space methodology is part of the OECM methodology used to map solar energy potential and onshore energy potential [42]. Open-source data and maps from various sources were collected and processed to visualise the country, its regions, and districts. Further demographic data related to the population and poverty were plotted on the maps, together with transmission networks and power plants. The main data sources and assumptions made for this mapping are summarised in Table 22.

Table 22: Malawi – [R]E 24/7 – GIS-mapping – data sources

Data	Assumptions	Source
Land Cover	Land cover classes suitable for the production of solar energy and wind energy were identified from Copernicus Global Land Cover 2019.	Copernicus Global Land Cover – 2019[43]
Digital Elevation Model (DEM)	For both wind and solar analyses, any land with a slope of > 30% was excluded from all scenarios.	SRTM Digital Elevation Data Version 4[44]
Population and Population Density	A population census was conducted in 2018 in Malawi, and the population and housing census are available.	Malawi National Statistical Office
Protected Areas	All protected areas designated national parks, wildlife reserves, hunting reserves, conservation areas, or buffer zones were excluded from all scenarios.	World Database on Protected Areas[45]
Power Plants, Transmission Lines, and Network	Solar and wind potential of areas ≤ 10 km from transmission lines were considered (Scenario 2).	Global Power Plant Database (v1.3.0)[46] Malawi Electricity Transmission Network (2017)[47]
Solar Irradiance (Direct normal irradiation: DNI)	The average yearly direct normal insolation/irradiation (DNI) values range from 1 to 5 MWh/m^2 per year (2.7–13.6 kWh/m^2 per day).	Global Solar Atlas[48]
Wind Speeds	Wind speeds ≥ 5 m/s at a height of 100 m were considered.	Global Wind Atlas[49]

The [R]E Space mapping procedure is summarised in Figure 13. The land areas available for the potential generation of solar and wind power were calculated and visualised at the national and provincial levels using ArcGIS. The land-cover map, elevation (digital elevation model, DEM), World Database of Protected Areas, solar irradiation (direct normal irradiation, DNI) and wind speed data were obtained as raster data from the website cited above, and were all converted into binary maps (0 = area not suitable as a potential site, 1 = area suitable as a potential site) against all the assumptions in Table 22, and

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[42] Miyake S, Teske S, Rispler J, Feenstra M (2024) Solar and wind energy potential under land-resource constrained conditions in the Group of Twenty (G20). Renewable and Sustainable Energy Reviews 202:114622. https://doi.org/10.1016/j.rser.2024.114622

[43] Copernicus Global Land Cover–2019: https://land.copernicus.eu/global/products/lc

[44] SRTM Digital Elevation Data Version 4: https://srtm.csi.cgiar.org/

[45] World Database on Protected Areas: https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA

[46] Global Power Plant Database (v1.3.0): https://datasets.wri.org/dataset/globalpowerplantdatabase

[47] Malawi – Electricity Transmission Network: https://kurma-monitor-prod.stanford.edu/catalog/stanford-xy243hj1082

[48] Global Solar Atlas: https://globalsolaratlas.info/map

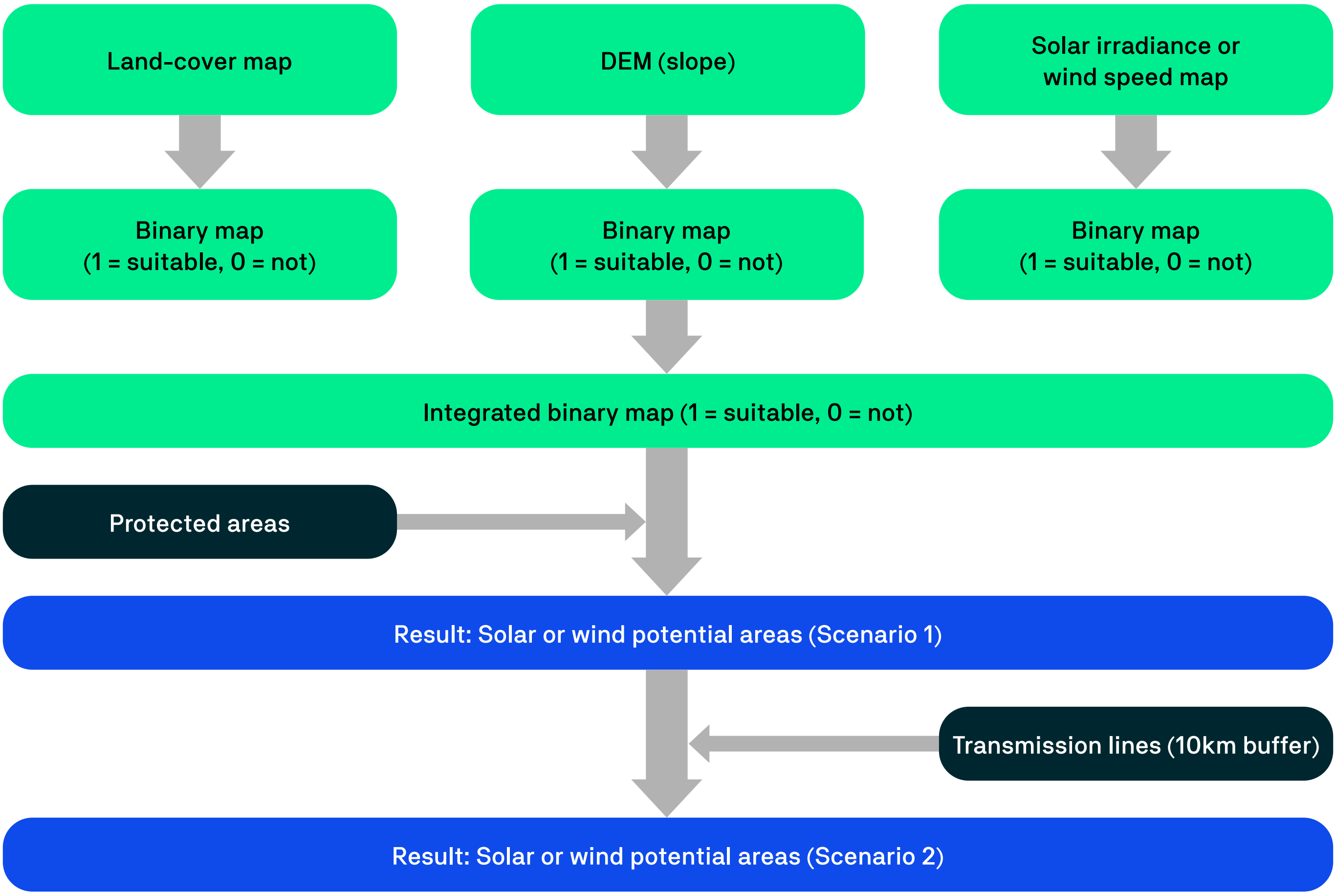
[49] Global Wind Atlas: https://globalwindatlas.info/en

then combined into one binary map by overlaying all the raster data. This map integrates all the criteria listed above in one map, with a value of 1 (land included in the potential area) or a value of 0 (land not included in the potential area).

Data on transmission lines and protected areas exist as vector data. All protected areas were excluded from the value-1 areas in the integrated raster data using a mask layer generated from the ‘erase’ function. For Scenario 2 (see Figure 13), buffer layers were generated from transmission line (10 km) data, and then the raster data without protected areas were clipped by these buffer layers to generate potential area maps under Scenario 2. This input was fed into the calculations for the [R]E 24/7 model, as described below.

Disclaimer: The environmental criteria used to identify suitable areas for utility-scale solar and wind projects do not reflect the current legislation in Malawi, and the potential provided is a conservative estimate and may ultimately be larger.

Figure 13: [R]E Space Methodology – solar potential analysis and wind potential analysis



3.2 Mapping Malawi

Malawi has large untapped potential for renewable energy and over 80% of Malawi's electricity was generated from renewable sources in 2022. Hydro power remains the most significant source, supplying 76% of the country's electricity in 2022, followed by bagasse power plants (2%). Solar PV produced 1% (12 GWh) in 2022, coming in third place, whereas wind power and geothermal power plants are currently not utilised.[50]

3.2.1 Solar Potential

The average annual solar irradiation (DNI) level in Malawi is 609–1,888 kWh/m^2 per day, and the higher end of that range is in the western part of the country.

Malawi's solar potential has been mapped under two different scenarios.

- **Scenario 1:** Available land – excluding protected areas (PA), extreme topography (slope > 30% [mountainous areas], S30), and certain land-cover classes, including closed forests, wetlands, moss and lichen, snow and ice, and water (permanent water bodies) (LU).
- **Scenario 2:** See 1, with the additional restriction that excludes areas ≤ 10 km from existing transmission lines (PT10).

Table 23: Malawi's potential for solar photovoltaic

Scenarios	1. LU + PA + S30		2. LU + PA + S30 + PT10	
Regions	**Solar Potential Area (km^2)**	**Solar Potential (GW)**	**Solar Potential Area (km^2)**	**Solar Potential (GW)**
1. Northern Region	16,805	420	5,297	132
2. Central Region	29,043	726	16,862	422
3. Southern Region	22,770	569	10,253	256
Total	**68,619**	**1,715**	**32,413**	**810**

Figure 14 shows the results of the spatial analysis, indicating the solar potential areas under Scenario 1 (LU + PA + S30). The scenario provides 68,619 km^2 of areas with solar potential and a total potential capacity for utility-scale solar PV of 1,715 GW. Scenario 1 excludes all protected areas and areas with slopes > 30%, because installing solar panels in steep mountainous areas is unrealistic. Open forests, shrubs, herbaceous vegetation, bare/spare vegetation, agricultural land, and urban/built-up land-cover classes in the Copernicus Global Land Cover 2019 dataset (Buchhorn et al. 2020) are included. However, certain land-cover classes (e.g., closed forests, wetlands, water bodies, snow and ice) are excluded from the scenarios selected for the consideration of solar energy potential.

Figure 15 shows the solar potential areas for Scenario 2 (LU + PA + S30 + PT10). When the land area is restricted by its proximity to power lines (£ 10 km), the potential solar areas decrease to 32,413 km^2. Under Scenario 2, utility-scale solar farms in Malawi can potentially harvest 810 GW of solar PV.

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[50] International Renewable Energy Agency (IRENA), Energy Profile, Malawi, online database, accessed September 2024, https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Malawi_Africa_RE_SP

Figure 14: Malawi – Areas of Solar Potential (Scenario 1: LU + PA + S30)

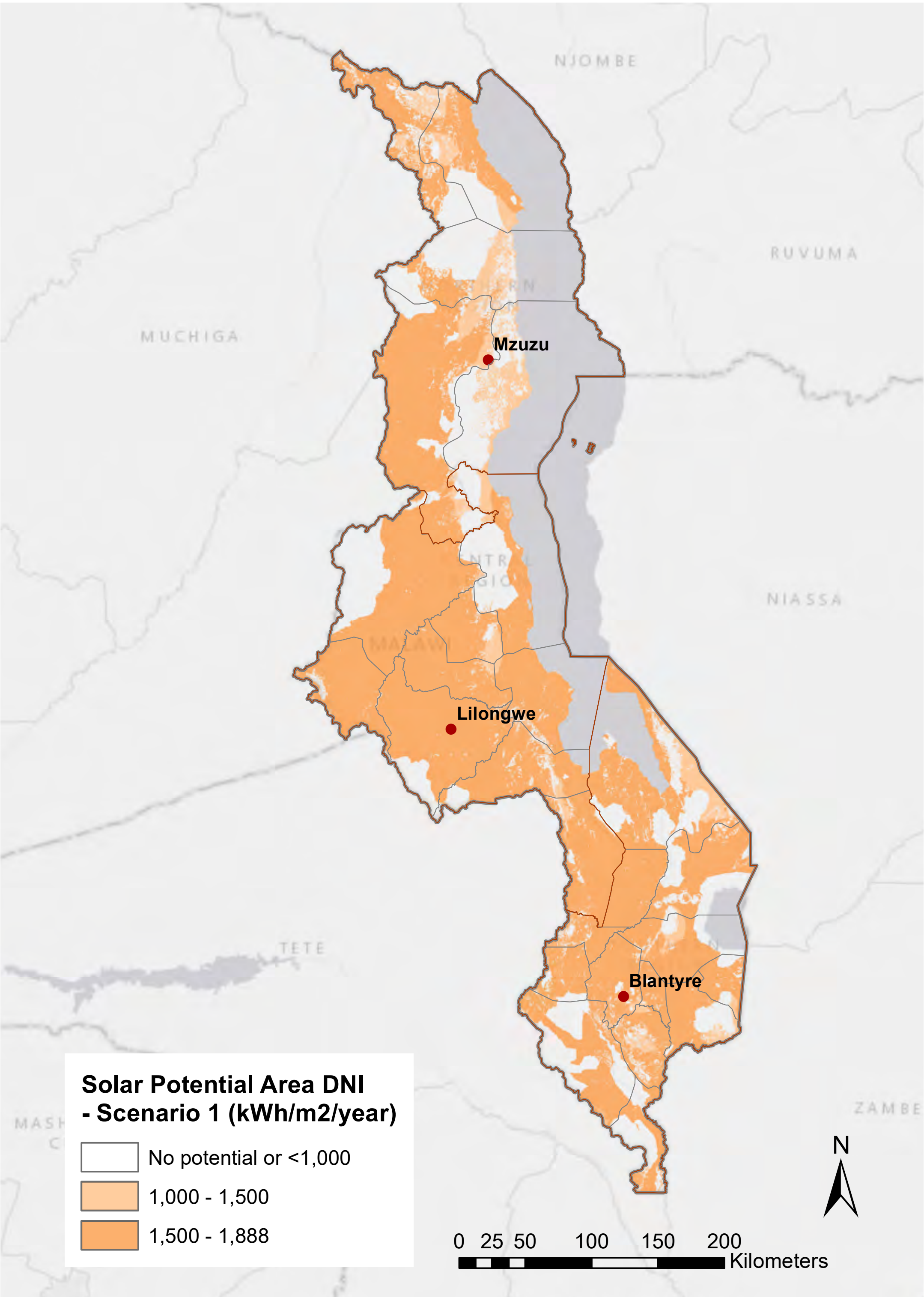
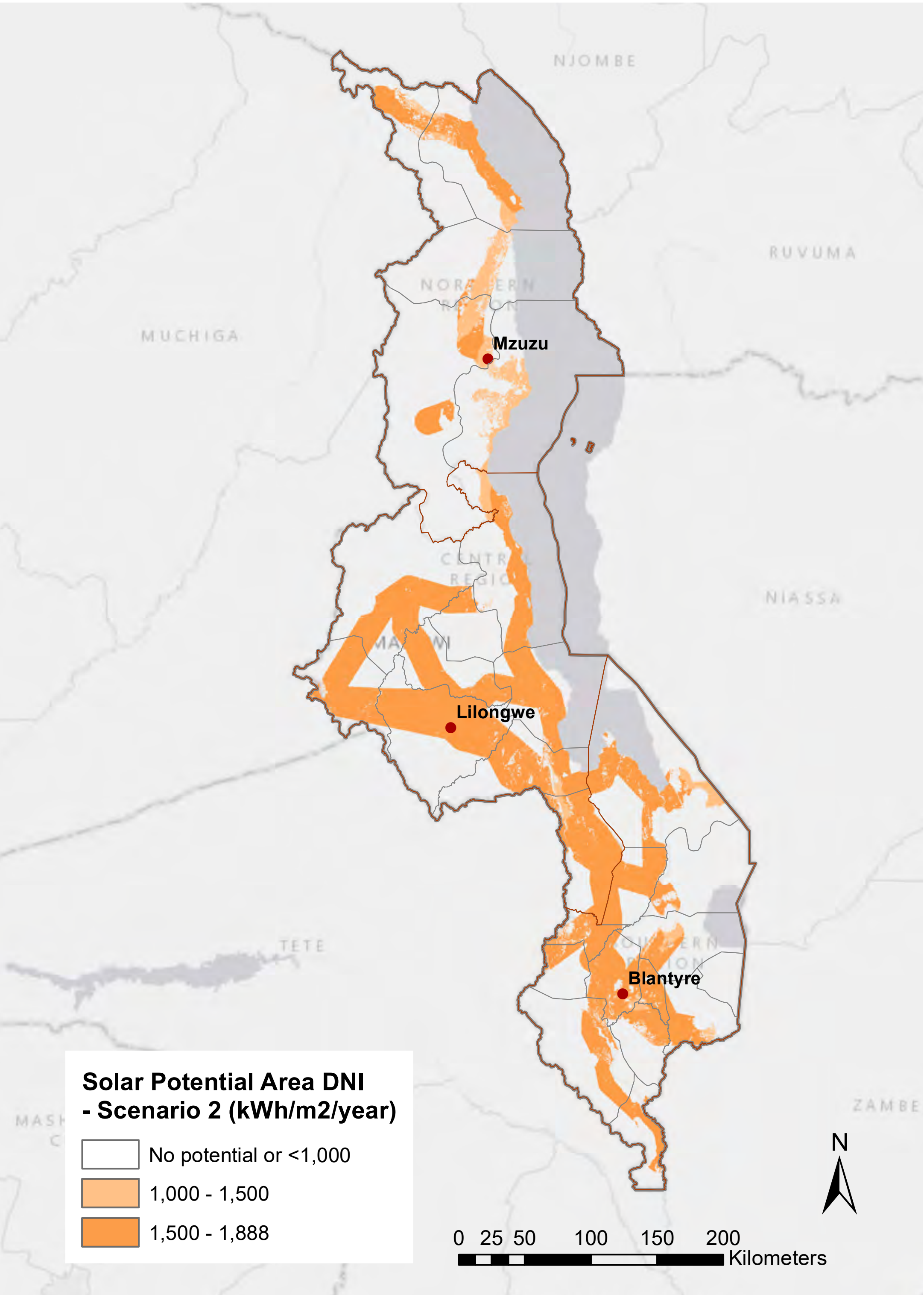


Figure 15: Malawi – Areas of Solar Potential (Scenario 2: LU + PA + S30 + PT10)



3.2.2 Onshore Wind Potential

The overall onshore wind resources on land are significantly lower in Malawi than its solar potential. The wind speeds in Malawi range from 0.8 to 14 m/s at 100 m height, and high-wind-speed areas are predominantly located in the mid-northern region (Global Wind Atlas). In this analysis, we have included only areas with an average annual wind speed of ≥ 5 m/s. Malawi's wind potential has been mapped under two different scenarios.

- **Scenario 1:** Available land – restricted by protected areas (PA), topography (slope > 30% [mountain areas], S30), and existing land use, including forests and urban areas (LU).
- **Scenario 2:** See 1, with the additional restriction excluding areas ≤ 10 km from existing transmission lines (PT10).

Open forest, shrubs, herbaceous vegetation, bare/sparse vegetation, and agricultural land were included in the available land (LU) for the two wind scenarios, whereas the land-cover classes including closed forests, wetland, moss and lichen, urban/built up areas, snow and ice, and permanent water bodies were excluded from this analysis of wind potential.

Table 24 shows that the overall wind potential under all restrictions is 195 GW from 39,036 km^2 of potential areas for Scenario 1. Overall, the spatial analysis identified slightly limited wind potential in Malawi, especially under Scenario 2 (83 GW from 16,521 km^2), because there are limited areas with an annual wind speed of ≥ 5 m/s and most of these areas are not located within close proximity to transmission lines (≤ 10 km).

Table 24: Malawi's potential for onshore wind power

Scenarios	**1. LU + PA + S30**		**2. LU + PA + S30 + PT10**	
Regions	**Onshore Wind Area (km^2)**	**Onshore Wind Potential (GW)**	**Onshore Wind Area (km^2)**	**Onshore Wind Potential (GW)**
1. Northern Region	10,009	50	1,655	8
2. Central Region	19,380	97	9,997	50
3. Southern Region	9,647	48	4,869	24
Total	**39,036**	**195**	**16,521**	**83**

Figure 16: Malawi – Areas of Onshore Wind Potential (Scenario 1: LU + PA + S30)

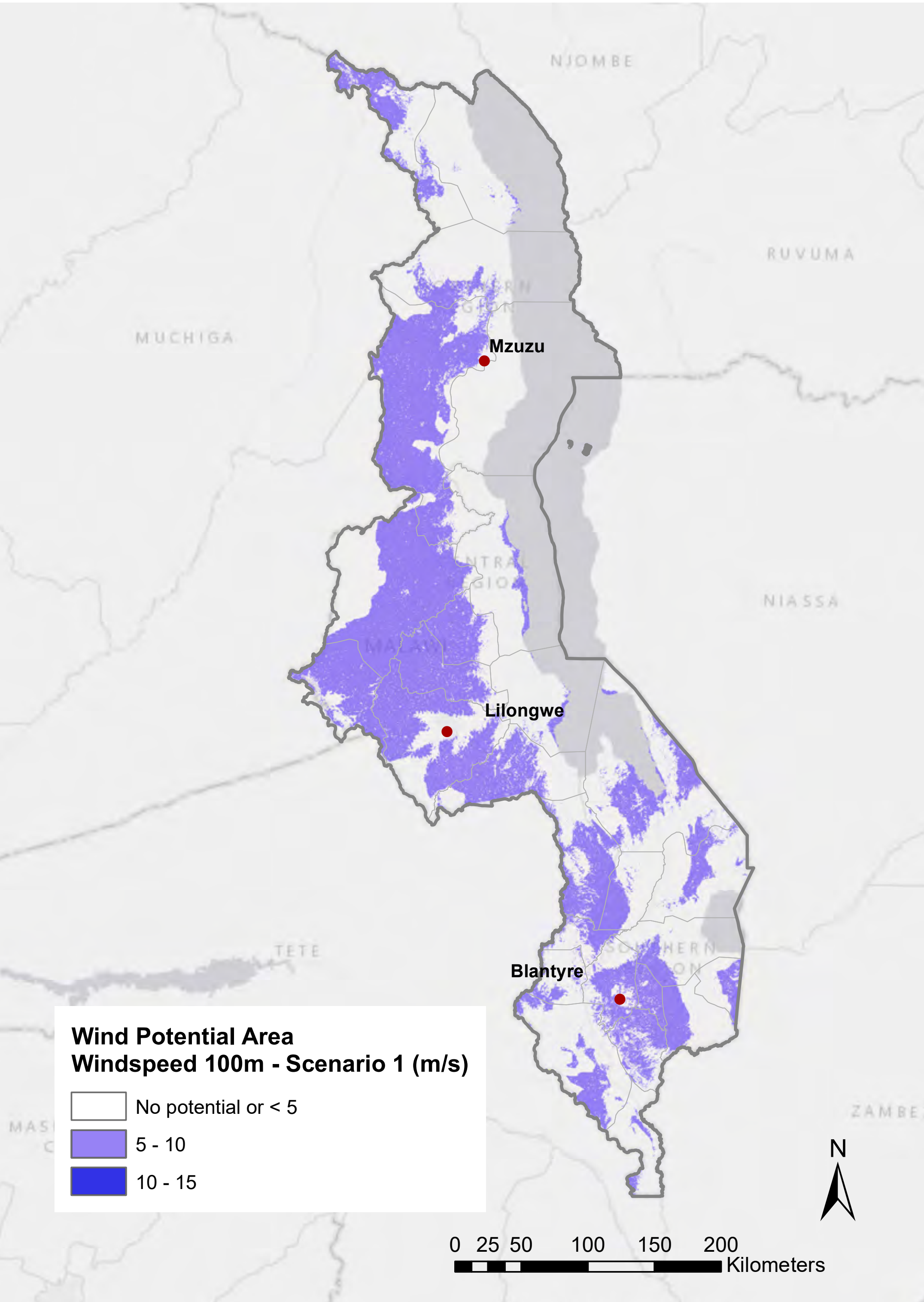
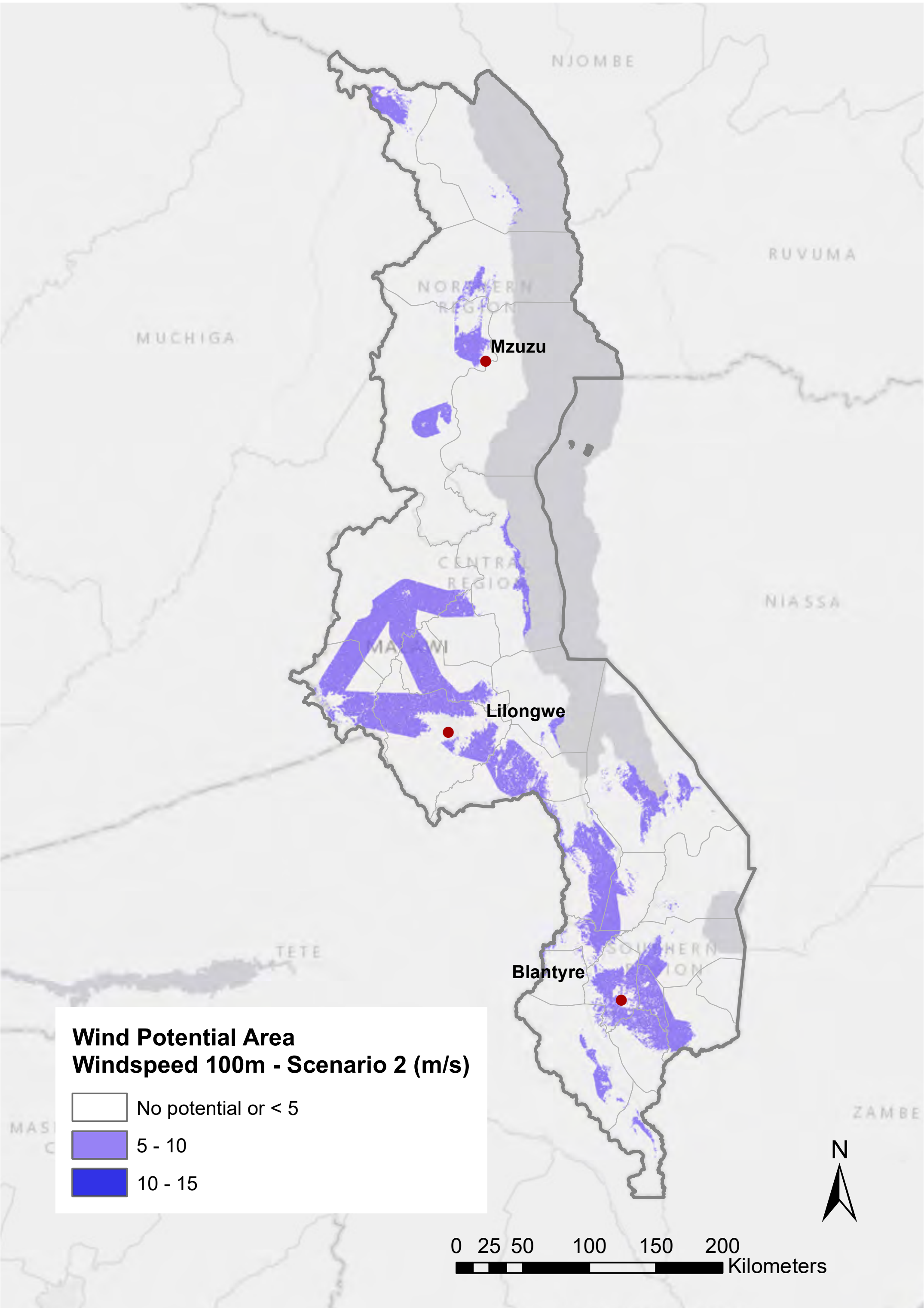


Figure 17: Malawi – Areas of Onshore Wind Potential (Scenario 2: LU + PA + S30 + PT10)



Main challenges for utility-scale solar PV are the availability of land and policy stability

To use Malawi's utility-scale solar PV potential as efficiently as possible, further research is required, breaking down the utility-scale PV potential further into ground-mounted solar PV, agricultural solar PV, and floating solar PV.

