Africa: Energy Development Plan to Decarbonise the Continent

prepared for Power Shift Africa

By The University of Technology Sydney
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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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The energy scenario software for the long-term projections and economic parameters is based on the development by 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 analyses.

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Contents

Introduction

In this report, we present the development of a 100% renewable energy pathway for the African continent, demonstrating both its technical and financial feasibility. The pathway is meticulously designed to be robust, and provides a clear framework for achieving a secure, sustainable energy supply across Africa's industrial, transport, and residential sectors. By ensuring energy security, the pathway not only promotes environmental sustainability but also supports economic resilience, laying the foundation for Africa's transition to a fully renewable energy future.

The scenarios for the energy pathways do not claim to predict the future, but provide a useful tool with which to describe and compare potential development pathways from the broad range of possible 'futures'. The Africa 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 Africa's energy supply system to a truly sustainable one. It can be used as a reliable basis for further analyses 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 enable 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 a 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 Africa's electricity infrastructure to ensure its reliability and resilience.

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

Since 2017, the University of Technology Sydney – Institute of Sustainable Future (UTS-ISF) has undertaken detailed country-specific energy analyses (see reference list), ranging from the global south, including Tanzania, 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 geographic information system (GIS) data under constrained land availability conditions (excluding protected areas, areas with steep slopes, and certain land-cover classes, such as closed forests, wetlands, snow and ice, and permanent water).
- The development of the 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 demand (see above) is broken down to the level of provinces.
- The development of the following scenario:
  - 1.5°C scenario[1] – 100% renewable energy plan to decarbonise the energy sector by 2050 within the carbon budget required to achieve a temperature rise of 1.5°C with 66% certainty (based on IPCC AR6, 2021).
  - compared with the Reference government scenario, if available.
- These scenarios are combined with renewable energy scenarios with different shares of variable power generation (solar photovoltaic [PV], wind, bioenergy, and hydropower).

1 1.5°C scenario: Series of scenarios with a total global carbon budget of 400 $GtCO_2$ to limit the mean global temperature rise to a maximum of 1.5°C with 67% likelihood, as defined in IPCC AR6.

1 The carbon budget

Achieving the goals of the Paris Climate Agreement requires a drastic reduction of energy and non-energy-related greenhouse gases (GHGs), including land-use-related emissions.[2] Based on the Paris Climate Agreement, countries have agreed to regularly report their GHG emissions and submit their 'Nationally Determined Contributions' (NDCs), describing their planned measures to reduce GHG emissions.

In 2021, the 'Global Stocktake' process began to collect the latest data on emissions and to assess future developments based on the NDCs already commenced. According to the United Nations Framework Convention on Climate Change (UNFCCC), the Global Stocktake 'enables countries and other stakeholders to see where they're collectively making progress toward meeting the goals of the Paris Agreement – and where they're not. It's like taking inventory'.[3]

In this chapter, we document the decarbonisation pathways for all G20 member countries[4] – which are responsible for over 80% of all energy-related CO_2 emissions – and compare them with the current and future carbon budgets for the continent of Africa.

The emissions are broken down into key industry sectors, and the energy-related national carbon budgets required to achieve the remaining global carbon budget of between 400 $GtCO_2$ and 500 $GtCO_2$ are calculated.[5] The historic CO_2 emissions for all G20 countries and the continent of Africa are also considered in determining the overall carbon budget until 2050, as a basis for the allocation of national carbon budgets and a contribution to the UNFCCC's 'Global Stocktake' process. Furthermore, a sensitivity analysis examines the impact of the delayed implementation of the 1.5°C decarbonisation scenarios on the global carbon budget.

2 Rogelj, J. et al. (2016) 'Paris Agreement climate proposals need a boost to keep warming well below 2°C', Nature, 534(7609):631–639. Available at: https://doi.org/10.1038/nature18307

3 UNFCCC (2023a) Global Stocktake, United Nations Climate Change. Available at: https://unfccc.int/topics/global-stocktake (Accessed: 17 July 2023).

4 G20 member countries – Canada, USA, Mexico, Brazil, Argentina, Germany, France, Italy, United Kingdom, Turkey, Russian Federation, Saudi Arabia, South Africa, Indonesia, India, China, Japan, South Korea, and Australia.

5 IPCC (2021) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by Masson-Delmotte SL, Zhai VP, Pirani A, Connors JBR, Péan C, Berger S, Caud N, Chen Y, Goldfarb L, Gomis MI, Huang M, Leitzell K, Lonnoy E, Matthews BZ, Maycock TK, Waterfield T, Yelekçi O, Yu R. Cambridge University Press. Available at: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf

1.1 Methodology

The decarbonisation pathways for all G20 countries, Africa, and the global scenario were developed with the One Earth Climate Model (OECM), noting that the overall remaining carbon budget cannot exceed 500 $GtCO_2$ between 2020 and 2050 if we are to limit the mean global temperature rise to +1.5°C with a likelihood of 50%. The OECM is an integrated energy assessment model that covers the entire energy system of a country or region, broken down into 16 industry-specific sectors. The methodology was developed by the Institute for Sustainable Futures at the University of Technology Sydney, with the support of the Institute of Networked Energy Systems and Energy Systems Analysis of the German Aerospace Center and in close co-operation with the finance sector of the Net-Zero Asset Owners Alliance and the United Nations Principles for Responsible Investment.

The methodology of the OECM provides high technical resolution and has been extensively documented in the scientific literature.[6,7,8,9] The sectoral breakdown is based on the Global Industry Classification Standard (GICS; MSCI 2020) and defines the system boundaries for the sector-specific decarbonisation scenarios (Teske and Guerrero 2022). The term 'technical resolution' refers to the level of detail with which the model captures specific technical processes, such as steel, aluminium, and cement production, transport modes, and vehicle types, and the energy-generation technologies used for power, (process) heat, and fuel supply.[10] The existing national industry sectors are calculated from the bottom up as part of the national energy scenario development. It is assumed that the market shares of national industry sectors will remain constant between 2020 and 2050. If a country produces 50% of global steel in 2020, it is assumed that this global market share will remain constant until 2050. This assumption was applied to all branches of industry analysed in the manufacturing sector and to raw material extraction.