- Utility-scale solar PV: Large-scale solar PV generators require space. Space is limited in Malawi and energy generation must often compete with other forms of land use. Therefore, space for solar power should be utilised as efficiently as possible, and multiple use options should be considered.
  - Agricultural solar PV is a new development that combines agricultural food production techniques with solar PV equipment. The solar generator is mounted above the field – sometimes several meters high – to leave enough space for harvesting and to ensure light access.
  - Research and development is required into floating solar generators on lakes, especially the water storage reservoirs of hydro power stations with dams. Floating solar is a fairly new form of solar PV. In standardised floating devices for utility-scale projects, solar panels designed for ground-mounted systems are usually used.

Furthermore, policy changes regarding licensing and electricity rates for generated solar electricity have undergone changes in the past, which has increased the risks to project development and the operation of systems. Higher risks lead to higher capital costs and lower economic advantages. Therefore, policy stability is a key driver of every technology, including utility-scale solar PV power plants.

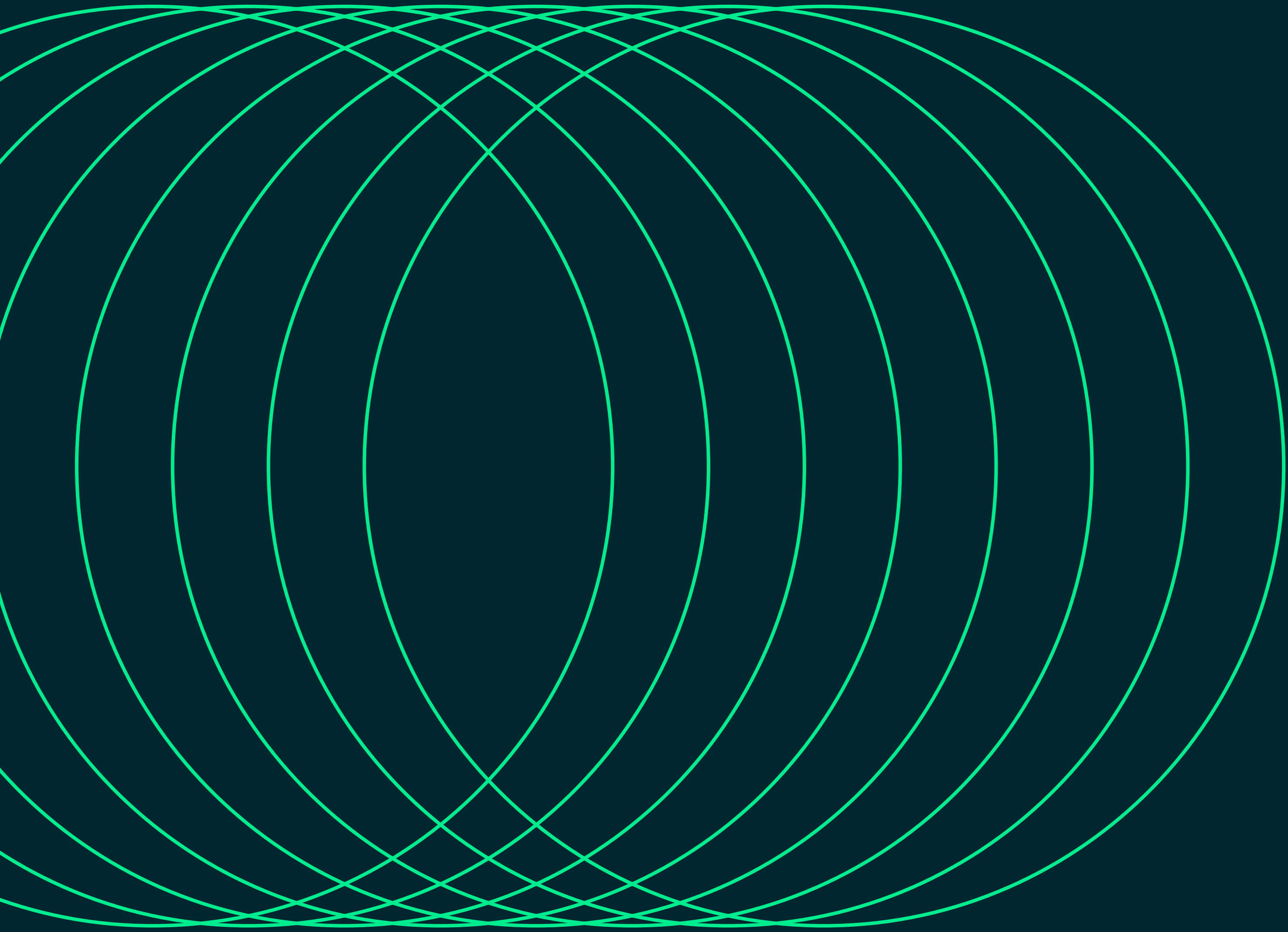
3.2.3 Assumptions for hydrogen and synfuel production

In the Malawi 1.5°C (M-1.5°C) scenario, hydrogen and sustainable synthetic fuels will be introduced as a substitute for natural gas. Unsustainable biomass will only play a minor role and will be used almost exclusively by industry after 2030. Hydrogen is assumed to be produced by electrolysis, generating an additional electricity demand, which will be supplied by the extra renewable power production capacity, predominantly solar PV and hydro power. Renewable hydrogen and synthetic fuels will be essential for a variety of sectors.

- In the industry sector, hydrogen will be an additional renewable fuel option for high-temperature applications, supplementing biomass in industrial processes whenever the direct use of renewable electricity is not applicable.
- The transport sector will also rely increasingly on hydrogen as a renewable fuel, where battery-supported electric vehicles reach their limits and where limited biomass potential restricts the extension of biofuel use. However, future hydrogen applications may be insufficient to replace the whole fossil fuel demand, especially in aviation, heavy-duty vehicles, and navigation. The M-1.5°C scenario introduces synthetic hydrocarbons from renewable hydrogen, electricity, and biogenic/atmospheric CO_2. These synthetic fuels will be introduced after 2030 and provide the remaining fossil fuel demand that cannot be met with biofuels because their potential is limited.

4

Areas of Forest Loss in Malawi



The Food and Agriculture Organisation of the United Nations (FAO) is a specialised agency that leads international efforts to abolish hunger and improve nutrition and food security. The FAO has published extensive food production data and other data related to agriculture and forestry.

According to the FAO[51], the forest area in Malawi in 2020 was 22,417 km^2 (including 757 km^2 of naturally regenerated forest), which represents a 36.3% reduction from 1990 and a 27.3% reduction from 2000. These increases in forest loss resulted in negative carbon emissions from the forest sector (Table 25).

Table 25: Extent of forest areas and net emissions from forested land in Malawi (FAO)

	Extent of Forest	
Year	**Areas (km^2)**	**Change from 1990**
1990	35, 017	-
2000	30,817	-12.4 %
2010	26,617	-24.3%
2020	22,417	-36.3%

Source: Extent of Forest (FAO Global Forest Resources Assessment Country Reports (2020)

Global Forest Watch also reported that in 2001–2023 Malawi lost 2,740 km^2 of tree cover (equivalent to a 16% reduction in tree cover since 2000), which generated 105 Mt of CO_2e emissions. This included the loss of 10.7 km^2 of humid primary forest between 2002 to 2023, and forest was predominantly cleared with the expansion of agriculture during that period[52]. The loss of forested areas in Malawi was also visualised with ArcGIS. The spatial dataset published by Hansen et al. (2013) was used to highlight forest loss (2000–2023) using ArcGIS (Figure 18). Areas of forest loss are mostly in the Northern Region (e.g., Nkhata Bay, Mzimba). Table 26 shows the areas of forest loss (km^2), which were also estimated from Hansen et al.[53], together with the estimated CO_2e emissions since 2000 (the baseline year of this dataset).

Table 26: Malawi – areas of forest loss (km^2) and estimated CO_2e emissions from that forest loss

Years	**Area (km^2)**	**CO_2e emissions (kilotonnes)**
2001–2005	52	10,893
2006–2010	53	12,452
2011–2015	81	27,195
2016–2020	93	30,531
2021–2023	66	23,866
Total areas of forest loss (2001–2023)	346	104,937

Source: Global Forest Watch

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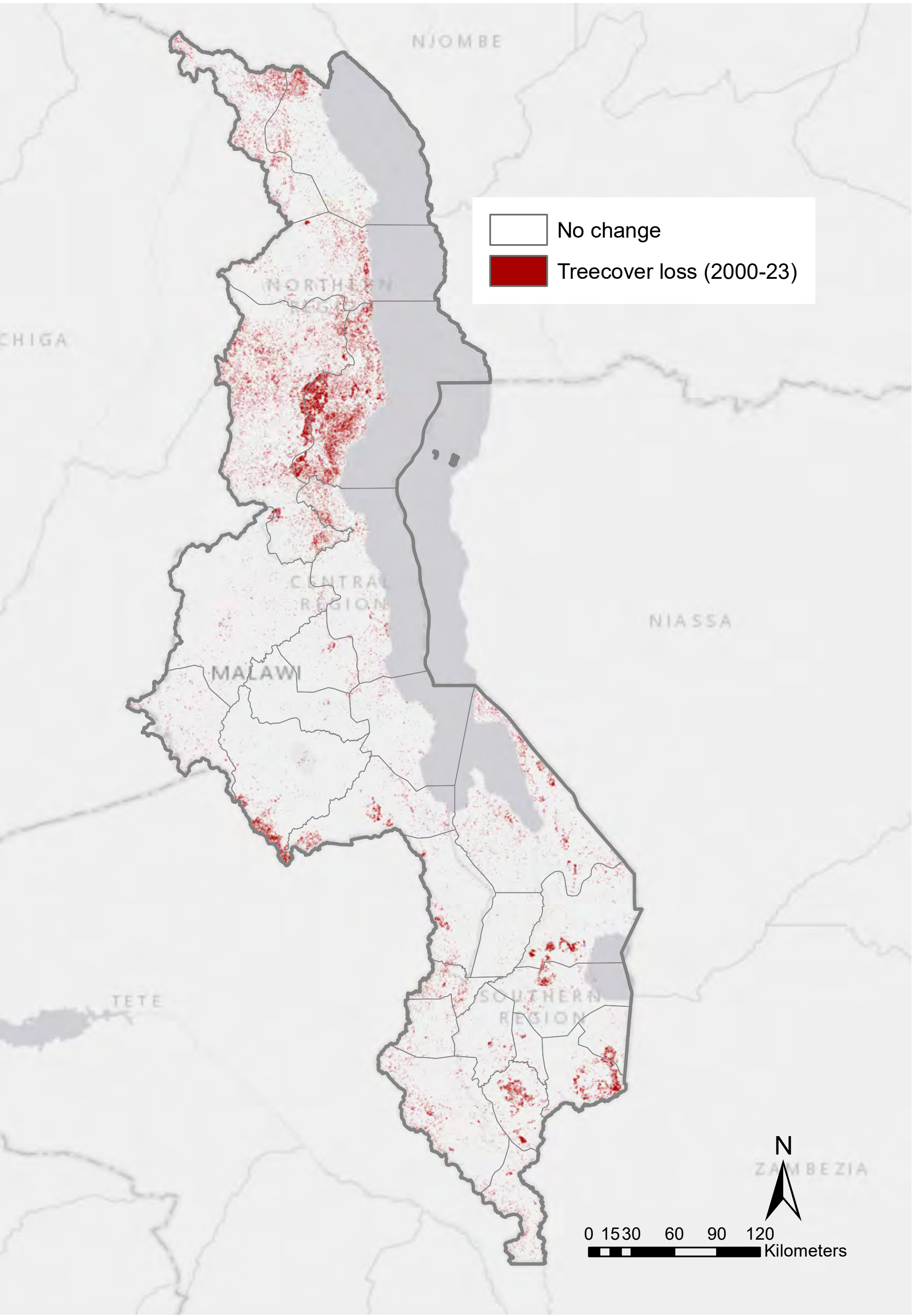
[51] FAO Global Forest Resources Assessment 2020 (Malawi): https://openknowledge.fao.org/server/api/core/bitstreams/bb629af6-5342-4a8e-9830-d5483e06f2fe/content

[52] Global Forest Watch (Malawi): https://www.globalforestwatch.org/dashboards/country/MWI/?map=eyJjYW5Cb3VuZCI6dHJ1ZX0%3D

[53] Hansen MC, Potapov R, Moore M, Hancher SA, Turubanova A, Tyukavina D, Thau SV, Stehman SJ, Goetz TR, Loveland A, Kommareddy A, Egorov L, Chini CO, Justice PV, Townshend JRG (2013) High-Resolution Global Maps of 21st-Century Forest Cover Change. Science 342 (15 November):50–53. Data available online at: https://glad.earthengine.app/view/global-forest-change

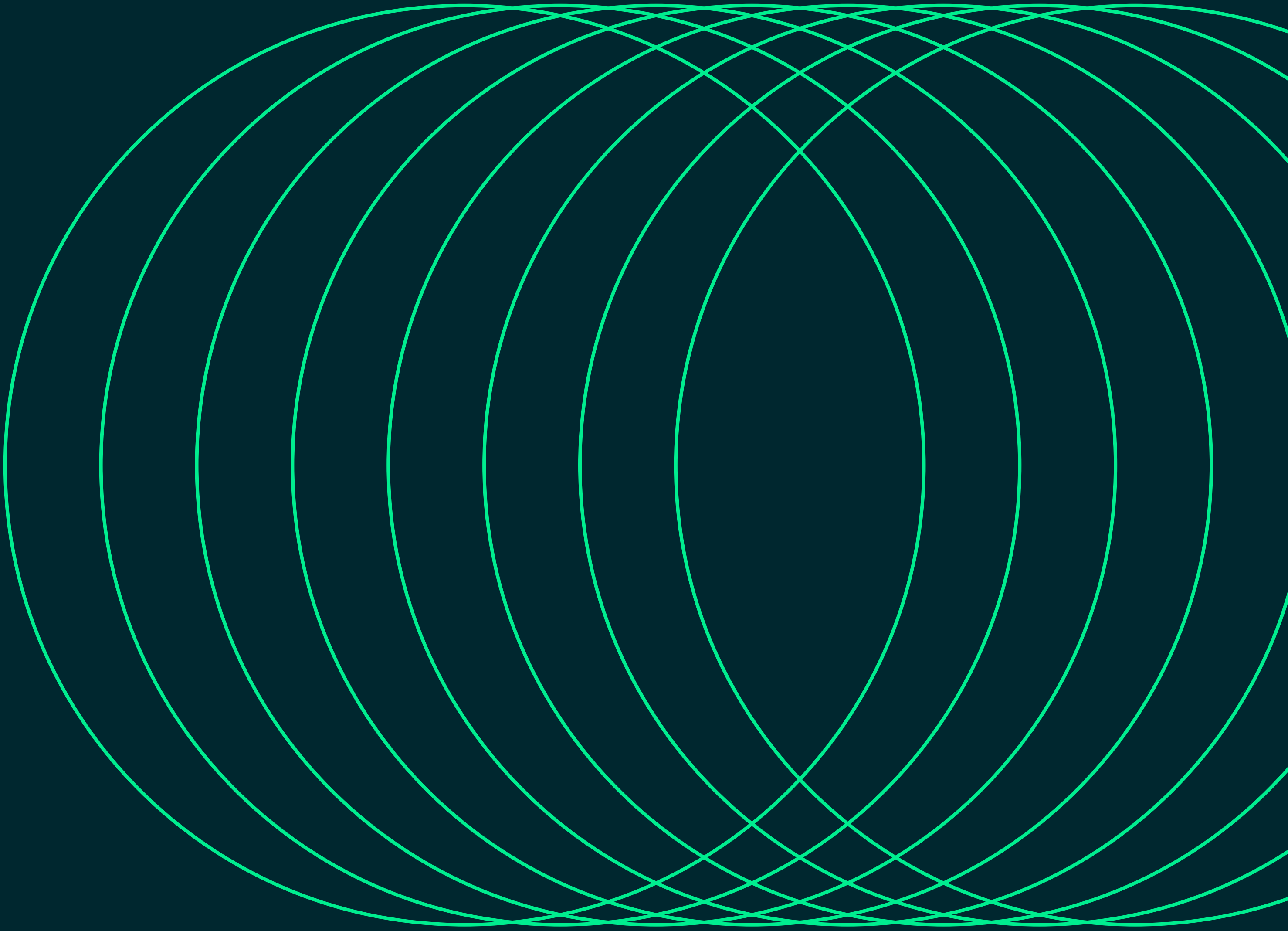
Figure 18: Areas of forest loss in Malawi 2000–2023



Source: generated by UTS-ISF using data from Hansen et al. (2013)

5

Key Results – Long-term Scenario



Malawi must build up and expand its power generation system to increase the energy access rate to 100%. Building new power plants – no matter the technology – will require new infrastructure (including power grids), spatial planning, a stable policy framework, and access to finance.

With lower solar PV and onshore wind prices, renewables have become an economic alternative to building new hydro or gas power plants. Consequently, renewables achieved a global market share of over 80% of all newly built power plants in 2021[54]. Malawi has significant solar resources, but only very limited wind potential. The costs of renewable energy generation are generally lower with stronger solar radiation and stronger wind speeds. However, constantly shifting policy frameworks often lead to high investment risks and higher project development and installation costs for solar and wind projects than those in countries with more stable policies.

The scenario-building process for all scenarios includes assumptions about policy stability, the role of future energy utilities, centralised fossil-fuel-based power generation, population and GDP, firm capacity, and future costs.

- **Policy stability:** This research assumes that Malawi will establish a secure and stable framework for deploying renewable power generation. Financing a gas power plant or a wind farm is quite similar. In both cases, a power purchase agreement that ensures a relatively stable price for a specific quantity of electricity is required to finance the project. Daily spot market prices for electricity and/or renewable energy or carbon are insufficient for the long-term investment decisions for any power plant with a technical lifetime of 20 years or longer.
- **Strengthened energy efficiency policies:** Existing policy settings – energy efficiency standards for electrical applications, buildings, and vehicles – must be strengthened to maximise the cost-efficient use of renewable energy and to achieve high energy productivity by 2030.
- **Role of future energy utilities:** With the 'grid parity' of roof-top solar PV below most current retail tariffs, this modelling assumes that the energy utilities of the future will take up the challenge of increased local generation and develop new business models that focus on energy services, rather than simply on selling kilowatt-hours.
- **Population and GDP:** Projections of population and GDP are based on historical growth rates. Projections of population growth are taken from the *World Bank Development Indicators*[55].
- **Firm capacity:** The scale of each technology deployed and the combination of technologies in the two scenarios target the firm capacity. Firm capacity is the "proportion of the maximum possible power that can reliably contribute towards meeting the peak power demand when needed."[56] Firm capacity is important to ensure a reliable and secure energy system. Note that variable renewable energy systems still have a firm capacity rating, and the combination of technology options increases the firm capacity of the portfolio of options.
- **Cost assumptions:** The cost assumptions are documented in Chapter 2.

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[54] REN21–Global Status report 2021.

[55] World Bank (2023) Reviewed at: https://data.worldbank.org/indicator/SP.POP.TOTL

[56] http://igrid.net.au/resources/downloads/project4/D-CODE_User_Manual.pdf

5.1 The Reference Scenario – Business-as-usual Malawi NDC (2021)

A few energy assessment and electrification concepts are available for Malawi, but no detailed long-term energy scenarios are available. Thus, the One Earth Climate Model (OECM) builds on existing information for the input assumptions. Table 31 provides an overview of the published energy scenarios and/or energy plans, including the National Determined Contribution (NDC). To compare the OECM for Malawi, a new reference has been developed because a direct comparison with published energy plans is not possible because the sectoral breakdowns and technical resolutions differ.

The BAU modelling approach documented in the NDC document in 2021 '*is based on detailed bottom-up activity and GHG projections developed for each emitting sector through 2040. These reflect a number of assumptions determining changes in inter alia energy supply and demand, agricultural output, waste generation, and technology uptake. In so doing, existing government projections and plans were assessed, and experts consulted within relevant ministries, agencies and organisations. The BAU projections were undertaken by separate consulting teams and separate technical reports have been prepared for these providing details on the projections made (…) At an aggregate level, total emissions are forecast to increase by more than three times over the 2017–2040 period, rising from 9.3 million tCO_2e in 2017 to 34.6 million tCO_2e in 2040 (…)*

The most rapid growth is forecast within energy use (energy industries, transport, other energy use and fugitive emissions), which expands its share of total emissions from 25% in 2017 to around 42% in 2030 and 57% by 2040 (…) These trends clearly indicate the growing contribution from fossil fuels to national emissions, arising from increasing demand for thermal power generation and transport services. At the same time, despite potential for increased productivity, agricultural output is expected to be limited, growing broadly in line with trends over the past decade.'

The resulting GHG emissions under Malawi's NDC 2021 are shown in Table 27. This analysis focuses on energy-related CO_2 emissions. The REFERENCE scenario is based on the emissions pathway for the energy sector only.

Table 27: Malawi–NDC 2021: BAU emissions projections to 2040, all sectors excluding food and land use (FOLU)

GHG emissions ($MtCO_2e$)	2017	2020	2030	2040
Energy	2.35	2.82	8.18	19.83
Industrial processes and product use (IPPU)	0.24	0.28	0.45	0.74
Agriculture	5.07	5.67	7.74	9.87
Waste	1.67	1.94	2.88	4.18
Total	**9.33**	**10.71**	**19.25**	**34.61**

Source: Updated NDC for Malawi, July 2021

Table 28: Malawi – Energy scenarios and parameters published in literature reviews

	Malawi – Parameter	Analysis	
Nr.	Key graphs drawn from our own modelling results:	One Earth Climate Model	Info IEA, Africa Energy Outlook 2019 Stated policy scenario Africa case
1.	Final energy demand until 2050, according to sector (transport, industry, residential)	Yes	Only 2018 and 2040 values
2.	Development electricity demand until 2050, TWh/a (transport, industry, residential)	Yes	Yes
3.	Heat demand final energy [PJ/a] until 2050 (industry, residential)	Yes	No
4.	Development of road transport final energy [PJ/a] until 2050 (road passenger, road freight)	Yes	No
5.	Breakdown of electricity generation capacity [GW] until 2050 (according to source: solar PV, wind, biomass, hydrogen, fossil fuels)	Yes	No
6.	Energy supply for cooking heat [PJ/a] until 2050 (according to source: solar collectors, heat pumps, electric direct heating, etc.)	Yes	Only 2018 and 2030 values
7.	Installed capacity for renewable heat generation [GW] until 2050 (according to source)	Yes	No
8.	Transport energy supply by energy source [PJ/a] until 2050 (according to electricity, hydrogen, natural gas, synfuel, biofuels, fossil)	Yes	No
9.	Total primary energy demand by energy source [PJ/a] until 2050 (according to wind, solar, etc.)	Yes	Yes
10.	CO_2 emissions per sector [Mt/a] until 2050 (industry, buildings, transport, power generation, other)	Yes	No
11.	Investment cost [billion US$/a] until 2050	Yes	No
12.	Shares of cumulative investment in power generation 2020–2050	Yes	Yes, cumulative investment in 2019–2040, for fuels, heating, but also networks
13.	Cumulative investment in heating technologies 2020–2050	Yes	No
14.	Installed PV capacities up to 2050	Yes	No

5.1.1 Assumptions for the Malawi 1.5°C scenario

The Malawi 1.5°C (M-1.5°C) scenario is built on a framework of targets and assumptions that strongly influence the development of individual technological and structural pathways for each sector. The main assumptions considered in this scenario-building process are detailed below.

- **Emissions reductions:** The main measures taken to meet the CO_2 emissions reductions in the M-1.5°C scenario include strong improvements in energy efficiency, which will double energy productivity over the next 10–15 years, and the dynamic expansion of renewable energy use across all sectors.
- **Growth of renewables industry**: Dynamic growth in new capacities for renewable heat and power generation is assumed based on current knowledge of the potential, costs, and recent trends in renewable energy deployment. Communities will play a significant role in the expanded use of renewables, particularly in terms of project development, the inclusion of the local population, and the operation of regional and/or community-owned renewable power projects.
- **Fossil-fuel phase-out:** The operational lifetime of gas power plants is approximately 30 years. In both scenarios, coal power plants will be phased-out early, followed by gas power plants**.**
- **Future power supply:** The capacity of large hydro power will remain relatively flat in Malawi over the entire scenario period, whereas the quantities of bio-energy will increase within the nation's potential for sustainable biomass (see below). Solar PV is expected to be the main pillar of the future power supply, complemented by the contributions of bio-energy and wind energy. The figures for solar PV combine those for roof-top and utility-scale PV plants, including floating solar plants.

- **Security of energy supply:** The scenarios limit the share of variable power generation and maintain a sufficient share of controllable, secured capacity. Power generation from biomass and gas-fired backup capacities and storage are considered important for the security of supply in a future energy system and are related to the output of firm capacity, discussed above. Storage technologies will increase after 2030, including battery electric systems, dispatchable hydro power, and hydro pump storage.
- **Sustainable biomass levels:** No data on Malawi's sustainable level of biomass are available. However, low-tech biomass use, such as inefficient household wood burners, is largely replaced in the M-1.5°C scenario by state-of-the-art technologies, primarily highly efficient heat pumps and solar collectors. This will results in a significant overall lowering of the total biomass use.
- **Electrification of transport**: Efficiency savings in the transport sector will result from fleet penetration by new highly efficient vehicles, such as electric vehicles, but also from assumed changes in mobility patterns and the implementation of efficiency measures for combustion engines. The scenarios assume the limited use of biofuels for transportation, given the limited supply of sustainable biofuels.
- **Hydrogen and synthetic fuels:** Hydrogen and synthetic fuels generated by electrolysis using renewable electricity will be introduced as a third renewable fuel in the transportation sector, complementing biofuels, the direct use of renewable electricity, and battery storage. Hydrogen generation can have high energy losses; but the limited potential of biofuels, and probably battery storage, for electric mobility means it will be necessary to have a third renewable option in the transport sector. Alternatively, this renewable hydrogen could be converted into synthetic methane or liquid fuels, depending on the economic benefits (storage costs versus additional losses) and the technological and market development in the transport sector (combustion engines versus fuel cells). Because Malawi's hydrogen generation potential is limited, it is assumed that hydrogen and synthetic fuels will be imported. Furthermore, hydrogen utilisation will be limited to the industry sector, and is not expected to contribute more than 5% of industry's energy supply by 2050.

Malawi's 1.5°C scenario (M-1.5°C) takes an ambitious approach to transforming Malawi's entire energy system to an accelerated new renewable energy supply. However, under the M-1.5°C scenario, a much faster introduction of new technologies will lead to the complete decarbonisation of energy for stationary energy (electricity), heating (including process heat for industry), and transportation. In the transport sector, there will be a strong role for storage technologies, such as batteries, synthetic fuels, and hydrogen.

Under the M-1.5°C scenario, the share of electric and fuel-cell vehicles will increase. This scenario also relies on the greater production of synthetic fuels from renewable electricity, for use in the transport and industry sectors. Renewable hydrogen will be converted into synthetic hydrocarbons, which will replace the remaining fossil fuels, particularly in heavy-duty vehicles and air transportation – albeit with the low overall efficiency typical of synthetic fuel systems. Because renewable synthetic fuels require a (gas) pipeline infrastructure, this technology is not widely used in Malawi's energy plan because the costs in the early development stages are relatively high. It is assumed that synthetic fuels and hydrogen will not enter Malawi's energy system before 2040. Compensating for the high energy losses associated with producing synthetic fuels will require fundamental infrastructure changes, which seem too costly for a developing country. Electricity and hydrogen will play larger roles in the heating sector (mainly heat for industry), replacing fossil fuels. In the power sector, natural gas will also be replaced by hydrogen. Therefore, electricity generation will increase significantly under the M-1.5°C scenario, assuming that power from renewable energy sources will be the future's main 'primary energy'.

The M-1.5°C scenario also models a shift in the heating sector towards the increased direct use of electricity because of the enormous and diverse potential for renewable power and the limited availability of renewable fuels for high-temperature process heat in industry. Increased implementation of a district heating infrastructure (interconnections of buildings in central business districts), bio-energy-based heat generation, and solar collectors and heat pumps for office buildings and shopping centres in larger cities are assumed, leading to growth in the electricity demand, which partly offsets the efficiency savings in these sectors. The rapid expansion of solar and geothermal heating systems is also assumed.

The increasing shares of variable renewable power generation, principally by solar PV, will require the implementation of smart grids and the fast interconnection of micro- and mini-grids with regional distribution networks, storage technologies such as batteries and pumped hydro, and other load-balancing capacities. Other infrastructure requirements will include an increasing role for the on-site generation of renewable process heat for industries and mining, and the generation and distribution of synthetic fuels.

5.1.2 Assumptions for the Malawi Reference Scenario

The REFERENCE scenario for Malawi has been developed based on the Malawi 1.5°C scenario but assumes an implementation delay of 15 years. The energy-related CO_2 emissions of the REFERENCE scenario are similar to those of the BAU scenario in Malawi's NDC submission for 2021. However, the NDC does not contain any information about the actual energy supply pathway. Therefore, a detailed comparison is not possible.

The key differences between the REFERENCE scenario and the M-1.5°C scenario are given below.

1. **Heating a sector:** In the REFERENCE scenario, the phase-out of coal, oil, and gas is delayed for the residential, service, and industry sectors within 15 years. Accordingly, electric heat pumps and solar collector systems will remain niche technologies until 2040, but will grow thereafter and increase their shares by 2050.
2. **Transport sector:** In the REFERENCE scenario, electric mobility will experience significant delays, whereas the transport demand will increase as projected in the M-1.5°C scenario. Vehicles with ICEs will remain dominant until 2040. Market shares for electric vehicles will start to grow significantly from 2040 onwards. Biofuels will also increase in the road transport sector.
3. **Power supply:** In the REFERENCE scenario, the delayed electrification in the heating and transport sectors will lead to the slower growth of the power demand than under the M-1.5°C scenario. It is also assumed that renewable power generation will not meet the increased electricity demand because its implementation is delayed, and fossil-fuel-based power generation will therefore increase.

5.2 Malawi – energy pathway until 2050

The following section provides an overview of the key results of three different energy scenarios (M-1.5°C and REFERENCE) for Malawi. The energy scenarios do not claim to predict the future. Instead, they provide useful tools with which to describe and compare potential development pathways from the broad range of possible 'futures'. The M-1.5°C scenario was designed to demonstrate the efforts and actions required to achieve the ambitious objective of a 100% renewable energy system and to illustrate the options available to change our energy supply system into one that is truly sustainable. The scenarios may be used as a reliable basis for the further analysis of the possible concepts and actions required to implement technical pathways to achieve measurable results.

5.2.1 Malawi – Final Energy Demand

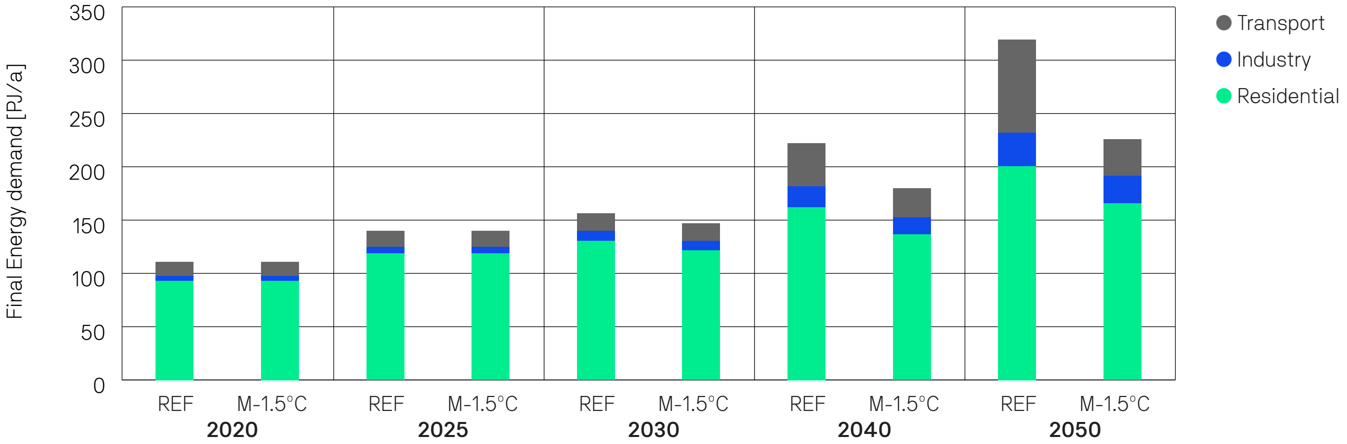
The projections of population development, GDP growth, and energy intensity are combined to project the future development pathways for Malawi's final energy demand. These are shown in Figure 19 for the REFERENCE and M-1.5°C scenarios. In the REFERENCE scenario, the total final energy demand will increase by 256% from 125 PJ/a to 319 PJ/a between 2020 and 2050. In comparison, in the M-1.5°C scenario, the total final energy demand will increase by 181% from 125 PJ/a to 226 PJ/a. The M-1.5°C scenario will reduce any additional costs by increasing the proportion of electric cars.

As a result of the projected continued annual GDP growth of 8% (on average) until 2035 and 4.5% thereafter until 2050, the overall energy demand is expected to increase under both scenarios (Figure 19). The residential sector will remain dominant in Malawi's energy demand, but the energy demand of the industry sector will increase continuously. By 2050, industry will consume at least five times more energy than in 2020, making this sector the second highest consumer after transport under both scenarios.

The energy demand of the transport sector will increase by 640% by 2050 under the REFERENCE scenario, whereas it will decrease by 250% under the M-1.5°C scenario. The main reason for the significant difference in growth projections is the high rates of electrification in the M-1.5˚C pathway.

The large efficiency gains achieved in the M-1.5°C pathway are attributable to the high electrification rates, mainly in the cooking and transport sectors, because combustion processes with high losses are significantly reduced.

Figure 19: Projections of the total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)



The increased projected electrification of the heating, cooking, and transport sectors, especially under the M-1.5°C scenario, will lead to a significantly increased electricity demand (see Figure 20).

The M-1.5°C pathway will accelerate the electrification of the heating, cooking, and transport sectors compared with the other pathways, and aims to replace more fossil fuels and biofuels with electricity. By 2050, Malawi's electricity demand will increase close to 50 TWh per year.

Electricity will become the major renewable 'primary' energy, not only for direct use for various purposes, but also for the generation of a limited amount of synthetic fuels, which will substitute for fossil fuels in providing industrial process heat. Under M-1.5°C, around 7 TWh will be used for electric vehicles and rail transport in 2050.

Figure 20: Development of electricity demand by sector

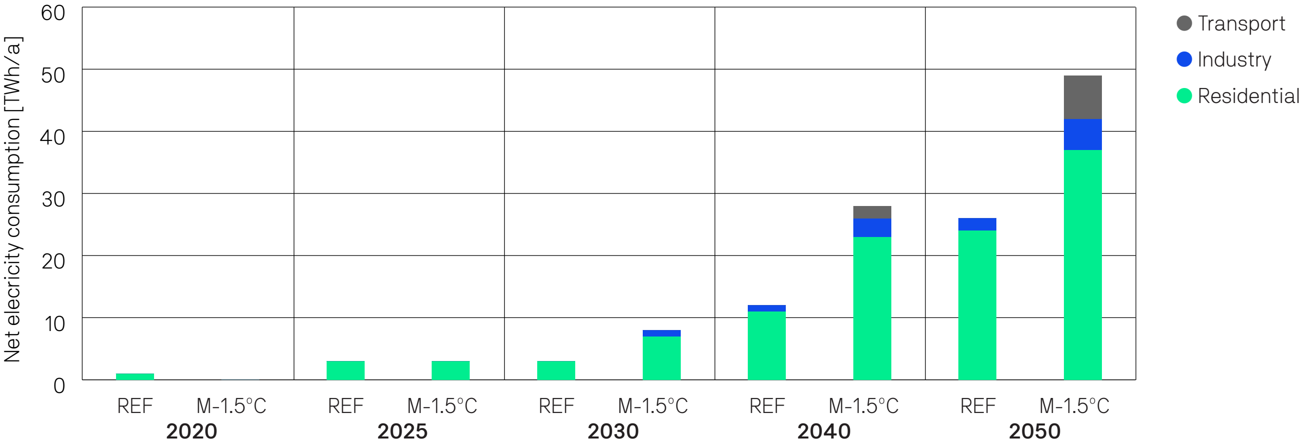
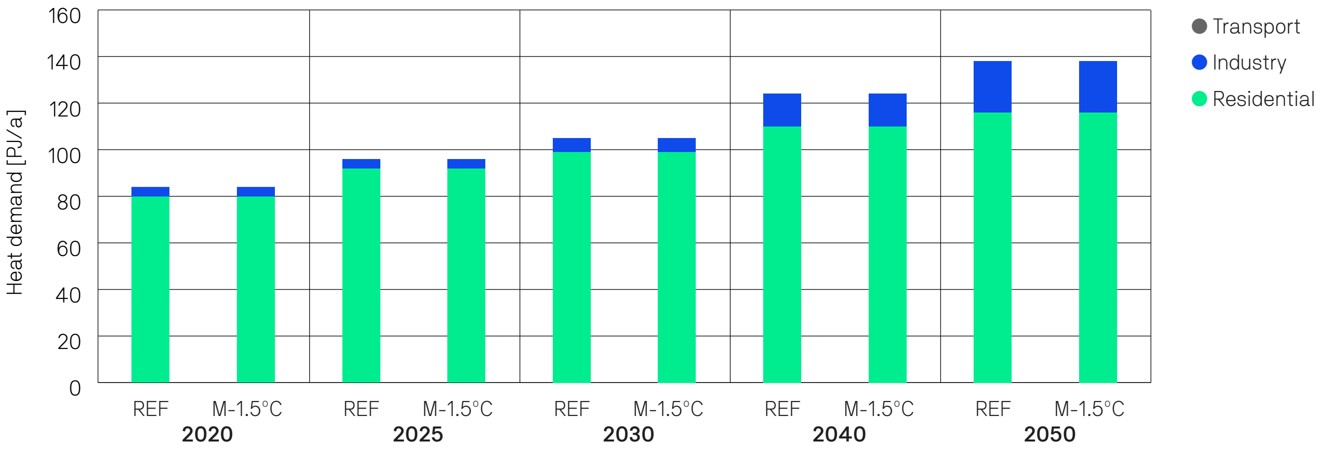


Figure 21: Development of the final energy demand for heat by sector

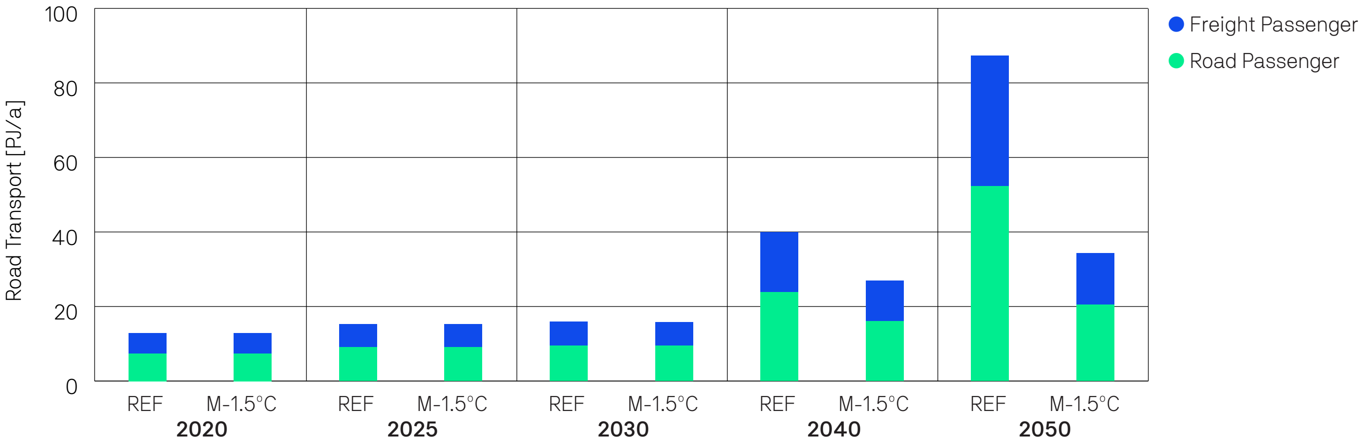


The energy demand for process heat, space heating in residential and commercial buildings, and cooking will continue to grow in the M-1.5°C pathway. The main driver will be a combination of population growth and the increased role of the industry sector in Malawi's GDP. The M-1.5°C pathway has an increased role in the electrification of the heating supply (with heat pumps) and the implementation of electric cooking.

As a result, the M-1.5°C pathway will lead to an annual heat demand of around 138 PJ/a.

The projected development of the road transport sector (see Figure 22) in terms of the assumed annual pkm and annual freight requirement in tkm is identical in the REFERENCE scenario and the M-1.5°C scenario. More details of the assumptions made for the transport sector projections, broken down into freight and passenger transport, are documented in section 2.6. The significantly different energy demand in the two pathways is entirely due to the higher electrification rate in the M-1.5°C for Malawi.

Figure 22: Development of the road transport energy demand for passengers and freight



5.2.2 Electricity generation

Electricity generation, capacity, and breakdown by technology

The development of the electricity supply sector is characterised by a dynamically growing renewable energy market and an increasing share of new renewable electricity, mainly from solar PV. The additional electricity demand caused by accelerated electric cooking and electric vehicles under the M-1.5°C scenario will greatly benefit new renewables, whereas hydro power will continue to generate bulk electricity for industry and export.

By 2035, the share of new renewable electricity production will remain > 90% and increase to 100% by 2050 under the M-1.5°C scenario. The installed capacity of new renewables will reach about 5.5 GW in 2030 and 40.5 GW in 2050.

Table 32 shows the comparative evolution of Malawi's power generation technologies over time. Solar PV will be the main power source. The continuing growth of solar PV and additional wind power capacities will lead to a total capacity of 38 GW, compared with 0.5 GW hydro power, under the M-1.5°C scenario. It will lead to a high share of variable power generation and demand-side management, and the management of electric vehicle charging and other storage capacities, such as stationary batteries and pumped hydro power. The development of smart-grid management will be required from 2025 onwards to increase the power system's flexibility for grid integration, load balancing, and a secure supply of electricity.

Figure 23: Breakdown of electricity generation by technology

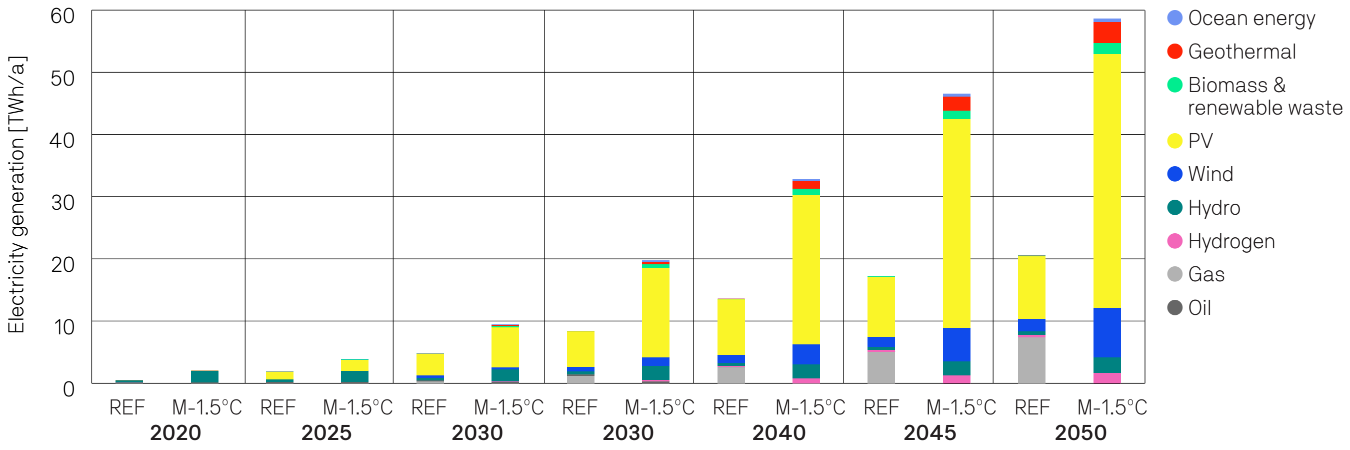


Table 29: Projection of renewable electricity generation capacities

Generation Capacity [GW]		2020	2030	2035	2040	2050
Hydro	REF	0	0	0	0	1
	M-1.5°C	0	0	0	1	1
Biomass	REF	0.0	0.1	0.032	0.1	0.1
	M-1.5°C	0.0	0.1	0.141	0.2	0.4
Wind	REF	0	0.3	1	1.3	2.1
	M-1.5°C	0.0	0.4	2	4.2	9.9
PV	REF	0	3.5	6	9.0	10.1
	M-1.5°C	0.0	4.5	5	16.8	28.7
Total	**REF**	**1**	**5**	**8**	**14**	**21**
	M-1.5°C	**1**	**6**	**13**	**23**	**41**

5.2.3 Energy supply for cooking and industrial process heat

Today, bio-energy meets over 90% of Malawi's energy demand for fuel-based cooking and heating. Dedicated support instruments are required to ensure its dynamic development, particularly the development of electric cooking stoves, renewable heating technologies for buildings, and renewable process heat production. In the M-1.5°C scenario, fuel-based cooking (mainly firewood and LPG) will be replaced by electric cooking stoves. The increased electricity used for e-cooking will increase the electricity demand but will replace a significant amount of bio-energy (firewood), the efficiency of which is low. Under M-1.5°C, the use of heat pumps as one of the leading new heating supply technologies will accelerate, and direct electric heating, such as radiators, will be introduced, but only as an interim measure between 2025 and 2030. These will be exchanged for heat pumps at the end of their lifetimes.