The annual energy-related CO_2 emissions between 2020 and 2050 in all country-specific OECM 1.5°C scenarios have been combined to calculate the total G20 carbon emissions. The accumulated carbon emissions for all industries, by country and globally, are also calculated. The results for all G20 countries are compared with the global emissions – on both national and sectoral levels. The historic emissions[11] of all G20 countries are included in the overall emissions balance. The total emissions – historic plus the projected energy-related CO_2 emissions until 2050 under the OECM 1.5°C scenarios – are then divided by the countries' populations in 2020 to determine a per capita carbon emissions index. Finally, we calculate the additional emissions for each sector and country if implementation is delayed by 5 or 7 years, assuming that a delay freezes emission at the 2022 levels for the period of the delay.

The African carbon emissions are taken from the AF-1.5°C pathway, documented in Section 5. Africa's historical emissions are based on South Africa – the only country for which carbon emissions before the 1990s have been documented.

6 Teske, S. et al. (2019) 'Methodology', in S. Teske (ed.) Achieving the Paris Climate Agreement Goals: Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2°C. Springer, Cham, pp. 25–78. Available at: https://doi.org/10.1007/978-3-030-05843-2_3

7 Teske, S. et al. (2022) 'Methodology', in S. Teske (ed.) Achieving the Paris Climate Agreement Goals: Part 2: Science-based Target Setting for the Finance industry – Net-Zero Sectoral 1.5°C Pathways for Real Economy Sectors. Cham: Springer International Publishing, pp. 25–59. Available at: https://doi.org/10.1007/978-3-030-99177-7_3

8 Teske S, Niklas S, Talwar S, Atherton A. 1.5°C pathways for the Global Industry Classification (GICS) sectors chemicals, aluminium, and steel. SN Appl. Sci. 4(4), (2022), doi: 10.1007/S42452-022-05004-0

9 Teske S, Nagrath K. (2022) Global sector-specific Scope 1, 2, and 3 analyses for setting net-zero targets: agriculture, forestry, and processing harvested products. SN Appl. Sci. 4(8):1–19, doi: 10.1007/S42452-022-05111-

10 Teske S, Guerrero J. (2022) One Earth Climate Model – integrated energy assessment model to develop industry-specific 1.5°C pathways with high technical resolution for the finance sector, Energies 15(9):3289, doi: 10.3390/EN15093289

11 Our World in Data (2022) Data on CO_2 and Greenhouse Gas Emissions by Our World in Data. Available at: https://github.com/owid/co2-data

1.2 Remaining carbon budgets for G20 countries and the African continent

In this study, we compare the calculated energy-related CO_2 emissions of all G20 countries and the African continent with the global scenario under a defined carbon budget limit. The details of all countries' scenarios – in terms of energy demand and supply pathways and the assumed market and/or demand developments for 16 industry sectors (outlined in Table 1) – are documented in a separate open-access paper, which allows the input and output of data (Teske et al., 2023). Figure 1 shows the historic cumulative energy-related CO_2 emissions in 1750–2019, as previously documented, and the calculated CO_2 emissions under the OECM 1.5°C pathways in 2020–2050. The historic and projected energy-related CO_2 emissions in 2020–2050 for each G20 country are divided by the current population to determine the country-specific emissions index. The Per Capita Carbon Index (PCCI) is introduced as a benchmark with which to compare cumulative historic and projected emissions. However, the calculation of the PCCI is simplified because historic and future population developments are not included. Therefore, the index is only an indication.

The global OECM 1.5°C pathway calculation in this analysis resulted in total cumulative energy-related CO_2 emissions of 426 $GtCO_2$ (2020–2050). The maximum value of 500 $GtCO_2$ was deliberately undercut to maximise the probability of achieving the 1.5°C target.

Carbon budgets: Historic (1750–2019) and 1.5°C pathway emissions (2020–2050) will lead to total global emissions of 2,091 $GtCO_2$, 75% (1,570 $GtCO_2$) of which will be emitted by the G20 countries. In terms of overall emissions, the USA is by far the greatest emitter, with 471 $GtCO_2$ – 87% of which are historic emissions. The future emissions allowance for the USA under the OECM pathway is 58.9 $GtCO_2$. The second greatest emitter is the 27 countries of the European Union (EU27), with 286 $GtCO_2$ of historic emissions, 30% less than the USA. African historical emissions – based on South Africa's emissions – add up to around 21 $GtCO_2$, similar to those of Japan and South Korea combined.

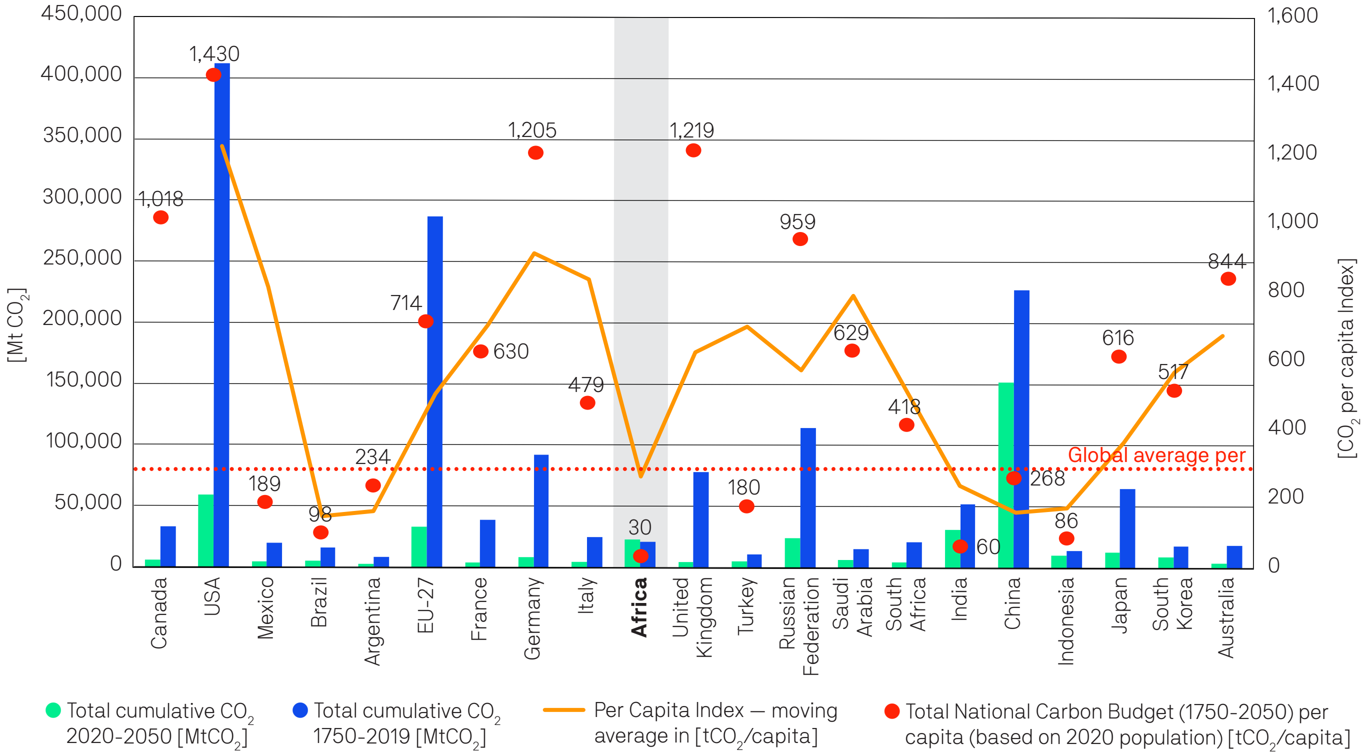
Under the OECM 1.5°C pathway, the EU27 will decarbonise with a total remaining carbon budget of 32.9 $GtCO_2$, 44% less than that of the USA, even though the EU27 population is 448 million, 26% larger than that of the USA. The European economy is significantly more energy efficient than the USA economy, and the renewable energy share (final energy) in 2020 was 28%, more than twice that of the USA (11%). Therefore, the faster decarbonisation of Europe's energy system is assumed. China is the third greatest emitter, with 227 $GtCO_2$ of historic emissions and a projected remaining carbon budget of 151 $GtCO_2$.

The remaining carbon budget for the continent of Africa – according to the AF-1.5°C OECM scenario – is calculated to be 23 $GtCO_2$. The smaller budget – relative to the EU or the USA – is due to Africa's advantage in leapfrogging directly into the (far more economically efficient) renewable energy supply. The currently existing fossil-fuel infrastructure is not as large as in the countries the Organisation for Economic Co-operation and Development (OECD), so the energy transition will be significantly faster and more cost efficient. A new renewable-energy-based energy industry is the fastest and cheapest option with which Africa can increase its energy supply to a per capita level similar to that of the OECD countries. Africa currently hosts 19% of the global population and was responsible for only 3% of global emissions in 2023.

The USA, EU27, and China represented 28% of the global population in 2020 and are responsible for 56% of historic emissions (926 $GtCO_2$). The 1.5°C OECM decarbonisation pathways for these three regions lead to a remaining carbon budget of 243 $GtCO_2$, 57% of the total global carbon budget of 426 $GtCO_2$. China is assumed to require the largest carbon budget to reach decarbonisation. Under its national OECM 1.5°C decarbonisation pathway, China – with a population of 1.4 billion people, compared with 0.8 billion for the EU27 and USA combined – will cumulatively emit 151 $GtCO_2$ in 2020–2050, more than 1.5 times the remaining carbon budget of the EU27 and USA combined.

In terms of the total combined historic and projected emissions, the fourth largest emitter is Russia, with 138.2 $GtCO_2$, followed by Germany (100.3 $GtCO_2$). All other G20 countries – including populous India – have significantly lower cumulative emissions, although some had significantly higher per capita emissions in 2020. Africa's cumulative energy-related CO_2 emissions add up to 43 $GtCO_2$.

Figure 1: G20 versus Africa: Carbon Stocktake–cumulative energy-related CO_2 emissions in 1750–2020 and 2020–2050 under OECM 1.5°C pathways and Per Capita Carbon Index (PCCI)



Per Capita Carbon Index: The total carbon emitted will determine the increase in global temperature, so an increase in global CO_2 emissions, and consequently the global carbon budget, will inevitably cause us to miss the 1.5°C target. Consequently, increasing the carbon budgets of countries with low historic emissions is not possible. Therefore, to still determine fair CO_2 budgets for developing countries, which have little responsibility for climate change, the Per Capita Carbon Index (PCCI) is introduced. The historic emissions and future emissions under the OECM 1.5°C pathway for each G20 member are divided by each country's population in 2020. The 'historic PCCI' shows the level of responsibility and the '1.5°C PCCI' provides a way to compare the remaining carbon budgets. In combination, the total PCCI provides a way to compare emissions, as required in the Global Stocktake. The overall PCCI for each country is compared with the global PCCI under the global OECM 1.5°C scenario and with historic global emissions.

G20 countries are the world's major economies, representing 85% of the global gross domestic product (GDP), 75% of international trade, and two-thirds of the global population.[12] However, the national historic emissions of the G20 member countries vary significantly, and their individual PCCIs differ greatly. India has the lowest, with only 60 tCO_2/capita, whereas the USA has the highest, with 1,430 tCO_2/capita – almost 24 times higher. The United Kingdom, Germany, and Canada have PCCIs > 1,000 tCO_2/capita.

The global average PCCI is calculated to be 269 tCO_2/capita – almost exactly the PCCI of China (268 tCO_2/capita). The results for all other developing countries are below the global average. The PCCI for Africa is calculated to be 30 tCO_2 per capita – half the value for India (60 tCO_2).