- Energy efficiency measures will help to reduce the currently growing energy demand for heating, especially building standards.
- In the industry sector, solar collectors, geothermal energy (including heat pumps), and electricity and hydrogen from renewable sources will increasingly substitute for fossil-fuel- and biofuel-fired systems.

Figure 24: Projection of heat supply by energy carrier (REFERENCE and M-1.5°C scenarios)

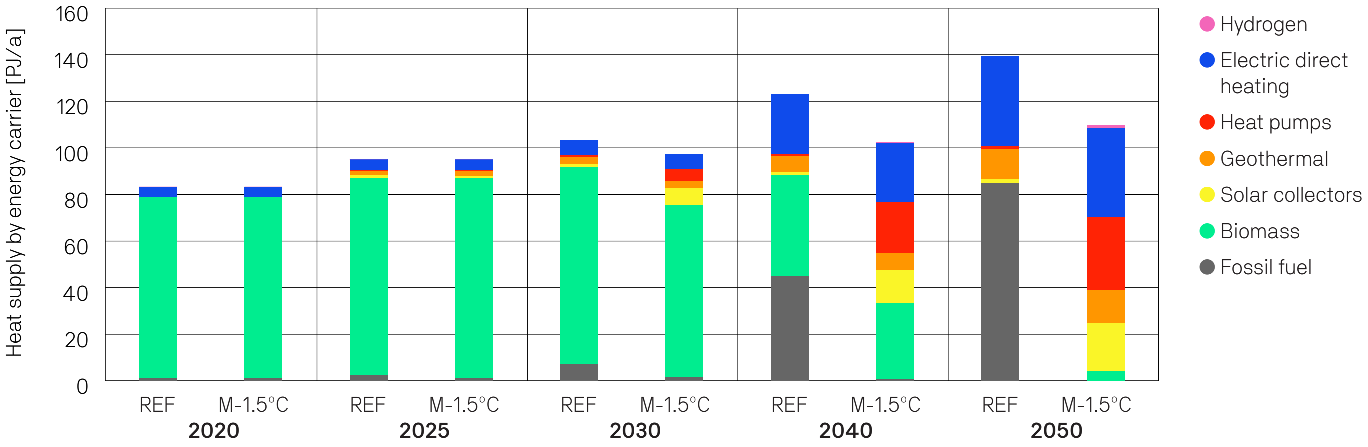


Table 30: Projection of renewable heat supply (cooking and process heat)

Supply (in PJ/a)		2020	2025	2030	2040	2050
Biomass	REF	78	85	85	44	0
	M-1.5°C	78	86	74	33	4
Solar Thermal Collectors	REF	0	1	1	1	2
	M-1.5°C	0	1	7	14	21
Heat Pumps (electric & geothermal)	REF	0	0	1	1	1
	M-1.5°C	0	0	5	22	31
Geothermal	REF	0	2	3	7	13
	M-1.5°C	0	2	3	7	14
Direct Electrical Heating	REF	4	5	6	25	39
	M-1.5°C	4	5	6	25	39
Total	**REF**	**83**	**95**	**103**	**123**	**139**
	M-1.5°C	**83**	**95**	**97**	**103**	**110**

Table 30 shows the development of different renewable technologies for heating in Malawi over time. Biomass will remain the main contributor, with increasing investments in highly efficient modern biomass technology. The installed capacity is presented in Table 31. After 2030, a massive increase in solar collectors and growing proportions of geothermal and environmental heat, as well as electrical heat and some limited renewable hydrogen for industrial process heat, will compensate for the phase-out of fossil fuels. The M-1.5°C scenario includes many efficient heat pumps, which can also be used for demand-side management and load flexibility (see also section 6.7.2.).

Table 31: Installed capacities for renewable heat generation

Capacity (in GW)		2020	2025	2030	2040	2050
Biomass	REF	48	53	59	64	66
	M-1.5°C	48	51	52	25	2
Geothermal	REF	0	1	2	3	6
	M-1.5°C	0	2	3	7	15
Solar Heating	REF	0	3	3	10	25
	M-1.5°C	0	8	13	26	39
Heat Pumps (electric and geothermal)	REF	0	2	2	5	27
	M-1.5°C	0	3	8	51	77
Total	**REF**	**82**	**95**	**105**	**128**	**150**
	M-1.5°C	**82**	**97**	**109**	**135**	**155**

5.2.4 Transport

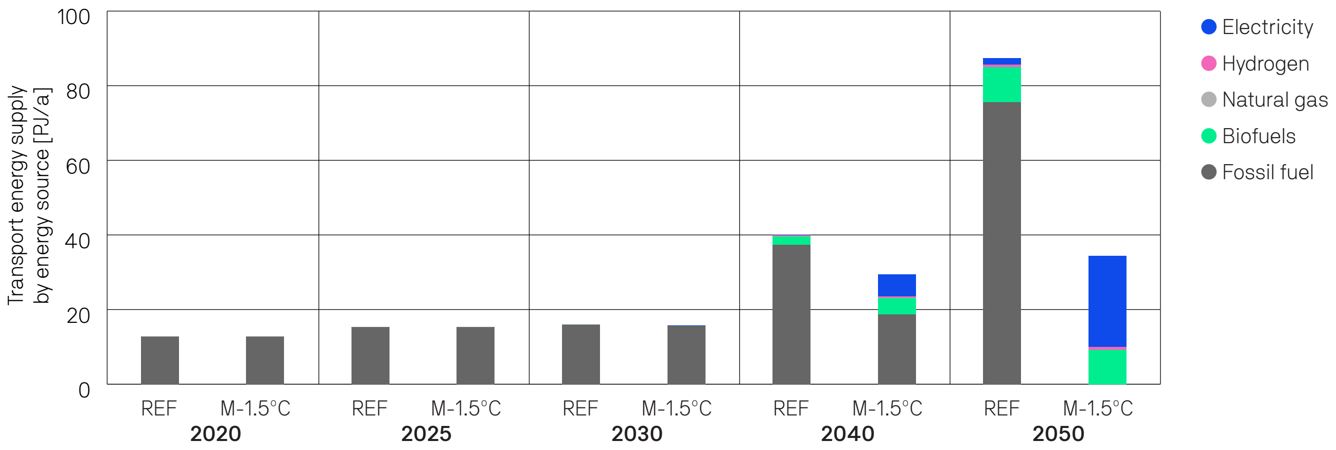
A key target in Malawi is to introduce incentives for people to support the transition towards electric mobility, especially in urban and semi-urban regions. It is also vital that transport use shifts to efficient public transport modes, such as rail, light rail, and/or electric buses, especially in the large expanding metropolitan areas.

Highly efficient propulsion technology, with plug-in hybrid and battery-electric power trains, will bring large efficiency gains. However, the infrastructural changes and addition of new power lines mean that electric mobility is assumed to have an increased role in road transport after 2035 under the M-1.5°C scenario. The M-1.5°C scenario will achieve the total decarbonisation of the transport sector in Malawi by 2050. More details about the assumptions made to calculate the development of the transport demand and supply are documented in section 2.5.

Table 32: Projection of transport energy demand by mode [PJ/a]

Transport Mode			2020	2025	2030	2040	2050
Rail	REF	[PJ/a]	0	0	0	0	0
	M-1.5°C	[PJ/a]	0	0	0	0	0
Road	REF	[PJ/a]	13	15	16	40	87
	M-1.5°C	[PJ/a]	13	15	16	27	34
Domestic Aviation	REF	[PJ/a]	0	0	0	0	0
	M-1.5°C	[PJ/a]	0	0	0	0	0
Total	**REF**	[PJ/a]	**13**	**15**	**16**	**40**	**87**
	M-1.5°C	[PJ/a]	**13**	**15**	**16**	**27**	**34**

Figure 25: Final energy consumption by transport under two scenarios

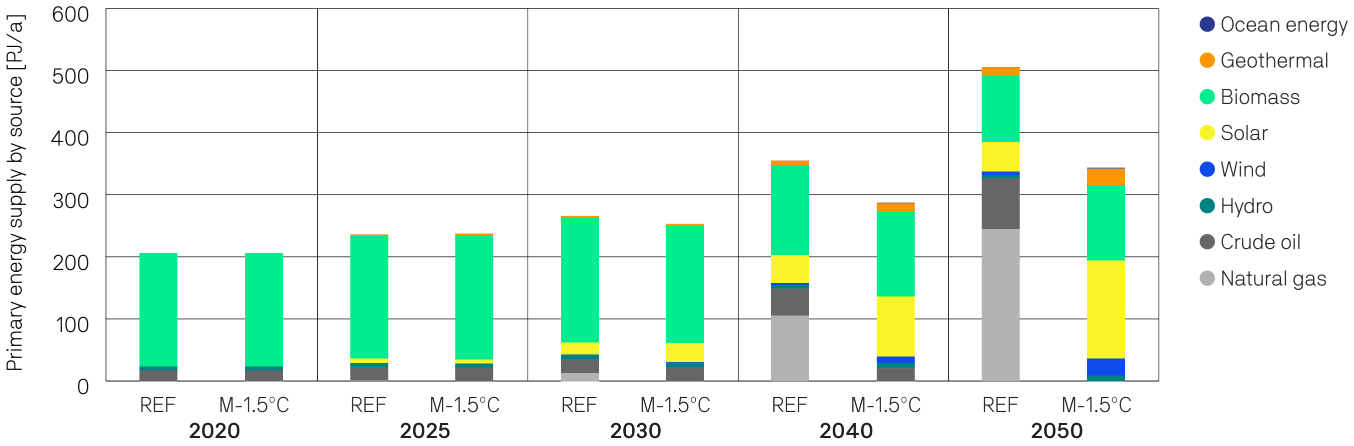


5.2.5 Primary energy consumption

Based on the assumptions discussed above, the resulting primary energy consumption under M-1.5°C is shown in Figure 26. The M-1.5°C scenario will result in primary energy consumption of around 345 PJ in 2050.

The M-1.5°C scenario aims to phase-out oil in the transport sector and oil for industrial use as fast as is technically and economically possible, through the expansion of renewable energies. The fast introduction of very efficient vehicle concepts in the road transport sector will replace oil-based combustion engines. This will lead to an overall renewable primary energy share of 100% in 2050 in the M-1.5°C scenario (non-energy consumption is included).

Figure 26: Projection of total primary energy demand by energy carrier (including electricity import balance)

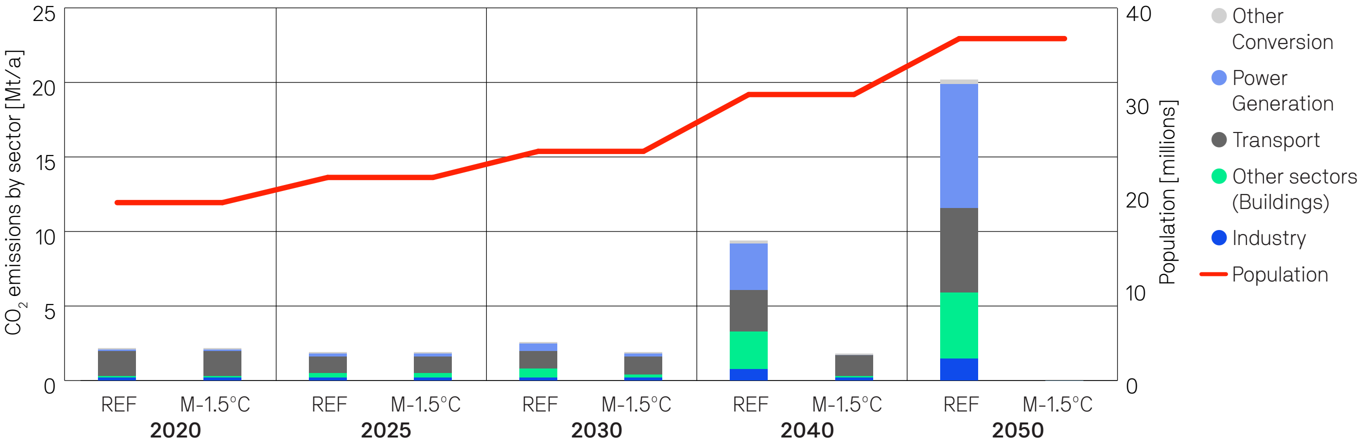


5.2.6 CO_2 emissions trajectories

The M-1.5°C scenario will reverse the trend of increasing energy-related CO_2 emissions after 2025, leading to a reduction of about 20% relative to 2020 by 2030 and of about 28% by 2040 (see Figure 27). In 2050, full decarbonisation of Malawi's energy sector will be achieved under the M-1.5°C scenario. The REFERENCE scenario will lead to annual emissions of 19.8 $MtCO_2$ – identical to the BAU scenario in Malawi's updated NDC of 2021.

In the M-1.5°C scenario, the cumulative emissions will sum to 50.3 Mt in 2020–2050 compared with 438.8 Mt CO_2 for the REFERENCE scenario.

Figure 27: Development of CO_2 emissions by sector



5.2.7 Cost analysis

Future costs of electricity generation

Figure 28 shows that introducing new generation capacities will increase the average electricity generation costs due to new investments, and consequently, additional capital costs will be required.

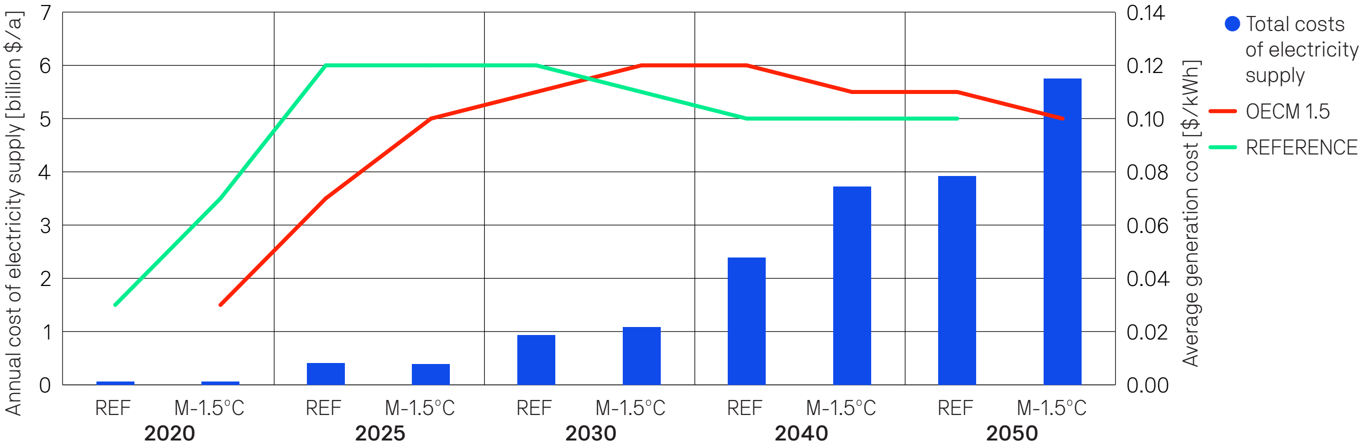
The solar PV capacity will increase from just under 200 MW in 2022 to 28,680 MW between 2020 and 2050under the M-1.5°C scenario. The reason for this high generation capacity is the far-reaching electrification strategy to replace fossil and biofuels with electricity for cooking, heating, and transport.

The M-1.5°C scenario has a cost advantage until 2030 compared with the REFERENCE scenario. Between 2030 and 2040, electricity generation costs are calculated to be around 25% above the REFERENCE scenario due to accelerated investment in renewable power generation capacities.

The full cost of generation will be about 190 trillion MWK/kWh (US$0.11/kWh) under the M-1.5°C scenario in 2030, when no consideration is given to the integration costs for storage or other load-balancing measures. By 2050, the M-1.5°C scenario will lead to average electricity generation costs of 156 trillion MWK/kWh (US$.09/kWh), equal to the estimated generation costs under the REFERENCE scenario.

Malawi's total electricity supply costs will increase with the increasing electricity demand. The M-1.5°C pathway will have the highest total electricity costs, but these will directly replace bio-energy and oil fuel costs.

Figure 28: Development of total electricity supply costs and specific electricity generation costs



Investments in power generation

Under the M-1.5°C scenario, Malawi will invest in new power generation – mainly solar PV. Here, the main difference between the M-1.5°C scenario and the other scenarios is the investment in other technologies, such as fossil gas, under the REFERENCE.

The onshore wind potential of Malawi is 195 GW (Scenario 1) or 83 GW (Scenario 2) in regions with annual average wind speeds of 5.0–14.0 m/s at 100 m height. The electrification of remote villages under the M-1.5°C pathway is mainly based on solar PV mini-grids with (battery) storage systems. However, wind energy systems can and should play a role at some limited locations. The generation pattern differs from that of solar, and will therefore reduce the energy storage requirements because electricity generation is distributed throughout the day and is not limited to daylight hours.

Figure 29: Shares of cumulative investment in power generation, M-1.5°C scenario, 2020–2050 [billion US$]

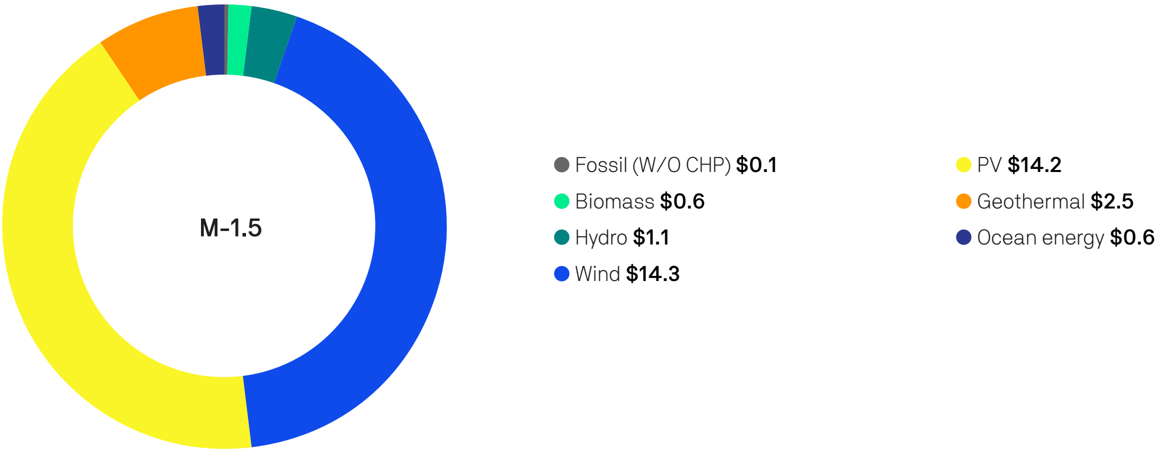
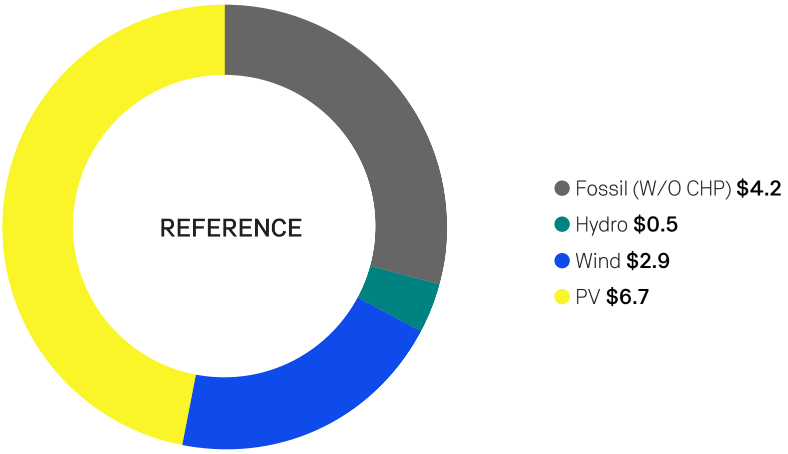


Figure 30: Shares of cumulative investment in power generation, REFERENCE scenario, 2020–2050 [billion US$]



The investment in solar PV under the M-1.5°C scenario will amount to around 24 trillion MWK (US$14.2 billion) over 30 years. This electricity will primarily be used to replace biomass for cooking and heating and to charge various electric vehicles, from two- and three-wheeler vehicles to cars and small delivery trucks.

Table 33: Investment costs in new power generation under the M-1.5°C and REFERENCE scenarios (exchange rate: 1 trillion MWK = US$0.0065, November 2024)

	2020–2050		Annual Average	
M-1.5°C	**MWK trillion**	**[billion US$]**	**MWK trillion**	**[billion US$]**
Hydro	1.9	1.1	0.1	0.0
Biomass	1.1	0.6	0.0	0.0
PV	24.1	14.2	0.8	0.5
Wind	24.4	14.3	0.8	0.5
Fossil & other	5.5	3.2	0.2	0.1
Total	56.9	33.5	1.9	1.1
	2020–2050		**Annual Average**	
REFERENCE	**MWK trillion**	**[billion US$]**	**MWK trillion**	**[billion US$]**
Hydro	0.8	0.5	0.0	0.0
Biomass	0.0	0.0	0.0	0.0
PV	11.5	6.7	0.4	0.2
Wind	5.0	2.9	0.2	0.1
Fossil & other	7.1	4.2	0.2	0.1
Total	**24.4**	**14.4**	**0.8**	**0.5**

Future investments in the heating sector

The main difference between the M-1.5°C pathway and other pathways is the significant variety in bio-energy use and the diversification of heating technologies. Electrical heat pumps, geothermal heat pumps, and solar thermal applications for space and water heating and drying will lead to a considerable reduction in demand for biogas and solid biomass, and will therefore reduce fuel costs. Figure 31 shows the shares of cumulative investments in the heating sector between 2020 and 2050 under the M-1.5°C scenario, for comparison with the cumulative investments under the REFERENCE scenario (Figure 32).

Figure 31: Cumulative investments in heating technologies (generation) under the M-1.5°C scenario for 2020–2050 [billion US$]

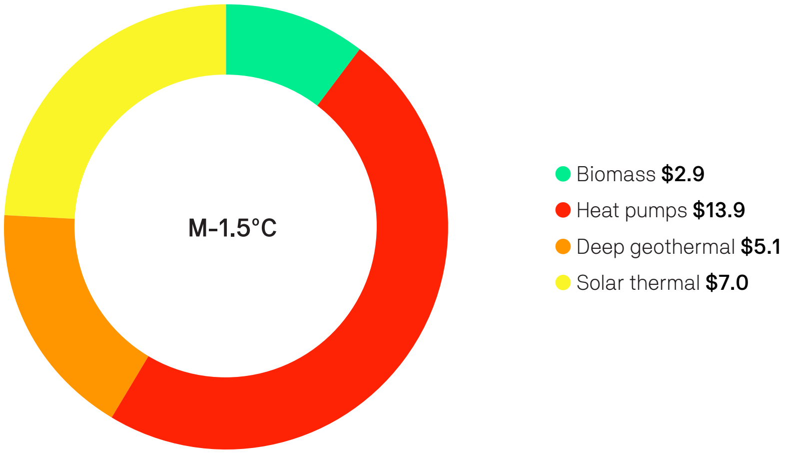


Figure 32: Cumulative investments in heating technologies (generation) under the REFERENCE scenario for 2020–2050 [billion US$]

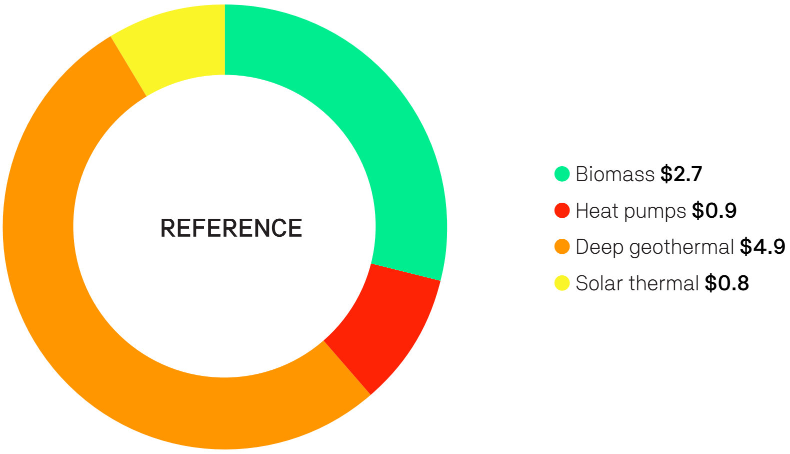


Table 34 shows the cumulative investment and fuel costs for heating and power generation for the M-1.5°C scenario and the REFERENCE scenario. The overall heat sector costs – investment and fuel costs – over the entire scenario period until 2050 will be US$152 billion under the M-1.5°C scenario (about US$5 billion annually), the same as under the REFERENCE scenario.