Carbon budget by sector: The 1.5°C carbon budgets (2020–2050) for all 16 industry sectors analysed are shown in Table 1. Each sectoral carbon budget is presented as the sum of the G20 member countries and compared with the results for Africa and the global pathway. The difference between the global and G20 emissions represents the carbon budget for all remaining countries. The OECM 1.5°C pathways for all G20 countries reflect the current distribution of industry sectors. The G20 steel industry, for example, represents almost 90% of the current production capacity of the global steel industry, and is assumed to remain so until 2050.

12 Australian Government (2023) The G20, Department of Foreign Affairs and Trade. Available at: https://www.dfat.gov.au/trade/organisations/g20 (Accessed: 11 July 2023).

Table 1: Cumulative energy-related CO_2 emissions by sector (2020–2050) for all G20 OECM 1.5°C pathways compared with the remaining global budget and the remaining carbon budgets for other countries

Sector	Industry	G20	G20 Shares	Africa	Africa Shares	Global
Cement (process heat, fuels, and electricity)	Industry	8,554	89%	485	5%	9,657
Steel (process heat, fuels, and electricity)	Industry	27,421	98%	263	1%	27,851
Chemical industry (process heat, fuels, and electricity)	Industry	19,080	97%	208	1%	19,589
Textiles and leather (process heat, fuels, and electricity)	Industry	3,877	84%	38	1%	4,623
Aluminium (process heat, fuels, and electricity)	Industry	5,108	92%	154	3%	5,558
Buildings: commercial, residential, and construction (heat, fuels, and electricity)	Services	57,803	91%	4,791	8%	63,368
Fisheries (fuels and electricity)	Services	415	68%	22	4%	614
Agriculture and food processing (heat, fuels, and electricity)	Services	13,558	100%	414	3%	13,607
Forestry and wood (heat, fuels, and electricity)	Services	8,442	94%	187	2%	8,993
Water utilities (heat, fuels, and electricity)	Services	305	69%	30	7%	439
Aviation – transport services	Transport	6,163	35%	143	1%	17,743
Aviation industry direct (fuels and electricity)	Transport	342	23%	16	1%	1,471
Navigation–transport services	Transport	2,079	16%	54	0%	12,653
Navigation industry direct (fuels and electricity)	Transport	484	27%	15	1%	1,770
Road transport – transport services	Transport	56,100	76%	5,983	8%	74,205
Road transport industry direct (fuels and electricity)	Transport	2,936	63%	286	6%	4,673
All other sectors	Other	158,230	99%	9,468	6%	159,965
Total cumulative CO_2 2020–2050	**[$MtCO_2$]**	**370,897**	**87%**	**22,555**	**5%**	**426,779**
Total cumulative CO_2 1750–2020		**1,198,388**		**20,593**		**1,664,542**
Total CO_2 budget from beginning to end of fossil-fuel era		**1,569,286**		**43,148**		**2,091,321**
2020–2050 carbon budget per capita (2020 population)		92		15		55
Carbon budget (1750–2050) per capita index (based on 2020 population)	[tCO_2/capita 1750–2050]	390		30		269
Regional CO_2 share	**[%]**	**86.90%**				**100.00%**
Population share	**[%]**	**51.80%**		**19%**		**100.00%**
Population in 2020	**[million]**	**4,022**		**1,460**		**7,762**

Impact of implementation delay of the 1.5°C OECM pathways: The total remaining global carbon budget required to limit the temperature increase to 1.5°C (with 67% likelihood) is 400 $GtCO_2$. An increased carbon budget of 500 $GtCO_2$ will reduce the likelihood to 50%, and one of 650 $GtCO_2$ will reduce it to only 33%, according to the IPCC. The impacts of delaying the implementation of the 1.5°C pathways by 5 or 7 years are shown, by sector, in Table 2. A delay of 5 years – across all sectors and countries – will increase global carbon emissions from 426 $GtCO_2$ under the 1.5°C OECM scenario to 585 $GtCO_2$, and the likelihood of meeting the +1.5°C target will decrease to < 50%. A delay of 7 years will increase the total emissions to 649 $GtCO_2$ in 2020–2050, reducing the likelihood of achieving the target to 33%.

Table 2: Total cumulative energy-related CO_2 emissions (2020–2050) for the G20, whole world, and Africa if implementation of the 1.5°C pathway is delayed by 5 or 7 years

	5-year delay			7-year delay		
Sector	**G20**	**Africa**	**Global**	**G20**	**Africa**	**Global**
Cement	12,320	559	13,821	13,826	589	15,487
Steel	35,145	318	35,709	38,234	339	38,852
Chemical industry	25,479	257	26,569	28,038	277	29,361
Textiles and leather	5,439	50	6,321	6,064	54	7,000
Aluminium	7,933	231	8,380	9,063	262	9,508
Buildings – commercial, residential, and construction	85,257	6,628	94,391	96,238	7,363	106,801
Fisheries	521	25	777	563	27	842
Agriculture and food processing	19,891	569	20,195	22,424	631	22,830
Forestry and wood	12,165	261	13,113	13,654	291	14,761
Water utilities	454	45	671	513	50	763
Aviation – transport services	8,518	168	23,799	9,460	179	26,221
Aviation industry direct	422	18	1,529	454	18	1,552
Navigation – transport services	2,747	69	16,815	3,014	75	18,479
Navigation industry direct	589	15	1,847	631	15	1,878
Road transport – transport services	77,641	7,552	103,095	86,257	8,180	114,651
Road transport industry direct	3,935	287	5,350	4,335	288	5,622
All other sectors	210,366	10,979	213,228	231,220	11,583	234,533
Total cumulative energy-related CO_2 emissions (2020–2050)	**508,822**	**28,031**	**585,610**	**563,991**	**30,221**	**649,142**

A closer look at the development of sector-specific emissions and the increase in emissions if implementation is delayed shows that those of the transport sector and building sector will be significant. A 7-year delay in the road transport sector alone will increase emissions in 2020–2050 by 39 $GtCO_2$.