Table 34: Malawi – heating, electricity, and fuel: cumulative investment and fuel costs in 2020–2050 and average annual investments

	2020-2050		Average Annual Investments	
M-1.5°C	**MWK trillion**	**US$ billion**	**MWK trillion**	**US$ billion**
Cumulative heating investment	49.1	28.9	1.6	1.0
Cumulative fuel costs	152.9	90	5.1	3.0
Cumulative electricity investment	56.9	33.5	1.9	1.1
Total cumulative costs	**259**	**152**	**9**	**5**
	2020-2050		**Average Annual Investments**	
REFERENCE	**MWK trillion**	**US$ billion**	**MWK trillion**	**US$ billion**
Cumulative heating investment: 2020–2050	15.8	9.3	0.5	0.3
Cumulative fuel costs: 2020–2050	216.7	127.5	7.2	4.2
Cumulative electricity investment: 2020–2050	24.4	14.4	0.8	0.5
Total cumulative costs: 2020–2050	**257.0**	**151.2**	**8.6**	**5.0**

5.2.8 Investment and fuel cost savings

Finally, the fuel costs for the power, heating, and transport sectors are presented.

All three sectors will reduce fuel cost over time because electricity generation is based on renewable energy – with significant shares of solar, but also wind power. However, increased electrification will lead to higher investment costs in power generation and higher overall electricity supply costs for Malawi.

The M-1.5°C scenario will require an investment of MWK 57 trillion (US$33.5 billion) in power generation (Table 33) and 29 trillion MWK (US$41 billion) in heat generation. Therefore, the total investment in power and heat generation capacities adds up to MWK 86 trillion (US$74 billion) (Table 34).

Table 35 shows all the accumulated fuel costs by sector and scenario and the calculated fuel cost savings in 10-year intervals between 2020 and 2050 in Malawian kwacha and US dollars.

Additional power generation investments will be compensated by fuel cost savings in the decade in which they are made. Fuel cost savings under the M-1.5°C scenario relative to the REFERENCE scenario across the entire scenario period will be MWK 322.4 trillion (US$189.7 billion). Additional investment in power and heat generation (including cooking) under the M-1.5°C scenario will pay-off the entire investment in comparison of the M-1.5˚C pathway.

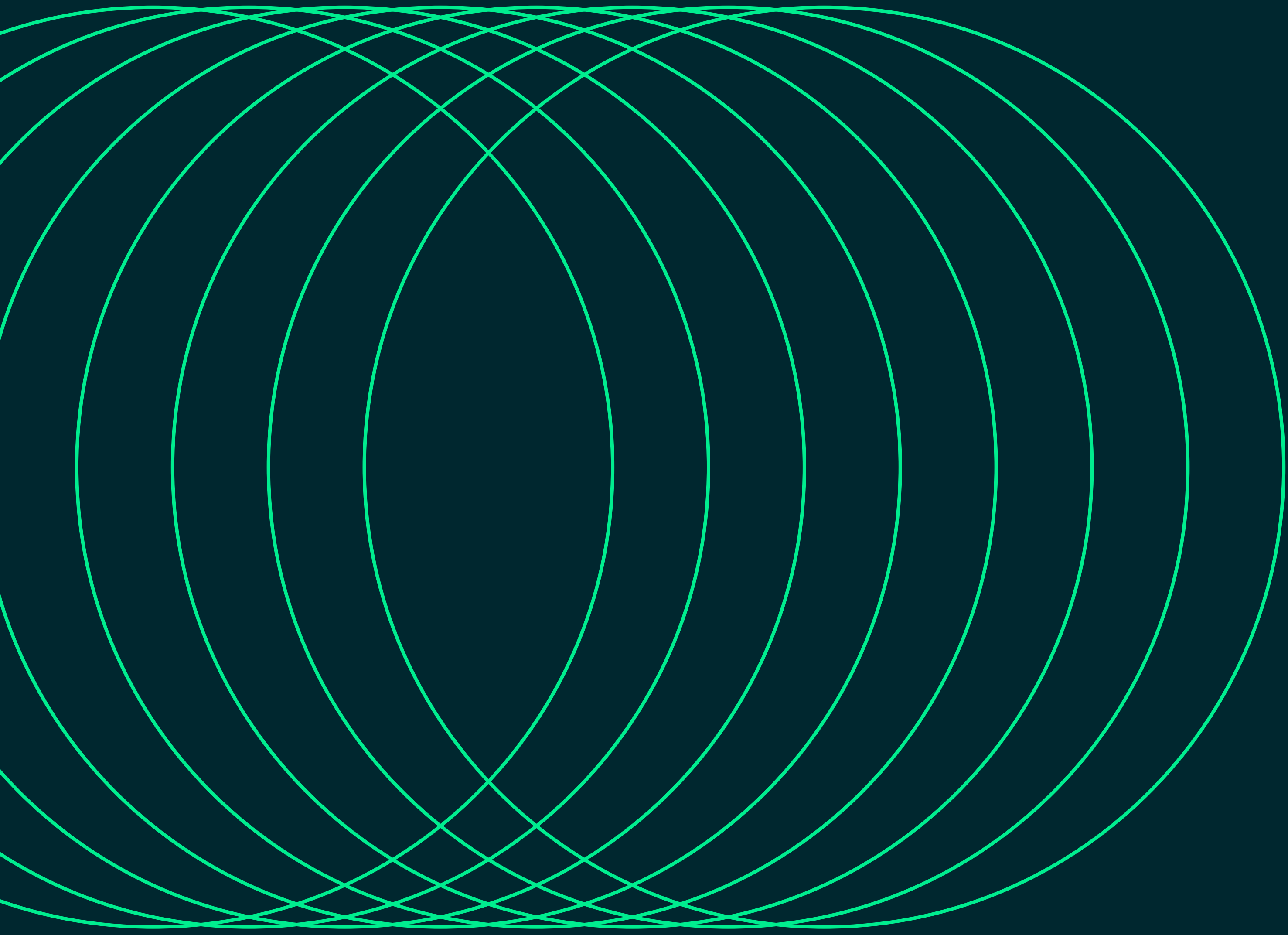
In countries with a high level of energy access, fuel cost savings almost always refinance the investment in new renewable energy generation. Malawi, however, has a low energy access rate and therefore, additional investment in energy infrastructure are required in any case.

Table 35: Cumulative fuel costs under the REFERENCE and M-1.5°C scenarios in billion US$ and trillion MWK

		2020–2030		**2031–2040**		**2041–2050**		**2020–2050**		**2020–2050 average per year**	
REFERENCE		**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**
Power	Total	55.5	32.6	58.3	34.3	45.4	26.7	170.5	100.3	5.7	3.3
Heat	Total	3.5	2.0	15.3	9.0	36.1	21.2	55.6	32.7	1.9	1.1
Transport	Total	60.2	35.4	79.7	46.9	97.2	57.2	249.3	146.6	8.3	4.9
Summed Costs		**119.2**	**70.1**	**153.3**	**90.2**	**178.7**	**105.1**	**475.4**	**279.6**	**15.8**	**9.3**
		2020–2030		**2031–2040**		**2041–2050**		**2020–2050**		**2020–2050 average per year**	
M-1.5°C		**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**	**[Trillion MWK]**	**Billion USD**
Power	Total	1.2	0.7	2.3	1.3	3.1	1.8	6.5	3.8	0.2	0.1
Heat	Total	54.0	31.8	48.6	28.6	34.2	20.1	136.8	80.5	4.9	2.9
Transport	Total	2.8	1.6	4.1	2.4	2.7	1.6	9.5	5.6	0.3	0.2
Summed Costs		58.0	34.1	55.0	32.4	39.9	23.5	152.9	90.0	5.5	3.2
Difference REFERENCE versus M-1.5°C		**61.2**	**36**	**98.3**	**57.8**	**138.8**	**81.7**	**322.4**	**189.7**	**10.3**	**6.1**

6

Malawi: Power Sector Analysis



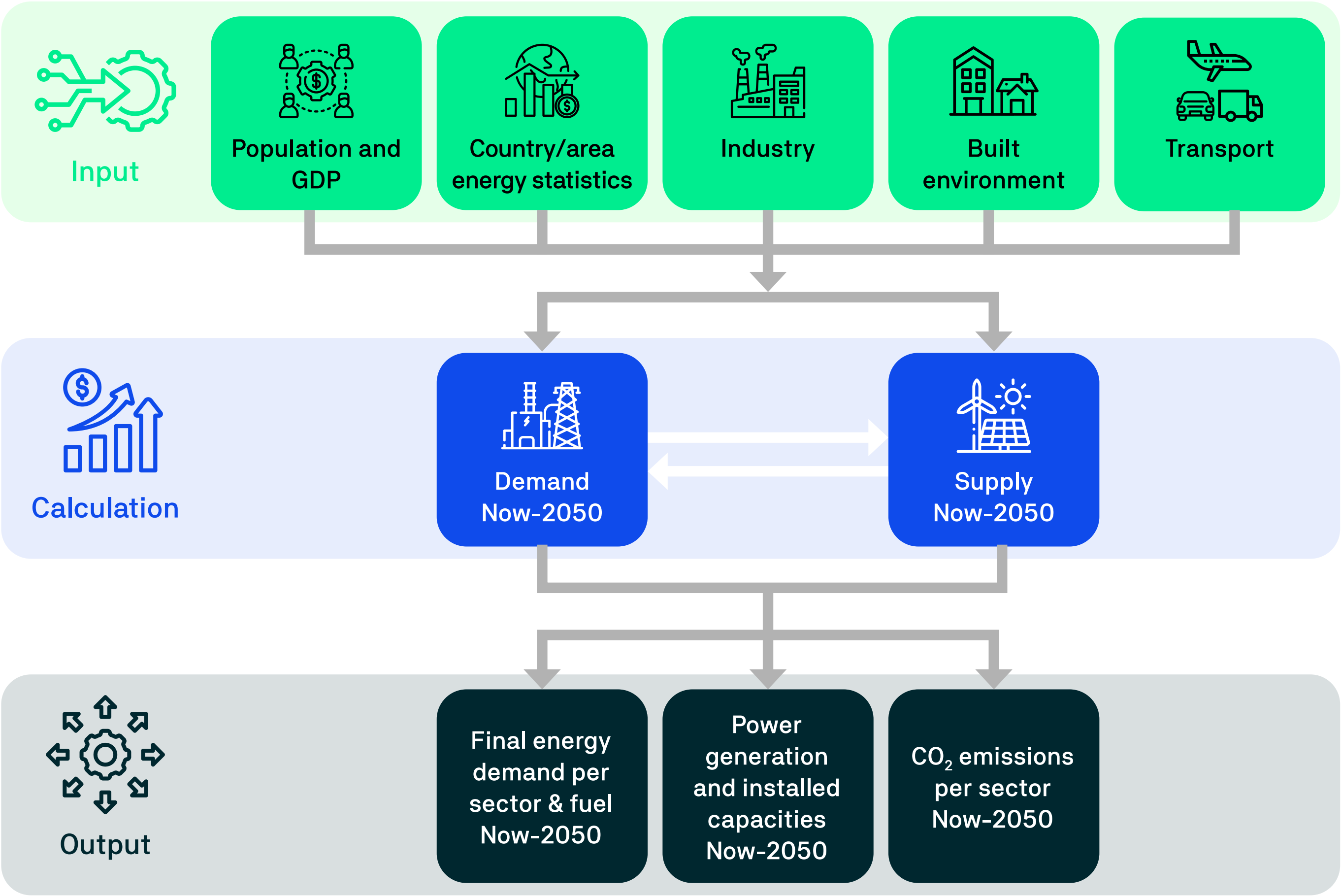
In this chapter, we summarise the results of the hourly simulations of the long-term scenarios (Chapter 5). The One Earth Climate Model (OECM) calculates the demand and supply by cluster. This section provides an overview of the possible increase in electrical load under the M-1.5°C scenario, and the consequent increased demand on the power grid transmission capacities, possible new inter-provincial connections, and/or expanded energy storage facilities.

6.1 Power Sector Analysis – Methodology

After the socio-economic (Chapter 2) and geographic analyses (Chapter 3) and the development of the long-term energy pathways for Malawi (Chapter 5), the power sector was analysed with the OECM in a third step.

The energy demand projections and resulting load curve calculations are important factors, especially for power supply concepts with high shares of variable renewable power generation. Calculation of the required dispatch and storage capacities is vital for the security of supply. A detailed bottom-up projection of the future power demand, based on the applications used, demand patterns, and household types, will allow a detailed forecast of the demand. Understanding the infrastructure needs, such as power grids combined with storage facilities, requires an in-depth knowledge of the local loads and generation capacities. However, this model cannot simulate frequencies or ancillary services, which would be the next step in a power sector analysis.

Figure 33: Overview – energy demand and load curve calculation module



6.1.1 Meteorological data

Variable power generation technologies are dependent on the local solar radiation and wind regimes. Therefore, all the installed capacities in this technology group are connected to cluster-specific time series. The data were derived from the database renewables.ninja (RE-N DB 2018)[57], which allows the hourly power output from wind and solar power plants at specific geographic sites throughout the world to be simulated. Weather data, such as temperature, precipitation, and snowfall, for the year 2019 were also available. To utilise climatisation technologies for buildings (air-conditioning, electric heating), the demand curves for households and services were connected to the cluster-specific temperature time series.

The demand for lighting was connected to the solar time series to accommodate the variability in the lighting demand across the year, especially in northern and southern global regions, which have significantly longer daylight periods in summer and very short daylight periods in winter.

For every region included in the model, hourly output traces are utilised for onshore and/or offshore wind, utility solar, and roof-top solar PV. Given the number of clusters, the geographic extent of the study, and the uncertainty associated with the prediction of the spatial distribution of future generation systems, a representative site was selected for each of the five generation types.

Once the representative sites were chosen, the hourly output values for typical solar arrays and wind farms were selected from the database of Stefan Pfenninger (at ETH Zurich) and Iain Staffell (renewable.ninja, see above). The model methodology used by the renewable.ninja database is described by Pfenninger and Staffell (2016a and 2016b)[58], and is based on weather data from global re-analysis models and satellite observations (Rienecker and Suarez 2011[59]; Müller and Pfeifroth 2015[60]).

Whereas in practice, the utility-scale solar sites will be optimised and the tilt angle is selected within a couple of degrees of the latitude of the representative site, an indicative system tilt of 35° was used for the generation trace for utility systems. For the roof-top solar calculations, this was left at the default of 35° because it is likely that the panels will match the tilt of the roof.

The onshore wind outputs were calculated at an 110 m hub height to reflect the potential wind resource available in each cluster and that is available to modern turbines with sufficiently high hub heights. It is possible that commercial hub heights will exceed this height before 2050, but 110 m was deemed appropriate and indicative of the resource available to both current and future generators. A turbine model of Vestas V90 2000 was used.

Limitations: Solar and wind resources can differ within one cluster. Therefore, the potential generation output can vary within a cluster and across the model period (2020–2050).

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57 RE-N DB (2018) Renewables.ninja, online database of hourly time series of solar and wind data for a specific geographic position, data viewed and downloaded between September and October 2022, https://www.renewables.ninja/

58 Pfenninger S, Staffell I (2016a) Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data. Energy 114:1251–1265. doi: 10.1016/j.energy.2016.08.060

Pfenninger S, Staffell I (2016b), Using bias-corrected reanalysis to simulate current and future wind power output. Energy 114:1224–1239. doi: 10.1016/j.energy.2016.08.068

59 Rienecker MM, Suarez MJ, Gelaro R, Todling R, et al. (2011). MERRA: NASA's modern-era retrospective analysis for research and applications. Journal of Climate, 24(14):3624–3648. doi: 10.1175/JCLI-D-11-00015.1

60 Müller R, Pfeifroth U, Träger-Chatterjee C, Trentmann J, Cremer R (2015). Digging the METEOSAT treasure – 3 decades of solar surface radiation. Remote Sensing 7:8067–8101. doi: 10.3390/rs70608067

6.1.2 Power Demand Projection and Load Curve Calculation

The OECM power analysis model calculates the development of the future power demand and the resulting possible load curves. The model generates annual load curves with hourly resolution and the resulting annual power demands for three different consumer sectors:

- Households
- Industry and business
- Transport

Although each sector has its specific consumer groups and applications, the same set of parameters was used to calculate the load curves:

- Electrical applications in use
- Demand pattern (24 h)
- Meteorological data
  - Sunrise and sunset, associated with the use of lighting appliances
  - Temperature and rainfall, associated with climatisation requirements
- Efficiency progress (base year 2018 for 2020–2050, in 5-year steps)
  - Possibility that the electricity intensity data for each set of appliances will change, e.g., change from compact fluorescent lamp (CFL) light bulbs to light-emitting diodes (LEDs) as the main technology for lighting

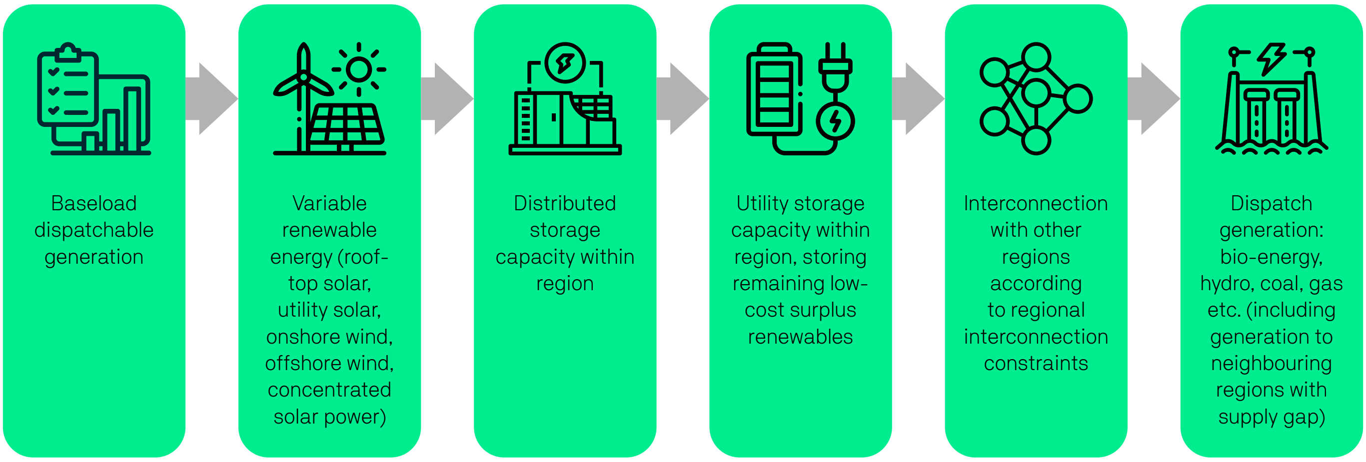
6.1.3 The OECM 24/7 Dispatch Module

The OECM 24/7 dispatch module simulates the physical electricity supply with an interchangeable cascade of different power generation technologies. The cascade starts with the calculated load in megawatts for a specific hour. The first-generation technology in the exogenous dispatch order provides all the available generation, and the remaining load is supplied by the second technology until the required load is entirely met. In the case of oversupply, the surplus variable renewable electricity can either be moved to storage, moved to other regions (including export to other countries if specified in modelling assumptions), or – if neither option is available – curtailed. In the case of undersupply, electricity will be supplied from either available storage capacities, neighbouring clusters, or dispatch power plants.

The key objective of the modelling is to calculate the load development by region, modifying the residual load (load minus generation), theoretical storage, and interconnection requirements for each cluster and for the whole survey region. It would be possible to produce an estimate of the additional required storage capacity required to avoid supply gaps, but in reality, the economic battery capacity is a function of the storage and curtailment costs, as well as the availability of dispatch power plants and their costs. Unmet generation is reported and, given the scope of this research, it is assumed to be derived from interconnections to neighbouring countries under the future decarbonisation pathway.

Figure 34 provides an overview of the dispatch calculation process. The model allows for the dispatch order to be changed in terms of the order of renewables and the dispatch power plant, as well as in terms of the order of the generation categories: variable, dispatch generation, or storage. In this analysis, a fixed dispatch order was used in the analysis: minimum baseload dispatch, variable renewables, distributed generation sources, utility storage, interconnection with other regions to allow exchange of low-cost surplus renewables, and finally remaining additional dispatch generation that was not dispatched as part of the minimum baseload output requirement. 'Baseload dispatch generation' represents the minimum amount of a fossil-fuel power plant capacity that must run for either economic, technical, or system requirements – for example, a coal plant may only be able to run at 30% capacity due to technical limits on generation equipment (thermal operating windows, minimum temperature), whereas a gas plant may be asked to run at 5% or 10% capacity throughout the day because the electrical system operator requires sufficient levels of inertia in a high-renewables system (the remaining capacity is then dispatched as required in step six of the dispatch order).

Figure 34: Dispatch order within one cluster



The following key parameters are used as input: generation capacity by type, the demand projection and load curve for each cluster, interconnections with other clusters, and meteorological data, from which solar and wind power generation are calculated with hourly resolution. The installed capacities are derived from the long-term projections described in Chapter 5, and the resulting annual generation in megawatt hours is calculated based on meteorological data (for solar and wind power) or dispatch requirements.

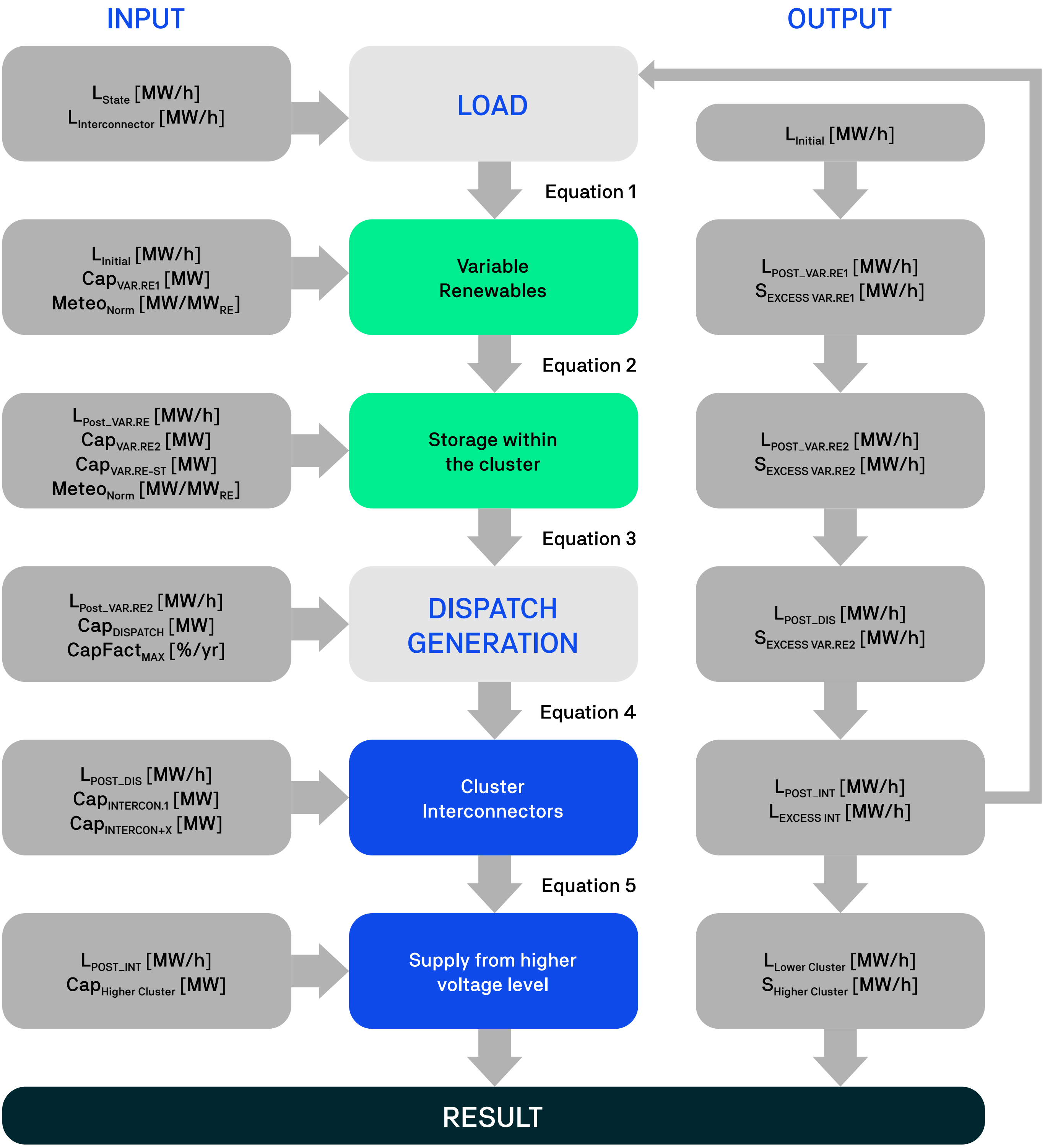
Overview: input and output – OECM 24/7 energy dispatch model

Figure 35 gives an overview of the input and output parameters and the dispatch order. Although the model allows changes in the dispatch order, a 100% renewable energy analysis always follows the same dispatch logic. The model identifies excess renewable production, which is defined as the potential wind or solar PV generation that exceeds the actual hourly demand in MW during a specific hour. To avoid curtailment, the surplus renewable electricity must be stored with some form of electrical storage technology or exported to a different cluster. Within the model, excess renewable production accumulates through the dispatch order. If storage is present, it will charge the storage within the limits of the input capacity. If no storage is included, this potential excess renewable production is reported as 'potential curtailment' (pre-storage). It is assumed that a certain number of behind-the-meter consumer batteries will be installed, independently of the system requirements.

Limitations

The calculated loads are not optimised in terms of local storage, the self-consumption of decentralised producers of solar PV electricity, or demand-side management. Therefore, the actual loads may be well below the calculated values.

Figure 35: Overview – Input, output, and dispatch order



6.2 Development of Power Plant Capacities

As discussed in Chapter 3, Malawi has substantial untapped renewable energy potential, and its renewable energy potential far exceeds the projected energy demand requirements by 2050. Despite Malawi's abundance of renewable energy resources, the nation has historically experienced significant levels of energy poverty, relying on a limited mix of fossil fuels, hydro power, and some renewables to supply electrical loads.

It should be noted that our projection aims to leverage Malawi's significant solar potential to alleviate energy poverty and limits on a sufficient supply of electricity for its people. The M-1.5°C pathway aims to install approximately 29 GW of solar capacity by 2050, and although this is an ambitious amount of growth relative to today's renewable (and overall total) capacity, this works out to be less than 2% of the 1,715 GW potential mapped out by the methodology described in Section 3. Therefore, under the M-1.5°C scenario, solar PV generators will expand rapidly and provide increasing electricity, and wind generation is also projected to increase significantly across Malawi.

Malawi has some existing electrical infrastructure, which will allow the addition of more renewable capacity in conjunction with sufficient areas of land with suitable resources. This is attractive from a project development perspective, and could enable the large expansion of Malawi's generation asset capacity. Given the limited existing electrical infrastructure, it could be expected that the majority of PV systems installed will be off-grid or micro-grid-connected, so in this chapter, we model a decarbonisation pathway propelled by distributed solar and battery storage installations. In terms of Malawi's renewable electricity potential, the vast majority of future generation will be solar PV, together with notable amounts of onshore wind.

The average solar PV market will range around 242 MW per year between 2021 and 2035 and peak at around 1,350 MW per year between 2035 and 2045. Malawi's wind power market requires a relatively constant installation rate between 2035 and 2050, requiring upwards of 450 MW installed/year until 2050. Malawi's renewable potential is diverse and not just limited to solar and wind power. The values for the full range of renewable technologies are shown below (Table 36).

Table 36:Malawi – average annual changes in installed power plant capacity (main technologies)

	Power generation: average annual changes in installed capacity [MW/a]						Annual average	
	2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021–2035	2021–2050
Biomass	6	8	15	18	18	17	9	14
Hard coal	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Fuel cell	0	3	16	33	36	23	6	19
Natural gas	-2	0	0	0	0	0	-1	0
Oil	18	5	5	-51	0	0	9	-4
Diesel	0	0	0	0	0	0	0	0
Hydro	9	14	20	12	5	18	14	13
Wind onshore	0	81	293	463	515	630	125	330
Wind offshore	0	0	0	0	0	0	0	0
PV	242	659	1,117	1,350	1,342	1,026	673	956
Geothermal	0	3	8	24	26	31	3	15
Total CHP plants	0	0	0	0	0	0	0	0
Biomass & waste	0	0	0	0	0	0	0	0
Hard coal	0	0	0	0	0	0	0	0
Lignite	0	0	0	0	0	0	0	0
Fuel cell	0	0	0	0	0	0	0	0
Gas	0	0	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0	0	0
Oil	0	0	0	0	0	0	0	0

6.3 Results: Utilisation of Power Generation Capacities

Table 37 and Table 38 show the installed capacities for roof-top and utility-scale solar PV under the M-1.5°C scenario in 2030 and 2050, respectively. The distributions are based on the regional solar potential for utility PV and according to the population distribution for roof-top solar, with the aim of generating electricity where the demand is located. Whereas roof-top solar PV power generation is modular and can be installed close to the consumer or even integrated into buildings, utility-scale solar PV is usually further away from settlements and close to medium- or high-voltage power lines. Furthermore, solar power plants (= utility-scale PV) have double-digit megawatt capacities, on average. The best solar resources are located in the central and southern areas of the country, as shown in Chapter 3.

Table 37: Malawi M-1.5°C pathway – Installed photovoltaic capacity by region (2030)

M-1.5°C Pathway 2030	Northern Region	Central Region	Southern Region
	[MW]	[MW]	[MW]
Photovoltaic (roof-top)	411	1,352	1,393
Photovoltaic (utility-scale)	451	451	451

Table 38: Malawi M-1.5°C pathway – installed photovoltaic capacity by region (2050)

M-1.5°C Pathway 2030	Northern Region	Central Region	Southern Region
	[MW]	[MW]	[MW]
Photovoltaic (roof-top)	2,614	8,604	8,860
Photovoltaic (utility-scale)	2,868	2,868	2,868

In this analysis, we have assumed that approximately 70% of the solar PV installations are distributed or roof-top and that 30% are utility-scale power plants (noting that distributed PV can still be connected to the grid and is not equivalent to a stand-alone system). This is because distributed solar assets can be taken up rapidly across society and do not require the same level of engineering and finance work associated with the design, financing, and construction of a large utility power plant. As discussed in previous sections, Malawi also has notable wind generation potential, and this is leveraged under the M-1.5°C scenario. Table 41 shows the percentage of variable generation and the dispatchable sources of power supplied throughout the year (renewable and fossil fuel disaggregated). The percentages shown in Table 41 are the output of the hourly power system modelling outlined in section 6.1, and are therefore indicative of not only the capacity factors, but also the need for generation dependent upon the demand in each hour. Table 39 shows the categorisation of the various generation types used in the power system modelling.

Table 39: Categorisation of generation types

Generation Type	Fuel	Technology
Limited Dispatchable	Fossil, uranium	Coal, brown coal/lignite, (including co-generation)
	Renewable	Hydro power, bio-energy, and synthetic fuels, geothermal, concentrated solar power (including co-generation)
Dispatchable	Fossil	Gas, oil, diesel (including co-generation)
		Storage systems: batteries, pumped hydro power plants, hydrogen- and synthetic-fuelled power and co-generation plants
	Renewable	Bio-energy, hydro, hydrogen- and synthetic-fuelled power, and co-generation plants
Variable	Renewable	Solar photovoltaic, onshore wind

The percentages shown in Table 40 are dependent upon multiple variables: the amount of existing fossil fuel infrastructure, projected solar and wind distributions (based on regional potential), roof-top solar adoption (based on population), and the installation rate of new renewable capacity.

Table 40 demonstrates that although in the short term, dispatchable renewables such as hydro power will play an important role in powering the central and southern regions, ultimately all regions will transition towards a very high variable renewable penetration supply, due to Malawi's excellent solar and wind resources. The regional differences in the power system shares – the ratio between dispatchable and non-dispatchable variable power generation – will require a combination of interchange, storage facilities, and demand-side management incentives to ensure that all regions maintain sufficient levels of supply security and system strength. In the long term, grid operators and market bodies must develop their systems and market arrangements to enable the functioning of Malawi's grid at very high levels of renewable penetration (> 90% supplied energy throughout the year). This is particularly the case for Malawi, given the high levels of solar generation that will be installed due to the disparity in resources between solar and wind.

Table 40: Malawi – power system shares of annual generation values by technology group

		M-1.5°C		
Percentage of Annual Supply [%/a]		**Variable Renewable**	**Dispatch Renewable**	**Dispatch Fossil**
Northern Region	2020	1%	29%	70%
	2030	94%	1%	5%
	2050	98%	2%	0%
Central Region	2020	0%	98%	2%
	2030	80%	18%	2%
	2050	97%	3%	0%
Southern Region	2020	0%	96%	3%
	2030	84%	14%	2%
	2050	99%	1%	0%

Experience from other jurisdictions indicates that the integration of large shares of variable power generation will require a more flexible market framework. Those power plants requiring high-capacity factors because of their technical limitations in terms of flexibility ("base-load power plants") will not be desirable to future power system operators. Therefore, capacity factors will become more a technical characteristic than an economic necessity, with flexibility being a commodity that increases in value over time. Future power systems must be structured to leverage the characteristics of each of the different generator categories to ensure sufficient supply and system strength. In Malawi's case, hydro power plants could be operated as peaking plants to cover supply gaps when there are insufficient solar and wind resources, until sufficient levels of interconnection and storage are in place and fossil fuels are no longer required as a backup generation source.

6.4 Results: Analysis of Peak Load, Generation, and Residual Load

Table 41 shows the calculated annual demand, maximum and minimum loads, and the calculated average load by region for 2020, which are based on the historical calibration process that was used as a baseline to develop the M-1.5°C pathway projections. To validate the data, we compared our results with the real-time data published by the local grid operator.

The statistical data for each province for 2020 were not available at the time of writing, so the values are estimates and may vary by ± 10% for each data point. However, the published online data for Malawi's power sector is within the same order of magnitude. The calculation of the maximum, minimum, and average loads for the base year (2020/21) are important to calibrate the OECM and to compare the values with future projections.

Table 41: Malawi – regional breakdown of modelled demand and generation values for 2020

Region	Maximum Load (Domestic) [MW]	Maximum Generation [MW]	Minimum Load [MW]	Average Load [MW]
Northern Region	52	52	16	25
Central Region	200	160	52	83
Southern Region	206	206	54	89
Malawi-wide Total (non-coincident values)	**458**	**418**	**122**	**197**

The calculated load for each province depends on various factors, including local industrial and commercial activities. A detailed analysis of the planned expansion of economic activity for each province was beyond the scope of this research, and the results are therefore estimates based on the regional distribution of GDP and population.

As discussed in the methodology above, the 24/7 model analyses both generation and load on a regional basis. Therefore, the data outputs can be analysed to provide insight into the maximum hourly demand and generation values for each region. The results indicate that the peak load will increase five-fold across each region by 2030 under the M-1.5°C pathway, and the maximum regional load will increase 24-fold in each region by 2050. The increase in load is attributable to the increase in the overall electricity demand with the electrification of cooking, heating, and cooling. Furthermore, the growth of the commercial and industrial sectors of Malawi and the electrification of transport will lead to a sharp increase in the electricity demand and therefore the overall power load.

Table 42 also shows data on the levels of residual load in each region, where 'residual load' is defined as the load remaining after the local generation from variable renewable sources within the analysed region is exhausted. In general, a positive residual load implies that a region has an insufficient amount of variable supply to cover the demand in each time step, and therefore that demand must be met from other supply sources (dispatchable renewables, dispatchable fossil fuel, storage, interconnection). The maximum residual value is the largest positive value experienced throughout the year, indicating the largest mismatch between variable renewable generation and demand to occur during the modelling period.

Table 42: Malawi – projection of load, generation, and residual load until 2050

Malawi		**M-1.5°C**			
Development of Load and Generation		**Maximum Load [MW]**	**Maximum Generation [MW]**	**Maximum Residual Load [MW]**	**Peak Load Increase [%]**
Northern Region	2020	52	52	52	-
	2030	291	625	178	560%
	2050	1,334	5,117	877	2565%
Central Region	2020	200	160	199	-
	2030	1,053	1,399	619	527%
	2050	4,836	10,001	3,335	2418%
Southern Region	2020	206	206	205	100%
	2030	1,085	1,453	945	527%
	2050	4,980	10,354	3,478	2417%
Malawi-wide Total (non-coincident values)	**2020**	**458**	**418**	**456**	**-**
	2030	**2,429**	**3,477**	**1,742**	**538%**
	2050	**11,150**	**25,472**	**7,690**	**2467%**

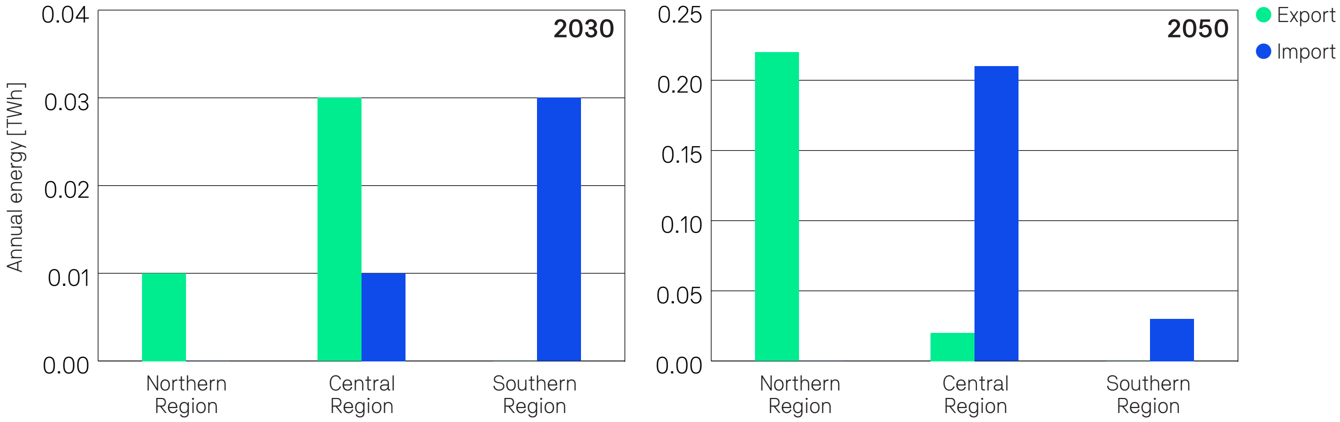
In our analysis, power generation is assumed to grow proportionally to the increase in the overall demand across Malawi. A more detailed assessment of the exact locations of power generation will be required to optimise the required expansion of transmission grids and to ensure that generation capacity is installed appropriately to provide system security and strength, congruent with grid operator requirements. A more detailed consideration of generation placement could lead to a reduction in the residual load to avoid over- and/or undersupply in each province. Either increased grid capacity or more storage systems will be required.

6.5 Results: Inter-regional Exchange of Capacity

As discussed in section 2.2, a map of Malawi's electricity infrastructure was used as the basis for the power sector analysis. This map was used to establish interconnection limits, with some growth in the network interconnection infrastructure assumed to allow power flow by region as Malawi's economy and nation grows. As discussed in the methodology of section 6.1, the 24/7 model distributes renewable generation capacity according to the regional potential, whereas load is distributed according to the relevant indicator (residential demand – population distribution, whereas industrial load is distributed according to GDP). The locations of existing hydro power plants are fixed, and the installation of new capacities will depend upon geographic conditions and nature conservation requirements. Malawi's existing gas generation assets were distributed according to their current locations based on publicly available information.[61] In this way, an accurate reconstruction of Malawi's electricity transmission infrastructure and generation was implemented in the 24/7 MATLAB model.

The following results show the levels of annual energy exchange (TWh/a) on a regional basis for each of the years modelled, demonstrating which regions are able to export power to surrounding regions, and which regions are more dependent upon their neighbouring areas for import (Figure 38; note that the x-axis is not constant). Also see the dispatch order in section 6.1.3.

Figure 36: Annual inter-regional exchange capacities, showing total import and export across the year for each region (2030, 2050)



An interesting result is that the southern region is a net importer of electricity in 2030, and the central region is an exporter. This occurs even though the central region has the majority of Malawi's population and thus a higher load. This shows that the central region is projected to experience strong growth in solar and renewables installed, such that it can export surplus to the southern region. As expected, this will change by 2050, when the strong demand growth mentioned in section 6.4 comes to fruition, and the central region becomes a net importer of power from its neighbours.

To prevent unnecessary expansion of the electricity grid, the projected increase in the regional electricity demand and additional electricity export plans should inform the expansion of the local power generation capacity. Grid operators can utilise a mixture of load management via demand-side measures and the storage to manage the exports and imports shown in Figure 38. Note that the interconnection values displayed above are dependent upon the assumed levels of distributed and utility storage, because interconnection comes after these energy sources in the fixed dispatch order. The results described above indicate that Malawi should be able to leverage the existing transmission infrastructure to enable the transition pathway set out in the M-1.5°C OECM model. By appropriately managing the transition, ensuring sufficient levels of storage and load management (demand-side, electric vehicle charging), government bodies and grid-operating agencies will leverage the existing transmission infrastructure, while ensuring the security of supply for the regions. It was beyond the scope of this project to analyse the low- and medium-voltage-level distribution systems, so the quantification of the effects of micro-grids and other such arrangements are also beyond the scope of this report.

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[61] Open Infrastructure Map, Malawi Power Plant Statistics, accessed September 2024: https://openinframap.org/stats/area/Malawi

6.5.1 Limitations

The calculated loads are not optimised in terms of local storage, self-consumption by decentralised producers of solar PV electricity, or demand-side management. Therefore, the calculated loads may differ from the actual values. Furthermore, the calculated export/import loads to neighbouring countries are not included in the regional interconnection analysis discussed in this chapter. Peak load and peak generation events do not occur at the same time, so their values cannot simply be summed. Moreover, peak loads can vary across all regions and appear at different times. Therefore, to sum all the regional peak loads will only provide an indication of the peak load for the whole country. The maximum residual load[62] shows the maximum undersupply in a region and indicates the maximum load that will be imported into that region. This event can only be several hours long, so the interconnection capacity might not be as high as the maximum residual load indicates. Optimising the interconnections for all regions was beyond the scope of this analysis. To guarantee the security of supply, the residual load of a region must be supplied by one or more of the following options:

- Imports from other regions through interconnections;
- Battery storage facilities on site at solar PV installations and for electric vehicles;
- Available back-up capacities, such as gas peaking plants;
- Load- and demand-side management.

In practice, security of supply will be achieved with a combination of several measures and will require the in-depth analysis of regional technical possibilities.

6.6 Results: Annual variation in renewable energy generation

Solar and wind power generation has different annual variation patterns, which are dependent on the climate zone and geographic location. This section provides a high-level analysis of the electricity import and/or export needs under the M-1.5°C scenario with high shares of variable power generation. In practice, the electricity demand (‘load’) and generation (‘supply’) must be balanced at all times. If local generation cannot meet the demand, electricity must be either imported from other regions or taken from existing storage facilities. If generation is higher than the load, either the surplus electricity can be exported to other regions or stored, the load increased, or production reduced. The term ‘curtailment’ is defined as the forced reduction of electricity generation, and is the energy generated by renewable resources in excess of demand that cannot be stored or transmitted within Malawi to other regions in a given time. To determine the annual distribution of Malawi’s solar and wind power generation, generation and expected load were simulated with 1-hourly resolution (8760 h/a).

Figure 37 shows the weekly values of supply imbalances in terms of both curtailment and the additional imports required. During times of high generation, generation exceeds demand (green line); the red line shows when demand exceeds generation (i.e., when additional electricity must be imported into Malawi). The modelling of Malawi’s transmission connections to its neighbouring countries (currently Mozambique, although they could be expanded during the modelling horizon) was beyond the scope of this study. Therefore, a further study is required to assess the availability of electricity imports at those times, or to investigate other measures that could be undertaken to address supply imbalances. The operation of a state-of-the-art power system for a grid dominated by renewably generated power requires a combination of demand- and generation-side management, export and import from neighbouring regions, and a cascade of different storage technologies, such as batteries, hydro pump storage, and at a later date, hydrogen/synthetic fuel production. This is beyond the scope of the 24/7 modelling undertaken.

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[62] Residual load is the load remaining after the local generation within the analysed region is exhausted. There could be a shortage of load supply due to the operation and maintenance of a coal power plant or reduced output from wind and/or solar power plants.

Figure 37: Malawi: weekly electricity imports and exports in 2030 and 2050

The results shown in Figure 38 underpin the significant amount of change that can be expected under the M-1.5°C scenario, with the values on the y-axis changing by a factor of *11*. In 2030, there will be increased use of renewable energy, but there will be limited curtailment because this capacity supplies a small proportion of the overall load and is only added to meet marginal increases in load and some reductions in fossil-fuel consumption. However, by 2050, a significant build-out of capacity is required to cover the energy demand throughout the year, leading to overbuilding/excess capacity throughout the year. The combination of significant increases in demand (both peak and annual consumption increase 24–26-fold) and the reliance on variable resources means that a consistently high level of excess power is produced throughout the year, given the load assumptions used in the 24/7 modelling. Because load and generation necessarily vary across time, the coincidence of peak demand and peak generation cannot be assumed, and unmet demand can even occur in weeks with excess renewable generation.

Figure 39 also highlights the importance of having sufficient battery storage, because unmet demand is kept to a minimum by having an ambitious storage projection. Optimisation of the system was beyond the scope of this work, so further research is required to understand the trade-offs between the oversupply of renewable generation, additional investments in storage options, the assessment of additional inter-regional and international electrical transmission infrastructure, and demand-side management.