1.3 Discussion and conclusion

It will be essential to remain within a global carbon budget well under 500 $GtCO_2$ if we are to meet the Paris Climate Agreement target of maintaining 'the global temperature rise this century well below 2 degrees Celsius above pre-industrial levels'.[13] 'The IPCC 6th Assessment Report (AR6)[14]highlighted that a global temperature rise of 1.5°C would already have significant impact on climate. Therefore, the OECM pathways aim to stay within a carbon budget that will limit the global temperature rise to 1.5°C with a probability of 50% or more.

The OECM 1.5°C decarbonisation scenarios were developed for countries, regions, and the world to provide possible mitigation pathways with high technical resolution and system boundaries that reflect the sector definitions used by the global finance industry. In this research, individual scenarios for all G20 countries have been created to assess how countries can decarbonise as quickly as possible while maintaining economic growth. Decarbonisation pathways differ significantly because the demand and supply structures of each country are very specific. The level of industrialisation, the dominant industry sectors, and the level of private consumption define their current emissions. Restructuring the energy sector to decarbonise a country's economy is possible in all OECM 1.5°C pathways, but the national requirements for a carbon budget that allows decarbonisation differ. Therefore, a fair distribution of the remaining carbon budget must consider the technical and economic situations of each country. Their historic emissions, in total and per capita, are also important factors.

Although the remaining global carbon budget required to remain well under +2°C is fixed and cannot be negotiated, the Global Stocktake must go beyond defining national carbon budgets. It must include financial and technical support from those countries with the highest historical emissions to countries that have minor historical emissions but still require energy for economic development.

The PCCI is one possible tool with which to develop such a global support mechanism. For instance, if a line is drawn at the global average PCCI of 269 tCO_2/capita, all countries above that value must provide financial and technical support to those countries below that value. The higher the PCCI, the greater a country's responsibility to actively invest in decarbonisation beyond its national borders. The determination of the carbon budget, including the PCCI, supports low- and middle-income countries in the allocation of funds for climate change adaptation and climate mitigation measures.

13 UNFCCC (2023b) Key aspects of the Paris Agreement, United Nations Climate Change. Available at: https://unfccc.int/most-requested/key-aspects-of-the-paris-agreement (Accessed: 12 July 2023).

14 IPCC (2021) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by Masson-Delmotte SL, Zhai VP, Pirani A, Connors JBR, Péan C, Berger S, Caud N, Chen Y, Goldfarb L, Gomis MI, Huang M, Leitzell K, Lonnoy E, Matthews BZ, Maycock TK, Waterfield T, Yelekçi O, Yu R. Cambridge University Press. Available at: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf

2 Scenario assumptions

2.1 Africa continent overview

Africa is the second-largest continent in both land area and population, after Asia. The African continent is bordered by the Mediterranean Sea to the north, the Atlantic Ocean to the west, the Indian Ocean to the east, and the Red Sea to the northeast. It is comprised of 54 sovereign nations, each with diverse cultures, languages, and histories. The continent is home to a wide range of geographic features, from the Sahara Desert in the north to the tropical rainforests of Central Africa, and to significant water bodies, such as the Nile River and Lake Victoria, the largest lake in Africa and the world's second-largest freshwater lake by surface area.[15] Africa's linguistic landscape is highly diverse, with over 2,000 languages spoken across the continent. English, French, Arabic, and Portuguese are official or widely spoken languages in many countries, alongside numerous indigenous languages, such as Swahili, Hausa, Yoruba, and Zulu.[16] Since gaining independence from colonial rule during the mid-20th century, African nations have worked to maintain their stability with varying degrees of success, focusing on economic growth and social development to improve the quality of life for their growing populations.

Africa is rich in natural resources, including oil, gas, minerals, and fertile agricultural land. The continent's economies are primarily based on agriculture, mining, and energy, with many countries making strides toward industrialisation and technological advancement.[17] The African Union, established in 2001, works to foster economic integration, peace, and sustainable development across the continent. Several African countries contribute significantly to the continent's economic growth. Nigeria, with its large population and oil industry, plays a pivotal role in West Africa's economic landscape. South Africa, one of the continent's most industrialised nations, leads in sectors such as finance, mining, and manufacturing. Kenya has emerged as a hub for technology and innovation in East Africa, and Ethiopia has seen rapid development in infrastructure and manufacturing. Egypt, with its diverse economy and strategic location, remains a key player in North Africa.[18] Ghana, Rwanda, and Morocco have also made notable strides in developing their economies through investment across an array of sectors (e.g., technology, agriculture, and tourism). Collectively, these nations are driving Africa's economic transformation, fostering innovation, improving infrastructure, and enhancing trade, positioning the continent as a dynamic and increasingly influential player in the global economy.

2.1.1 Climate and energy policy context

Africa's political landscape is increasingly shaped by a strong commitment to environmental sustainability and climate change mitigation, as leaders recognise the continent's acute vulnerability to climate impacts, particularly in sectors such as agriculture and water resources. African nations have integrated these priorities into their political agendas, as seen in initiatives like the African Union's Agenda 2063, which seeks inclusive growth and sustainable development.[19] Morocco, Rwanda, and Ethiopia have emerged as leaders in renewable energy investments and climate adaptation strategies. Africa's partnerships with global institutions have deepened, with the World Bank and the International Monetary Fund (IMF) playing key roles. In 2023, the World Bank launched the Africa Climate Business Plan to mobilise billions of dollars in financing for climate-resilient infrastructure and adaptation, particularly in the most vulnerable countries.[20] The Africa Adaptation Acceleration Program, backed by the African Development Bank (AfDB) and global donors, further demonstrates Africa's commitment to addressing climate risks while promoting sustainable growth.[21] These efforts are aligned with global net-zero goals, and Africa's participation in international negotiations reflects its advocacy of climate justice and equitable access to resources, ensuring that environmental stewardship remains central to the continent's political and economic vision for the future.