Figure 38: Weekly values for inter-province transmission – analyses for 2030 and 2050

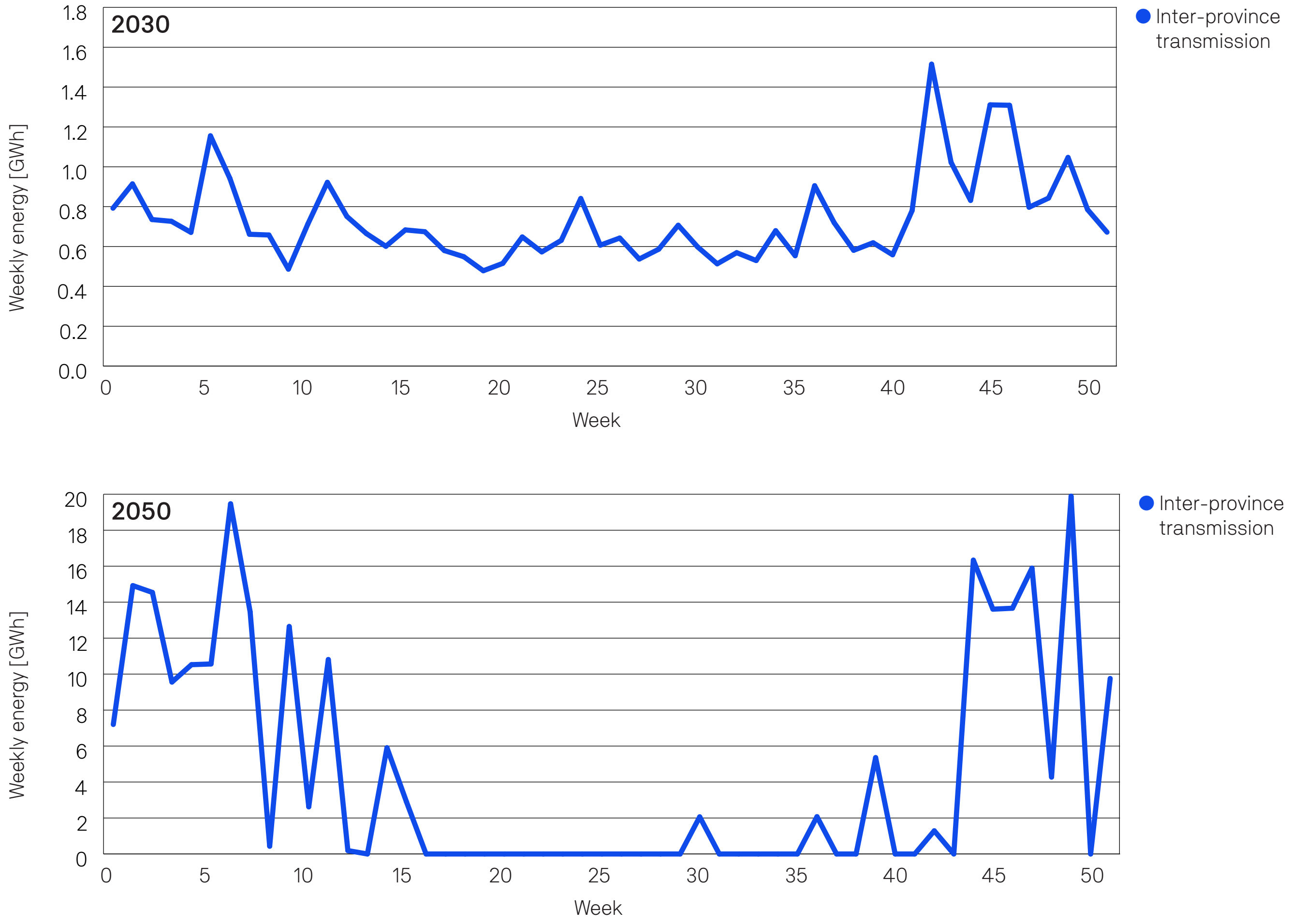
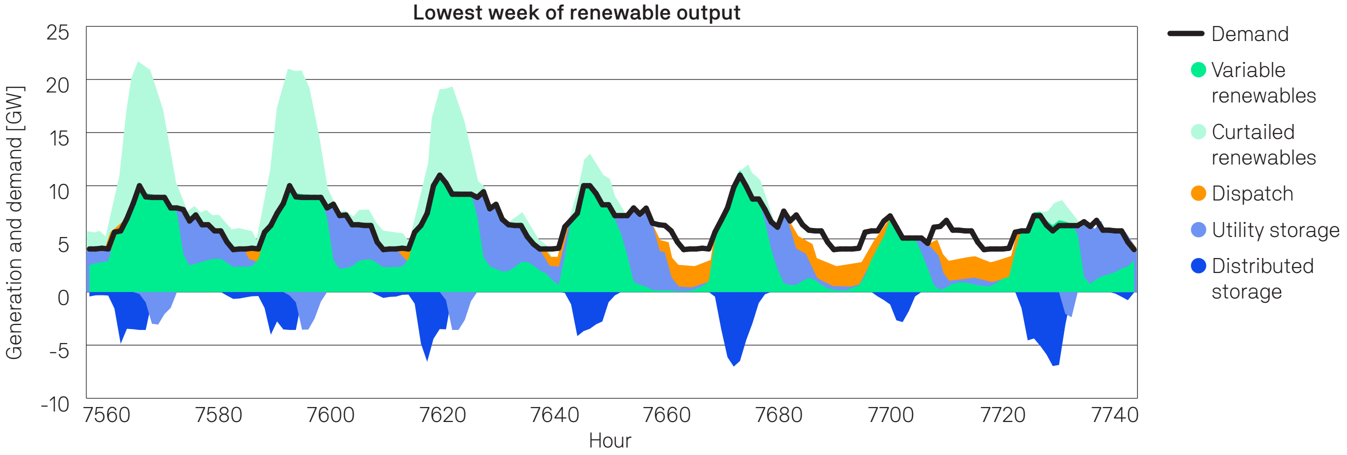


Figure 39 shows the weekly values for the inter-province transmission requirements under the M-1.5°C scenario in 2030 and 2050, which are a function of the import and export requirements on the national level. Therefore, these figures show the weekly variation in the inter-provincial energy exchanges shown in Figure 38. It can be inferred from this figure that during the period between 2030 and 2050, the interconnection between regions will be relied upon less consistently throughout the year, *yet* to a greater proportion of its maximal capacity rating. Energy exchange between regions becomes more important in times of greater imbalance between supply and demand. For example, the inverse relationship between interconnection and unmet demand in 2050 occurs in periods close to the beginning and end of the year.

In the following section, we look deeper into two representative weeks from the 2050 modelling undertaken, contrasting the weeks of lowest and highest renewable generation relative to demand. The purple areas (Figure 39 and Figure 40) show the charging (negative values) and discharging (positive values) of storage systems. Brown areas specify times with dispatch needs (import or export of electricity) and green areas show renewable power generation. The white areas, which indicate periods of unmet demand, are further investigated. Therefore, the analysis of the variation in local annual solar and wind power generation is the first step in determining the technical storage requirements.

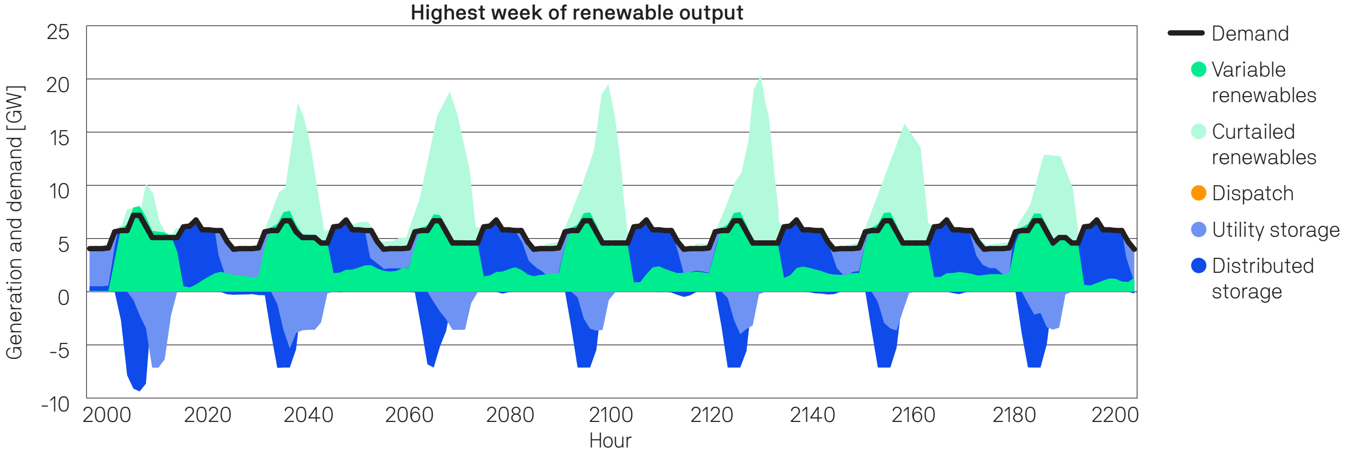
The modelling undertaken – based on historical meteorological data (section 6.1.1) – indicates that there may be cloudy periods of the year in Malawi that are accompanied by low wind speeds, as shown in Figure 39, and power generation from both wind and solar is at the lowest levels within the entire year (occurring in October). The production of onshore wind generators is limited to low levels outside solar hours for several days, and the solar output is constrained to less than half the maximal output for the week. However, with high levels of storage, the effects of this lull are reduced, although supply gaps occur in the evenings for several days. This occurrence may be an anomaly given that only 1 years' worth of data were used in the analysis, and that consecutively low periods of wind were not characteristic of other weeks in October. Further analysis is required to examine the extent to which this could impact Malawi's security of supply.

Figure 39: Malawi – lowest renewable electricity production under the M-1.5°C scenario in 2050



The other extreme – a period with very high-power generation rates – occurred earlier in the year, around May. In this week, there is some wind generation in the evenings, but the excess generation is limited to the hours of solar generation, where overproduction during the middle of the day can be clearly seen (Figure 40). This figure indicates that having sufficient transmission to neighbouring countries (existing interconnections to Mozambique) could provide a significant economic benefit to Malawi through the export of excess generation. Excess generated power may also be utilisable for the generation of clean fuels and chemical feedstocks.

Figure 40: Malawi – highest renewable electricity production under the M-1.5°C scenario in 2050



As discussed, optimising the balance between generation assets, transmission infrastructure, and additional storage capacity is beyond the scope of the modelling undertaken. The following section provides insights into the usage of the projected levels of storage capacity assumed in the modelling undertaken.

6.7 Storage Requirements

6.7.1 Introduction

The quantity of storage required will be largely dependent upon the storage costs, grid expansion possibilities, and the generation mix itself. In terms of grid expansion, the geographic situation greatly influences the construction costs; crossing mountains, rivers, or swamps is significantly more expensive than crossing flat lands (Wei 2016)[63]. Furthermore, the length of the permission process and whether people will be displaced by grid expansions may make storage economically preferable to grid expansion, even though the current transmission costs are lower per megawatt–hour than the storage costs. Cebulla et al. (2018)[64] reported that "in general terms, photovoltaic-dominated grids directly correlate to high storage requirements, in both power capacity and energy capacity. Conversely, wind-dominated scenarios require significantly lower storage power and energy capacities, if grid expansion is unlimited or cheap". In an analysis of 400 scenarios for Europe and the USA, they also found that once the share of variable renewables exceeds 40% of the total generation, the increase in electrical energy storage power capacity is about 1–2 GW for each percentage of variable renewable power generated in wind-dominated scenarios and 4–9 GW for that in solar-PV-dominated scenarios.

When the shares of variable power generation exceed 30%, storage requirements increase. The share of variable generation will exceed 30% between 2025 and 2030 under the M-1.5°C scenario in all regions. Therefore, a smart-grid integration strategy that includes demand-side management and the installation of additional decentralised and centralised storage capacities must be established.

Over the past decade, the cost of batteries, especially lithium batteries, has declined significantly. However, solar PV costs have also declined significantly. Storage is economic when the cost per kilowatt-hour is equal to or lower than the cost of generation. Therefore, if storage costs are high, curtailment could be economic. However, there are several reasons for curtailment, including transmission constraints, system balancing, and economic reasons (NREL 2014)[65]. The California Independent System Operator (CISO)[66] defines economic curtailment during times of oversupply as a market-based decision. "During times of oversupply, the bulk energy market first competitively selects the lowest cost power resources. Renewable resources can 'bid' into the market in a way to reduce production when prices begin to fall. This is a normal and healthy market outcome. Then, self-scheduled cuts are triggered and prioritised using operational and tariff considerations. Economic curtailments and self-scheduled cuts are considered 'market-based'".

6.7.2 Analysis of Energy Storage

Although Malawi currently relies on dispatchable renewable generation (such as hydro power) for a significant proportion of electricity generation, the nominal capacity is limited when there are negligible amounts of storage capacity. According to the Global Pumped Hydro Atlas (ANU 2022)[67], Malawi has several high-quality pumped hydro sites, with the most attractive sites located in the southern region or on the border of the central and southern regions.

However, the successful implementation of pumped hydro projects is likely to be subject to barriers in Malawi, given their cost, complexity, and infrastructure requirements. Therefore, the M-1.5°C pathway does not rely heavily on the expansion of hydro power for generation or on pumped hydro storage for the development of storage capacity.

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[63] Wei W, et al. (2016) Regional study on investment for transmission infrastructure in China based on the State Grid data,10.1007/s11707-016-0581-4, Frontiers of Earth Science, June 2016.

[64] Cebulla et al. (2018), How much electrical energy storage do we need? A synthesis for the U.S., Europe, and Germany. Journal of Cleaner Production, February 2018, https://www.researchgate.net/publication/322911171_How_much_electrical_energy_storage_do_we_need_A_synthesis_for_the_US_Europe_and_Germany/link/5a782bb50f7e9b41dbd26c20/download

[65] Wind and Solar Energy Curtailment: Experience and Practices in the United States; Lori Bird, Jaquelin Cochran, and Xi Wang, National Renewable Energy Laboratory (NREL), March 2014, https://www.nrel.gov/docs/fy14osti/60983.pdf

[66] Impacts of renewable energy on grid operations, factsheet, https://www.caiso.com/documents/sb350study-renewableintegrationgridreliability-fastfacts.pdf

[67] ANU (2022) Australian National University, 100% Renewable Energy Group, Global Pumped Hydro Energy Storage Atlas, https://re100.eng.anu.edu.au/global/

Our analysis is undertaken on an hourly basis, so the modelling of demand spikes that occur for a limited time – from minutes to hours – are modelled at less-fine resolution, and peak demand is caused by heating/cooling loads in addition to the tendency of households to use more electricity in the morning and evening. Therefore, our model captures peaks, but these are smoother than would occur in reality, and the actual grid and storage capacity must react to those changes. In reality 'peak-shaving' could be used to avoid peak generation events. The term 'peak-shaving' refers to a reduction in the solar or hydro generation capacity in times of high production. Peak-shaving involves pro-actively managing solar generation by reducing the output – e.g., from utility-scale PV – to eliminate short-term spikes.

To build up the additional storage capacity required, we assume that a percentage of the solar PV capacity will be installed with battery storage. The suggested solar battery system must be able to store the entire peak capacity for 4 full-load hours. The M-1.5°C scenario uses an ambitious growth trajectory, such that on aggregate, sufficient battery capacity exists that the nominal storage depth (in GWh) is the same order of magnitude as the aforementioned ratio of aggregate solar capacity ´ 4 full-load hours (i.e., approximately 23 GW of utility battery storage by 2050).

The estimates provided for storage requirements also presuppose that variable renewables, such as solar PV and wind, will be first in the dispatch order, ahead all other types of power generation. Priority dispatch is the economic basis for investment in utility-scale solar PV and wind projects. The curtailment rates or storage rates will be significantly higher when priority dispatch is given to, for example, hydro power plants in 'base-load' generation mode. This case has not been calculated because it would involve a lack of investment in solar in the first place. With decreasing storage costs, as projected by Bloomberg (2019)[68], interconnections may become less economically favourable than batteries. The storage estimates provided are technology neutral and do not favour any specific battery technology.

Table 43 shows the storage assumptions utilised in the M-1.5°C scenario. Given that Malawi has limited capacity for pumped hydro storage, no specific level of economic curtailment was targeted. Instead, curtailment was allowed to remain as dependent upon the modelling assumptions, and the additional generation highlights Malawi's potential to export power to neighbouring countries and also become an important nation in the production of H_2 and other clean fuels. (Note: the H_2 value in Table 46 refers to the H_2 used for the generation of electricity and is therefore restrained to a low value).

The storage demands for micro-grids and off-grid systems must be calculated individually and is not part of this assessment. However, micro-grids always require either a storage system with a capacity large enough (in terms of both the electricity supply in kilowatt-hours and the required load in kilowatts) to bridge the gap in times of low or no generation possibilities.

Table 43: Malawi – calculated electricity storage capacities by technology and year

Storage Capacity	Units	2020	2025	2030	2035	2040	2045	2050
Battery – distributed	[MW]	-	0.2	1.3	3.5	5.7	7.9	11.5
Electric Vehicle – V2G	[MW]	-	0.0	0.0	0.0	0.0	0.0	0.0
Battery – utility scale	[MW]	-	0.2	1.3	3.5	5.7	7.9	11.5
Hydro Pump Storage	[MW]	-	0.0	0.0	0.0	0.0	0.0	0.0
H_2	[MW]	-	0.0	0.0	0.0	0.0	0.0	0.0
Total	**[MW]**	**-**	**0.4**	**2.6**	**6.9**	**11.3**	**15.8**	**23.0**

The outcomes of the above modelling assumptions are given below in Figure 41 and Table 44 These show that the assumed levels of utility storage are used consistently throughout the year, dealing with the kind of supply gaps described in section 6.6. This is also indicative of the shallow nature of the storage capacity used, because without long-term storage there is limited ability to shift energy generation from lull periods of variable power to high-demand periods.

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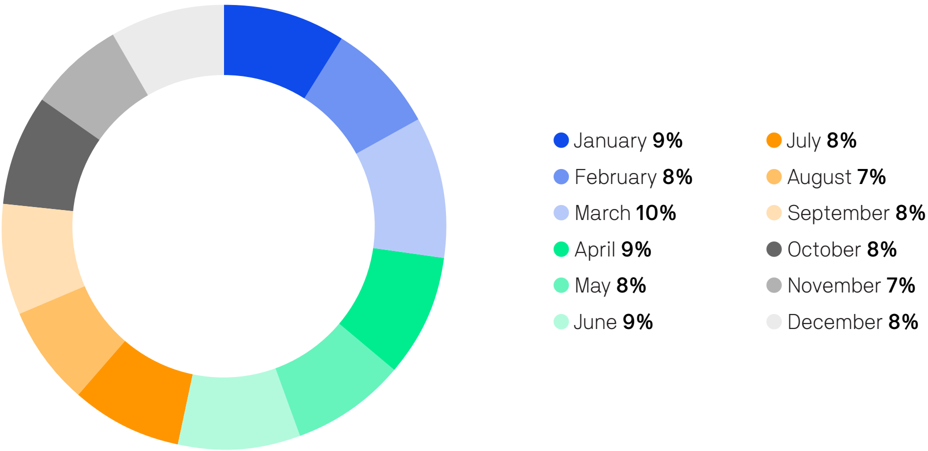
[68] Bloomberg (2019), A Behind the Scenes Take on Lithium-ion Battery Prices, Logan Goldi-Scot, Bloomberg NEF, March 5 2019, https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

Figure 41: Storage usage by month in 2050



The results shown in Table 44 are interesting, particularly because the battery storage capacity is distributed evenly across all regions. Table 47 shows that although the regions have similar levels of capacity, the northern region is only utilised to a small extent (4% of total annual used storage capacity), whereas the central and southern regions use their battery storage capacity to a much larger extent.

These results are understandable when viewed in the context of population, which in Malawi's case is the most significant driver of both demand and generation – due to household demand and the distributed solar systems powering these households. The southern and central regions both contain ~43% of Malawi's population within their boundaries (a total of 87% between the two). Because these areas have significant solar generation, household demand outside the hours of solar generation, and sufficient battery storage, these households and regions can remain more self-sufficient than the northern region in terms of their energy usage. These findings suggest that battery storage would be best allocated proportionally to the population (which also links to demand and solar capacity), which will reduce the need for overall storage capacity – thus reducing investment costs relative to the amount of battery capacity modelled under the M-1.5°C pathway.

Table 44: Storage usage – annual charge and discharge

	Total Charge [GWh]	Total Discharge [GWh]
Northern Region	-581	542
Central Region	-9,198	9,198
Southern Region	-5,178	5,149

6.7.3 Cost development – Battery storage technologies

Battery technologies have developed significantly over the past decade, and the global annual market increased from 700 MW in 2015 to close to 16,000 MW in 2021 (IEA-BAT 2024)[69]. The market is split roughly equally between grid-scale storage and 'behind-the-meter' storage for solar PV projects. The rapidly growing demand for electric vehicles has significantly accelerated the development of battery technologies, and manufacturing capacities have grown by double digits, with costs decreasing accordingly. The battery costs per kilowatt-hour storage capacity decreased from US$668 (trillion MWK 1,157,072) in 2013 to US$137 (trillion MWK 237,304) in 2020 – a reduction of 79% over the past 7 years. Bloomberg New Energy Finance estimates that battery costs will decline further to around US$58 (trillion MWK 100,464) by 2030.

6.7.4 Further research required

The calculation of the investment costs in the storage technologies that will be required after 2030 and by 2050 entails high levels of uncertainty, and would require both a range of scenarios and optimisations to provide meaningful insight into low-cost system solutions for Malawi. This level of detail is beyond the scope of this study. More-detailed storage technology assessments will be required if stand-alone grids are considered in the modelling of the M-1.5°C scenario.

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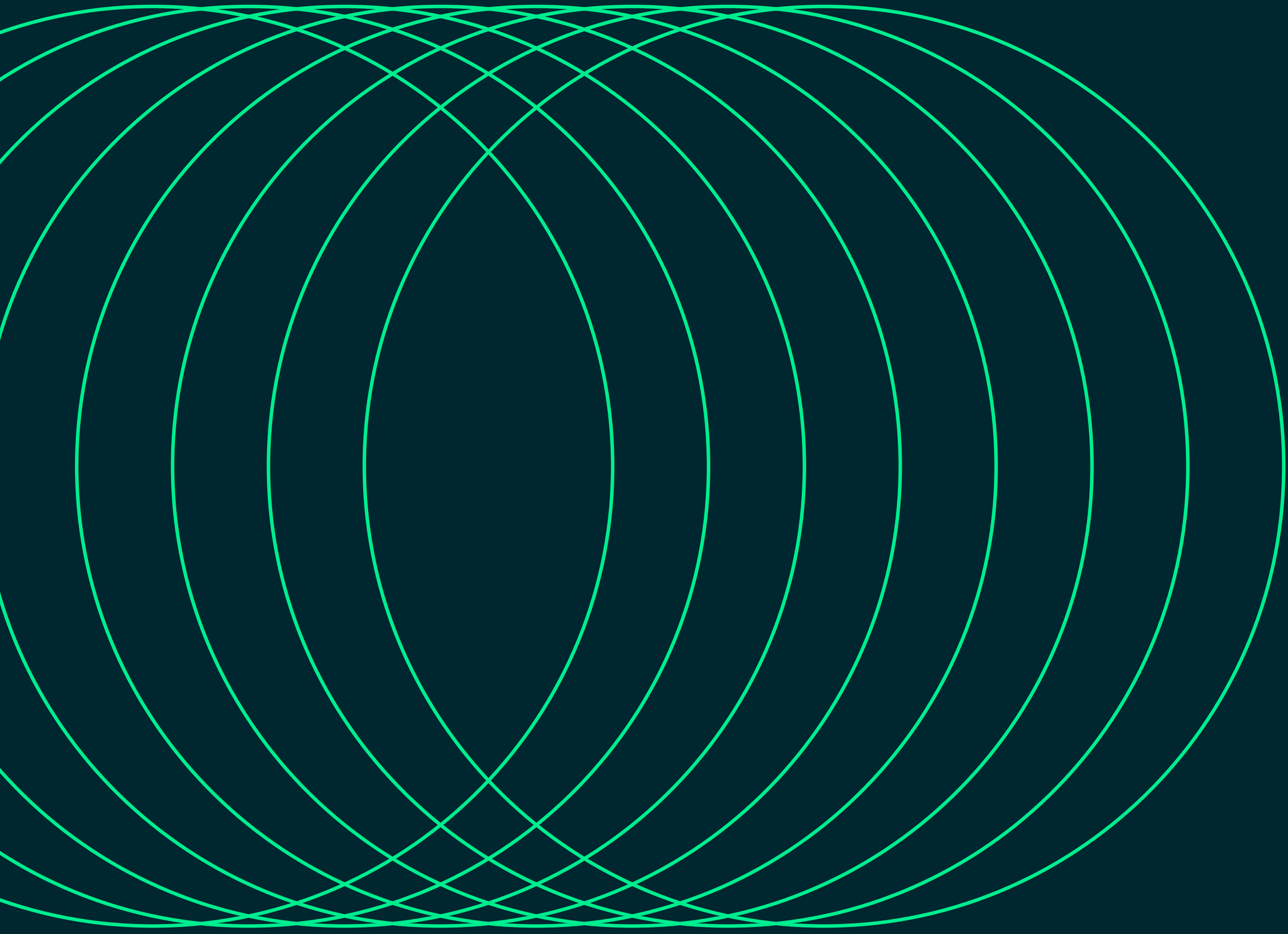
[69] IEA-BAT (2024) – website viewed April 2024. https://www.iea.org/reports/batteries-and-secure-energy-transitions

7

Malawi: Data Appendix



Malawi: Electricity generation [TWh/a] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Power plants	1	1	1	1	1	2	2	4	9	20	33	46	58
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
of which from H_2	0	0	0	0	0	0	0	0	0	0	1	1	2
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass (& renewable waste)	0	0	0	0	0	0	0	0	0	1	1	1	2
– Hydro	1	1	1	1	1	2	2	2	2	2	2	2	2
– Wind	0	0	0	0	0	0	0	0	0	1	3	5	8
of which wind offshore	0	0	0	0	0	0	0	0	0	0	0	0	0
– PV	0	0	0	0	0	0	0	2	6	14	24	34	41
– Geothermal	0	0	0	0	0	0	0	0	0	0	1	2	3
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	1
Combined heat and power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
of which from H_2	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass (& renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
CHP by producer													
– Main activity producers	0	0	0	0	0	0	0	0	0	0	0	0	0
– Autoproducers	0	0	0	0	0	0	0	0	0	0	0	0	0
Total generation	1	1	1	1	1	2	2	4	9	20	33	47	59
– Fossil	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	1	1	2
– of which renewable H_2	0	0	0	0	0	0	0	0	0	0	0	0	0
– Renewables (w/o renewable hydrogen)	1	1	1	1	1	2	2	4	9	19	33	47	59
– Hydro	1	1	1	1	1	2	2	2	2	2	2	2	2
– Wind	0	0	0	0	0	0	0	0	0	1	3	5	8
– PV	0	0	0	0	0	0	0	2	6	14	24	34	41
– Biomass (& renewable waste)	0	0	0	0	0	0	0	0	0	1	1	1	2
– Geothermal	0	0	0	0	0	0	0	0	0	0	1	2	3
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	1
Distribution losses	0	0	0	0	0	0	0	0	1	1	2	3	3
Own consumption electricity	0	0	0	0	0	0	0	0	1	1	2	3	4
Electricity for hydrogen production	0	0	0	0	0	0	0	0	0	0	1	3	3
Electricity for synfuel production	0	0	0	0	0	0	0	0	0	0	0	0	0
Final energy consumption (electricity)	1	1	1	1	1	2	2	4	9	18	30	42	53
Variable RES (PV, Wind, Ocean)	0	0	0	0	0	0	0	2	7	16	28	39	49
Share of variable RES	0%	1%	1%	0%	0%	0%	0%	45%	72%	81%	84%	85%	84%
RES share (domestic generation)	91%	86%	86%	84%	85%	89%	93%	94%	97%	99%	100%	100%	100%