15 Natural history on the net, online version. Accessed October 2024, https://www.naturalhistoryonthenet.com/Continents/africa.htm

16 Radar Africa, online version. Accessed October 2024, https://radarafrica.com/africa/africas-linguistic-diversity-over-2000-languages-spoken/

17 World Bank Group, online version. Accessed October 2024, https://www.worldbank.org/en/region/afr/overview

18 African Development Bank. Accessed October 2024, https://www.afdb.org/sites/default/files/2024/06/06/aeo_2024_-_chapter_1.pdf

19 IPCC. Accessed October 2024, https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-9/

20 World Bank. Accessed October 2024, https://thedocs.worldbank.org/en/doc/967741469570264685-0010022016/original/Chapter07Africaclimatebusinessplan.pdf

21 AfDB Group. Accessed October 2024, https://www.afdb.org/en/topics-and-sectors/initiatives-partnerships/africa-adaptation-acceleration-program

2.1.2 Economic context

According to the World Bank, Africa has achieved respectable growth in the past, averaging 3.7% between 2009 and 2019. However, Africa faces significant vulnerabilities in achieving inclusive and sustainable growth. The ongoing disruptions caused by the COVID 19 pandemic have worsened the existing structural challenges, including slow domestic job creation and Africa's high vulnerability to natural disasters and climate change. Insufficient infrastructure in key sectors, such as energy and health care, has made it harder to address both the pandemic and environmental risks. Furthermore, rising debt levels due to the pandemic-induced economic slowdown present a significant challenge, which must be managed to ensure long-term stability.[22] 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 3 are based on projections by the African Governments, and have been used for NDCs and long-term energy plans.

Annual economic growth data for the African continent are derived as a weighted aggregate of all 54 African nations based on 'Pledges data'.[23] Projections of Africa's annual economic growth are compared with the figures for both least-developed countries (LDCs) and non-LDCs in Africa, and aligns closely with the trajectories of non-LDCs, as detailed in Appendix A. GDP is analysed for specific sectors, including 'Agriculture, Forestry, and Fishing', 'Manufacturing', 'Industry', 'Chemicals', 'Textiles and Clothing', and 'Food'. The comparative analysis of each sector between the African continent and LDCs versus non-LDCs is presented in Appendix A. The classification of countries designated 'LDC' is sourced from https://www.un.org/ohrlls/content/list-ldcs.[24]

Table 3: Africa's population and GDP projections until 2050

Africa	Units	2020	2025	2030	2035	2040	2045	2050
Population	[individuals]	1,360,677,231	1,530,031,248	1,673,845,127	1,899,296,806	2,093,408,427	2,289,760,656	2,485,135,538
Annual population growth	[%/a]	2.48%	2.34%	2.20%	2.06%	1.90%	1.75%	1.59%
GDP	[US$ billion]	2585.1	3175.4	3942.0	4947.9	6284.8	8078.7	10508.5
Annual economic growth	[%/a]	-2.20%	4.30%	4.50%	4.75%	5.00%	5.25%	5.50%
GDP/person (calculated)	[US$/ capita]	1900	2075	2355	2605	3002	3528	4229

2.1.3 Population development

Population data for the LDCs and non-LDCs in Africa are provided in conjunction with their respective land areas and their population densities sourced from the United Nations (Table 4).[25] The mean population densities for LDCs and non-LDCs are approximately 40% and 54%, respectively, leading to an overall population density of 47% for the African continent in 2021. A population density map was generated for the African continent, based on 2020 data from the Socioeconomic Data and Applications Centre.[26] Figure 1 also shows the population density of Africa. The highest population concentrations are shown in dark colour and the lowest in white.

22 World Bank 2024, online database. Accessed October 2024, https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG

23 World Bank 2024, online database. Accessed October 2024, https://data.worldbank.org/indicator/NY.GDP.MKTP.KD

24 United Nations 2024, online database. Accessed October 2024, https://www.un.org/ohrlls/content/list-ldcs

25 United Nations 2024, online database. Accessed October 2024, https://population.un.org/dataportal/

26 Socioeconomic Data and Applications Centre (SEDAC), Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11.

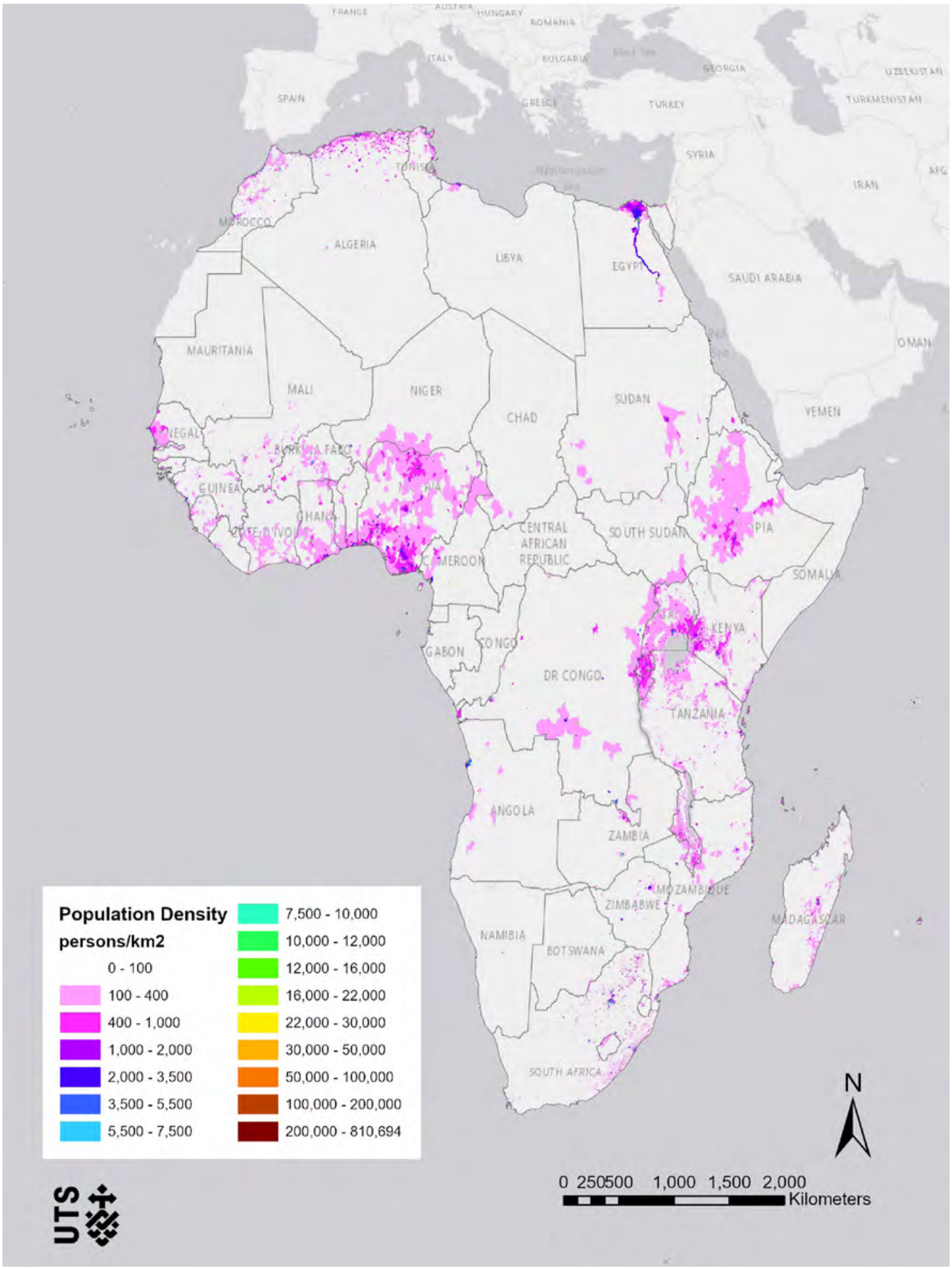
Table 4: Regions: LDCs and non-LDCs in Africa with population statistics for 2021

Region	Country	Population [millions]	Area [km²]	Population density [people/km²]
LDC	Angola	34.50	1247.0	27.70
	Benin	13.00	115.0	115.30
	Burkina Faso	22.10	274.0	80.80
	Burundi	12.55	28.0	483.70
	Central African Republic	5.46	623.0	8.80
	Chad	17.18	1284.0	13.60
	Comoros	0.82	2.0	441.50
	Congo	5.84	342.0	17.10
	Djibouti	1.11	23.0	47.70
	Eritrea	3.62	121.0	29.90
	Ethiopia	120.28	1104.0	120.30
	Gambia	2.64	11.0	260.90
	Guinea	13.53	246.0	55.10
	Guinea-Bissau	2.06	36.0	73.30
	Lesotho	2.28	30.0	75.10
	Liberia	5.19	111.0	53.90
	Madagascar	28.92	587.0	49.70
	Malawi	19.89	118.0	210.40
	Mali	21.91	1240.0	18.00
	Mauritania	4.62	1031.0	4.50
	Mozambique	32.08	799.0	40.80
	Niger	25.25	1267.0	19.90
	Rwanda	13.46	26.0	556.00
	Sao Tome and Principe	0.22	1.0	232.40
	Senegal	16.88	197.0	87.70
	Sierra Leone	8.42	72.0	117.40
	Somalia	17.07	638.0	27.20
	South Sudan	10.91	619.7	19.30
	Sudan	46.87	1886.1	21.60
	Togo	8.64	57.0	158.90
	Uganda	45.85	242.0	229.50
	United Rep. of Tanzania	63.59	947.0	71.80
	Zambia	19.47	753.0	26.20
LDC total		**646.21**	**16077.80**	**40.19**

Region	Country	Population [millions]	Area [km²]	Population density [people/km²]
Non-LDC	Algeria	44.18	2382.0	18.50
	Botswana	2.59	582.0	4.60
	Cabo Verde	0.59	4.0	145.90
	Cameroon	27.20	476.0	58.40
	Côte d'Ivoire	27.48	322.0	86.40
	Dem. Rep. of the Congo	95.89	2345.0	42.30
	Egypt	109.26	1002.0	109.80
	Equatorial Guinea	1.63	28.0	58.30
	Eswatini	1.19	17.0	68.70
	Gabon	2.34	268.0	9.10
	Ghana	32.83	239.0	144.30
	Kenya	53.01	592.0	91.30
	Libya	6.74	1676.0	4.00
	Mauritius	1.30	2.0	639.90
	Morocco	37.08	447.0	83.10
	Namibia	2.53	825.0	3.10
	Nigeria	213.40	924.0	234.30
	Seychelles	0.11	0.5	233.00
	South Africa	59.39	1221.0	48.70
	Tunisia	12.26	164.0	78.90
	Zimbabwe	15.99	391.0	41.30
Non-LDC total		**746.99**	**13907.46**	**53.71**
Africa total		**1393.68**	**29648.0**	**47.20**

Source: United Nations Standard Population Database

Figure 2: Population density in Africa (projection for 2020)