Malawi: Transport – Final Energy [PJ/a] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Road	7	10	10	10	10	11	13	15	16	26	27	26	34
– Fossil fuels	7	10	10	10	10	11	13	15	16	24	19	5	0
– Biofuels	0	0	0	0	0	0	0	0	0	1	2	4	9
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Natural gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	1
– Electricity	0	0	0	0	0	0	0	0	0	1	6	15	24
Rail	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Electricity	0	0	0	0	0	0	0	0	0	0	0	0	0
Navigation	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
Aviation	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
Total (incl. Pipelines)	7	10	10	10	10	11	13	15	16	26	27	26	34
– Fossil fuels	7	10	10	10	10	11	13	15	16	24	19	5	0
– Biofuels (incl. Biogas)	0	0	0	0	0	0	0	0	0	1	2	4	9
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Natural gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	1
– Electricity	0	0	0	0	0	0	0	0	0	1	6	15	24
Total RES	0	0	0	0	0	0	0	0	0	2	8	20	34
RES share	0%	0%	0%	0%	0%	0%	0%	0%	2%	7%	31%	79%	100%

Malawi: Heat supply and air conditioning [PJ/a] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
District heating plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar collectors	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat from CHP 1)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
Direct heating	61	63	63	65	71	73	85	95	97	95	103	106	110
– Fossil fuels	0	0	0	1	1	1	1	1	2	2	1	0	0
– Biomass	57	59	59	61	67	69	80	86	74	49	33	18	4
– Solar collectors	0	0	0	0	0	0	0	1	7	11	14	16	21
– Geothermal	0	0	0	0	0	0	0	2	3	4	7	10	14
– Heat pumps 2)	0	0	0	0	0	0	0	0	5	17	22	27	31
– Electric direct heating	3	3	3	3	4	4	4	4	5	11	22	29	32
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	1	1
Total heat supply 3)	61	63	63	65	71	73	85	95	97	95	103	106	110
– Fossil fuels	0	0	0	1	1	1	1	1	2	2	1	0	0
– Biomass	57	59	59	61	67	69	80	86	74	49	33	18	4
– Solar collectors	0	0	0	0	0	0	0	1	7	11	14	16	21
– Geothermal	0	0	0	0	0	0	0	2	3	4	7	10	14
– Heat pumps 2)	0	0	0	0	0	0	0	0	5	17	22	27	31
– Electric direct heating (incl. process heat)	3	3	3	3	4	4	4	5	6	12	25	34	39
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	1	1
RES share (including RES electricity)	99%	99%	98%	98%	98%	98%	98%	98%	98%	98%	99%	100%	100%
Electricity consumption heat pumps (TWh/a)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Malawi: Installed Capacity [GW] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total generation	0	0	0	0	0	0	0	2	6	13	23	32	41
– Fossil	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas (w/o H_2)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil & Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen (fuel cells, gas power plants, gas CHP)	0	0	0	0	0	0	0	0	0	0	0	0	1
– Renewables	0	0	0	0	0	0	0	2	6	13	22	32	41
– Hydro	0	0	0	0	0	0	0	0	0	1	1	1	0.8
– Wind	0	0	0	0	0	0	0	0	0	2	4	7	10
of which wind offshore	0	0	0	0	0	0	0	0	0	0	0	0	0
– PV	0	0	0	0	0	0	0	1	5	10	17	24	29
– Biomass (& renewable waste)	0	0.0	0.0	0.0	0.0	0.0	0.000	0.028	0.068	0.141	0.229	0.3	0.4
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	0	0	0	0	0	0	1	5	12	21	31	39
Share of variable RES	0%	0%	1%	0%	0%	0%	1%	65%	86%	91%	94%	95%	95%
RES share (domestic generation)	71%	51%	52%	48%	50%	59%	75%	89%	96%	97%	99%	99%	100%

Malawi: Final Energy Demand [PJ/a] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-Energy use)	86	91	91	94	97	101	125	140	148	164	189	212	248
Total Energy use 1)	86	91	91	94	97	101	125	140	147	160	180	198	226
Transport	7	10	10	10	10	11	14	15	16	26	27	26	34
– Oil products	7	10	10	10	10	11	14	15	16	24	19	5	0
– Natural gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	1	2	4	9
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Electricity	0	0	0	0	0	0	0	0	0	1	6	15	24
– RES electricity	0	0	0	0	0	0	0	0	0	1	6	15	24
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	1
– RES share Transport	0%	0%	0%	0%	0%	0%	0%	0%	2%	7%	31%	79%	100%
Industry	3	3	3	4	5	5	6	6	9	10	16	21	26
– Electricity	0	1	1	1	1	1	1	1	3	5	9	13	17
– RES electricity	0	1	1	1	1	1	1	1	2	5	9	13	17
– Public district heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– RES district heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal & lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil products	0	0	0	0	1	1	1	1	1	1	1	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar	0	0	0	0	0	0	0	0	0	1	1	2	2
– Biomass	2	2	2	3	3	4	4	4	4	3	4	4	4
– Geothermal	0	0	0	0	0	0	0	0	0	0	1	1	1
– Hydrogen	0	0	0	0	0	0	0	0	0	0	1	1	2
– RES share Industry	89%	87%	86%	86%	78%	80%	82%	81%	83%	84%	95%	100%	100%
Other Sectors	76	78	79	80	82	84	105	119	122	125	137	151	166
– Electricity	1	1	1	1	2	2	6	11	26	54	83	110	133
– RES electricity	1	1	1	1	2	2	5	10	25	53	83	110	133
– Public district heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– RES district heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal & lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil products	0	0	0	0	0	0	0	1	1	1	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar	0	0	0	0	0	0	0	1	7	10	13	15	19
– Biomass	75	77	77	78	80	82	99	105	86	56	34	17	1
– Geothermal	0	0	0	0	0	0	0	2	3	4	7	9	13
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
– RES share Other Sectors	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	100%	100%	100%
Total RES	78	80	81	83	85	88	109	122	128	134	161	192	226
RES share	91%	88%	88%	88%	88%	87%	87%	87%	87%	83%	89%	97%	100%
Non energy use	0	0	0	0	0	0	0	0	2	4	9	15	22
– Oil	0	0	0	0	0	0	0	0	2	4	9	14	22
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Coal	0	0	0	0	0	0	0	0	0	0	0	0	0

Malawi: Energy-Releated CO_2 Emissions [Million tons/a] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil + Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
Combined heat and power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
CO_2 emissions power and CHP plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil + Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– CO_2 intensity fossil electr. generation	1,051	1,006	926	931	916	915	1,060	795	818	842	0	0	0
– CO_2 intensity total electr. generation	92	139	128	147	140	102	77	48	23	12	0	0	0
CO_2 emissions by sector	1	2	2	2	2	2	2	2	2	2	2	0	0
0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
– Industry 1)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Other sectors 1)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Transport	1	1	1	1	1	2	2	1	1	2	1	0	0
– Power generation 2)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Other conversion 3) – part of industry & transport	0	0	0	0	0	0	0	0	0	0	0	0	0
Population (Mill.)	15	17	17	18	18	19	19	22	25	28	31	34	37
CO_2 emissions per capita (t/capita)	0	0	0	0	0	0	0	0	0	0	0	0	0

Malawi: Primary Energy Demand [PJ/a] – 1.5°C

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy-use)	152	156	157	160	166	172	206	238	256	282	295	324	367
– Fossil (excluding on-energy use)	11	12	12	12	13	15	17	22	23	31	21	5	0
– Hard coal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Natural gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Crude oil	11	12	12	12	13	14	17	22	23	31	21	5	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Renewables	141	143	145	148	152	157	189	215	231	248	266	304	345
– Hydro	3	4	4	4	4	6	7	6	7	8	8	8	9
– Wind	0	0	0	0	0	0	0	0	1	5	11	19	28
– Solar	0	0	0	0	0	0	0	7	30	61	96	129	157
– Biomass	138	139	141	144	148	152	182	200	189	167	138	129	122
– Geothermal	0	0	0	0	0	0	0	2	3	6	12	18	26
– Ocean energy	0	0	0	0	0	0	0	0	0	1	1	2	2
Total RES	136	143	145	148	152	157	188	214	228	242	256	291	328
RES share	94%	92%	92%	92%	92%	91%	92%	91%	91%	89%	92%	98%	100%

Malawi: Electricity generation [TWh/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Power plants	1	1	1	1	1	2	2	4	8	14	24	32	41
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	1	3	8	15	21
of which from H_2	0	0	0	0	0	0	0	0	0	0	1	1	1
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass (& renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydro	1	1	1	1	1	2	2	2	2	2	2	2	2
– Wind	0	0	0	0	0	0	0	0	0	1	1	1	2
of which wind offshore	0	0	0	0	0	0	0	0	0	0	0	0	0
– PV	0	0	0	0	0	0	0	2	5	8	13	14	14
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	0
Combined heat and power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
of which from H_2	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass (& renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
CHP by producer													
– Main activity producers	0	0	0	0	0	0	0	0	0	0	0	0	0
– Autoproducers	0	0	0	0	0	0	0	0	0	0	0	0	0
Total generation	1	1	1	1	1	2	2	4	8	14	24	32	41
– Fossil	0	0	0	0	0	0	0	0	1	4	8	15	21
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	1	3	8	15	21
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	1	1	1
– of which renewable H_2	0	0	0	0	0	0	0	0	0	0	0	0	0
– Renewables (w/o renewable hydrogen)	1	1	1	1	1	2	2	4	7	11	16	18	19
– Hydro	1	1	1	1	1	2	2	2	2	2	2	2	2
– Wind	0	0	0	0	0	0	0	0	0	1	1	1	2
– PV	0	0	0	0	0	0	0	2	5	8	13	14	14
– Biomass (& renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	0
Distribution losses	0	0	0	0	0	0	0	0	1	1	2	2	2
Own consumption electricity	0	0	0	0	0	0	0	0	1	1	1	2	2
Electricity for hydrogen production	0	0	0	0	0	0	0	0	0	0	1	1	2
Electricity for synfuel production	0	0	0	0	0	0	0	0	0	0	0	0	0
Final energy consumption (electricity)	1	1	1	1	1	2	2	4	7	13	22	30	37
Variable RES (PV, Wind, Ocean)	0	0	0	0	0	0	0	2	5	9	14	15	16
Share of variable RES	0%	1%	1%	0%	0%	0%	0%	46%	65%	60%	58%	46%	39%
RES share (domestic generation)	91%	86%	86%	84%	85%	89%	93%	93%	87%	74%	68%	55%	47%

Malawi: Transport – Final Energy [PJ/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Road	7	10	10	10	10	11	13	15	16	27	40	59	87
– Fossil fuels	7	10	10	10	10	11	13	15	16	26	37	54	76
– Biofuels	0	0	0	0	0	0	0	0	0	1	2	4	9
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Natural gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	1
– Electricity	0	0	0	0	0	0	0	0	0	0	0	1	2
Rail	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Electricity	0	0	0	0	0	0	0	0	0	0	0	0	0
Navigation	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
Aviation	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
Total (incl. Pipelines)	7	10	10	10	10	11	13	15	16	27	40	59	87
– Fossil fuels	7	10	10	10	10	11	13	15	16	26	37	54	76
– Biofuels (incl. Biogas)	0	0	0	0	0	0	0	0	0	1	2	4	9
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Natural gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	1
– Electricity	0	0	0	0	0	0	0	0	0	0	0	1	2
Total RES	0	0	0	0	0	0	0	0	0	1	3	5	11
RES share	0%	0%	0%	0%	0%	0%	0%	0%	1%	4%	6%	9%	12%

Malawi: Heat supply and air conditioning [PJ/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
District heating plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar collectors	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
Heat from CHP 1)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass	0	0	0	0	0	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
Direct heating	61	63	63	65	71	73	85	95	103	111	123	132	139
– Fossil fuels	0	0	0	1	1	1	1	2	7	30	45	72	85
– Biomass	57	59	59	61	67	69	80	85	85	62	44	15	0
– Solar collectors	0	0	0	0	0	0	0	1	1	1	1	2	2
– Geothermal	0	0	0	0	0	0	0	2	3	4	7	9	13
– Heat pumps 2)	0	0	0	0	0	0	0	0	1	1	1	1	1
– Electric direct heating	3	3	3	3	4	4	4	4	5	11	22	29	32
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
Total heat supply 3)	61	63	63	65	71	73	85	95	103	111	123	132	139
– Fossil fuels	0	0	0	1	1	1	1	2	7	30	45	72	85
– Biomass	57	59	59	61	67	69	80	85	85	62	44	15	0
– Solar collectors	0	0	0	0	0	0	0	1	1	1	1	2	2
– Geothermal	0	0	0	0	0	0	0	2	3	4	7	9	13
– Heat pumps 2)	0	0	0	0	0	0	0	0	1	1	1	1	1
– Electric direct heating (incl. process heat)	3	3	3	3	4	4	4	5	6	12	25	34	39
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
RES share (including RES electricity)	99%	99%	98%	98%	98%	98%	98%	97%	92%	70%	57%	34%	24%
Electricity consumption heat pumps (TWh/a)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Malawi: Installed Capacity [GW] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total generation	0	0	0	0	0	0	0	2	5	8	14	17	21
– Fossil	0	0	0	0	0	0	0	0	0	1	3	5	7
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas (w/o H2)	0	0	0	0	0	0	0	0	0	1	3	5	7
– Oil & Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen (fuel cells, gas power plants, gas CHP)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Renewables	0	0	0	0	0	0	0	2	4	7	11	12	13
– Hydro	0	0	0	0	0	0	0	0	0	0	0	0	0.5
– Wind	0	0	0	0	0	0	0	0	0	1	1	2	2
– of which wind offshore	0	0	0	0	0	0	0	0	0	0	0	0	0
– PV	0	0	0	0	0	0	0	1	3	6	9	10	10
– Biomass (& renewable waste)	0	0.0	0.0	0.0	0.0	0.0	0.000	0.009	0.018	0.032	0.052	0.1	0.1
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Solar thermal power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	0	0	0	0	0	0	1	4	6	10	11	12
Share of variable RES	0%	0%	1%	0%	0%	0%	1%	66%	81%	77%	75%	66%	59%
RES share (domestic generation)	71%	51%	52%	48%	50%	59%	75%	88%	90%	83%	79%	69%	64%

Malawi: Final Energy Demand [PJ/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-Energy use)	86	91	91	94	97	101	125	140	158	189	232	284	347
Total Energy use 1)	86	91	91	94	97	101	125	140	156	185	222	266	319
Transport	7	10	10	10	10	11	14	15	16	27	40	59	87
– Oil products	7	10	10	10	10	11	14	15	16	26	37	54	76
– Natural gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biofuels	0	0	0	0	0	0	0	0	0	1	2	4	9
– Synfuels	0	0	0	0	0	0	0	0	0	0	0	0	0
– Electricity	0	0	0	0	0	0	0	0	0	0	0	1	2
– RES electricity	0	0	0	0	0	0	0	0	0	0	0	0	1
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	1
– RES share Transport	0%	0%	0%	0%	0%	0%	0%	0%	1%	4%	6%	9%	12%
Industry	3	3	3	4	5	5	6	6	9	12	20	26	31
– Electricity	0	1	1	1	1	1	1	1	2	4	6	9	12
– RES electricity	0	1	1	1	1	1	1	1	2	3	4	5	5
– Public district heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– RES district heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal & lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil products	0	0	0	0	1	1	1	1	1	2	3	4	5
– Gas	0	0	0	0	0	0	0	0	1	2	6	12	14
– Solar	0	0	0	0	0	0	0	0	0	0	0	0	0
– Biomass	2	2	2	3	3	4	4	4	5	4	4	0	0
– Geothermal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
– RES share Industry	89%	87%	86%	86%	78%	80%	82%	80%	73%	61%	42%	22%	19%
Other Sectors	76	78	79	80	82	84	105	119	131	146	162	181	201
– Electricity	1	1	1	1	2	2	6	11	22	39	65	88	109
– RES electricity	1	1	1	1	2	2	5	10	19	29	44	48	52
– Public district heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– RES district heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal & lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil products	0	0	0	0	0	0	0	1	1	1	0	0	0
– Gas	0	0	0	0	0	0	0	1	6	30	42	66	78
– Solar	0	0	0	0	0	0	0	1	1	1	1	1	1
– Biomass	75	77	77	78	80	82	99	104	99	71	47	17	0
– Geothermal	0	0	0	0	0	0	0	2	3	4	7	9	13
– Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0
– RES share Other Sectors	99%	99%	99%	99%	99%	99%	99%	98%	93%	72%	61%	42%	33%
Total RES	78	80	81	83	85	88	109	121	129	113	110	86	82
RES share	91%	88%	88%	88%	88%	87%	87%	87%	82%	61%	50%	32%	26%
Non energy use	0	0	0	0	0	0	0	0	2	4	10	18	28
– Oil	0	0	0	0	0	0	0	0	2	4	10	18	28
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Coal	0	0	0	0	0	0	0	0	0	0	0	0	0

Malawi: Energy-Releated CO_2 Emissions [Million tons/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	0	0	0	0	0	0	0	0	1	2	3	6	8
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	1	3	6	8
– Oil + Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
Combined heat and power plants	0	0	0	0	0	0	0	0	0	0	0	0	0
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0	0	0	0	0	0
CO_2 emissions power and CHP plants	0	0	0	0	0	0	0	0	1	2	3	6	8
– Hard coal (& non-renewable waste)	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0	0	1	3	6	8
– Oil + Diesel	0	0	0	0	0	0	0	0	0	0	0	0	0
CO_2 intensity (g/kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0	0	0	0	0	0	0	0
– CO_2 intensity fossil electr. generation	1,051	1,006	926	931	916	915	1,060	748	527	453	415	401	388
– CO_2 intensity total electr. generation	92	139	128	147	140	102	77	52	67	117	132	180	204
CO_2 emissions by sector	1	2	2	2	2	2	2	2	3	6	9	15	20
0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
– Industry 1)	0	0	0	0	0	0	0	0	0	0	1	1	1
– Other sectors 1)	0	0	0	0	0	0	0	0	1	2	3	4	4
– Transport	1	1	1	1	1	2	2	1	1	2	3	4	6
– Power generation 2)	0	0	0	0	0	0	0	0	1	2	3	6	8
– Other conversion 3) - part of industry & transport	0	0	0	0	0	0	0	0	0	0	0	0	0
Population (Mill.)	15	17	17	18	18	19	19	22	25	28	31	34	37
CO_2 emissions per capita (t/capita)	0	0	0	0	0	0	0	0	0	0	0	0	1

Malawi: Primary Energy Demand [PJ/a] – REFERENCE

	2012	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy-use)	152	156	157	160	166	172	206	238	268	319	364	445	533
– Fossil (excluding on-energy use)	11	12	12	12	13	15	17	24	36	94	149	244	326
– Hard coal	0	0	0	0	0	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0	0	0	0	0	0
– Natural gas	0	0	0	0	0	0	0	1	13	60	106	186	245
– Crude oil	11	12	12	12	13	14	17	22	23	34	43	58	81
– Nuclear	0	0	0	0	0	0	0	0	0	0	0	0	0
– Renewables	141	143	145	148	152	157	189	214	230	221	205	183	179
– Hydro	3	4	4	4	4	6	7	6	6	6	6	6	6
– Wind	0	0	0	0	0	0	0	0	1	2	3	4	6
– Solar	0	0	0	0	0	0	0	7	19	29	45	46	47
– Biomass	138	139	141	144	148	152	182	198	201	180	145	117	107
– Geothermal	0	0	0	0	0	0	0	2	3	4	7	9	13
– Ocean energy	0	0	0	0	0	0	0	0	0	0	0	0	0
Total RES	136	143	145	148	152	157	188	213	228	218	201	177	173
RES share	94%	92%	92%	92%	92%	91%	92%	90%	86%	70%	57%	42%	35%

Notes

Notes

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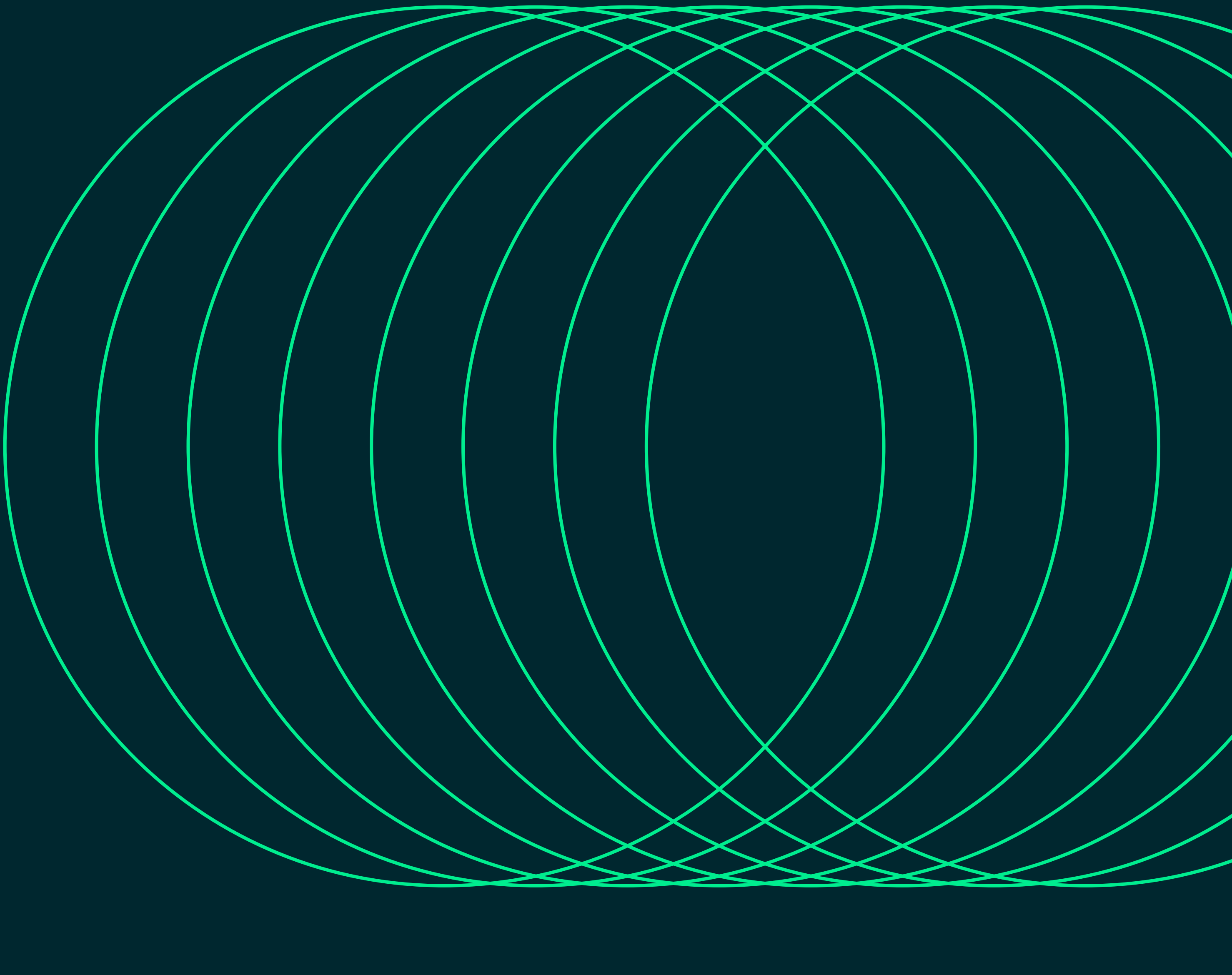

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