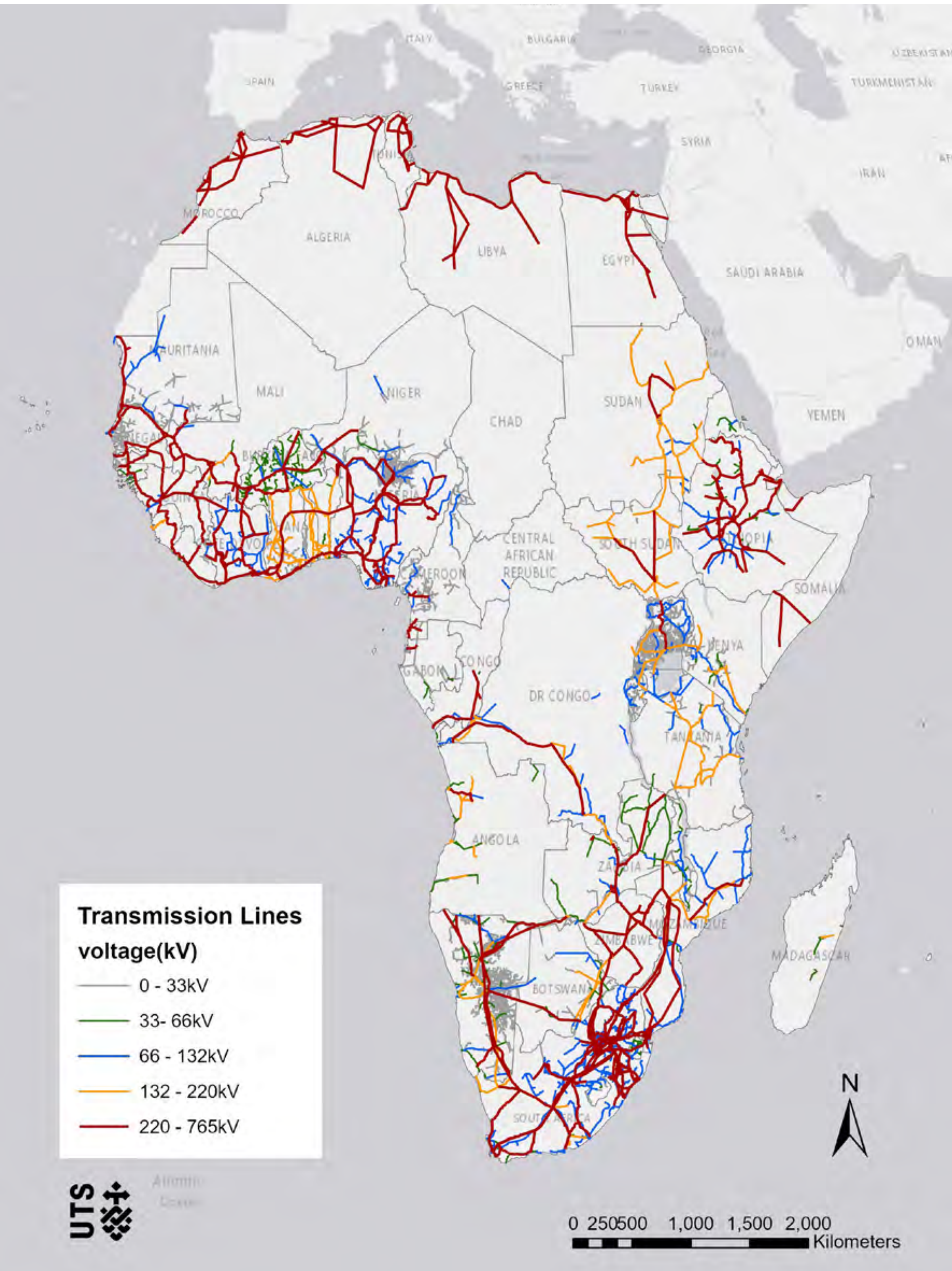


Source: Map generated from Socioeconomic Data and Applications Centre (SEDAC) data

2.2 Electricity infrastructure and energy access

Figure 3 provides an overview of the locations of the transmission line network across the African continent.

Figure 3: Electricity transmission line network (existing and planned) in Africa.



Source: Africa – Electricity Transmission and Distribution Grid Map, World Bank Group (2017);

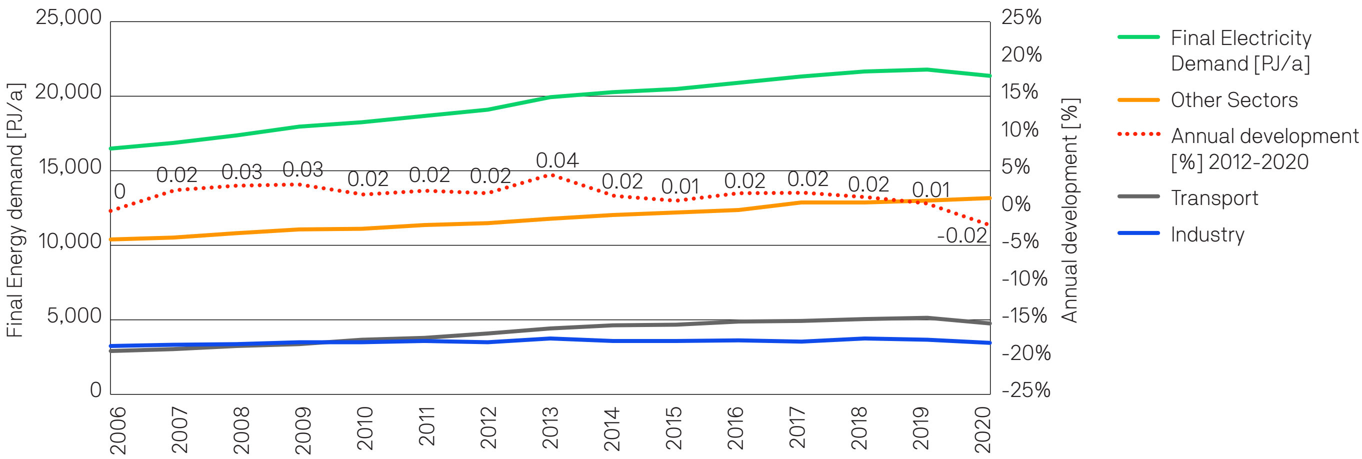
In Figure 3, the legend describes the different categories of the transmission line infrastructure according to the respective voltage level. Higher voltages are used to supply larger loads in population centres and areas of economic activity, as well as to transmit power flows between neighbouring regions in which sufficient capacity exists to warrant interconnection to neighbouring countries. A comparison of Figures 2 and 3 demonstrates, as expected, a high degree of correlation between population and the availability of energy infrastructure. Some exceptions apply; for example, where generation assets are located some distance from population centres, or when industrial activity and other load centres are located away from densely populated city areas.

2.3 Energy demand – development since 2005

It is necessary to analyse the development of the past energy demand in order to project the future demand. Therefore, the statistical data for Africa's energy demand between 2005 and 2019 have been analysed (IEA 2022).[27]

Figure 4 shows the development of Africa's final energy demand between 2005 and 2019. The overall energy demand grew constantly, despite years of reduced demand due to reduced economic activity. The gross final energy demand has grown by about 19% since 2005 to around 21,359 petajoules per annum (PJ/a). The main energy demand occurs in the residential sector, whereas only 16% of the energy is for industry use and 22% for the transport sector.

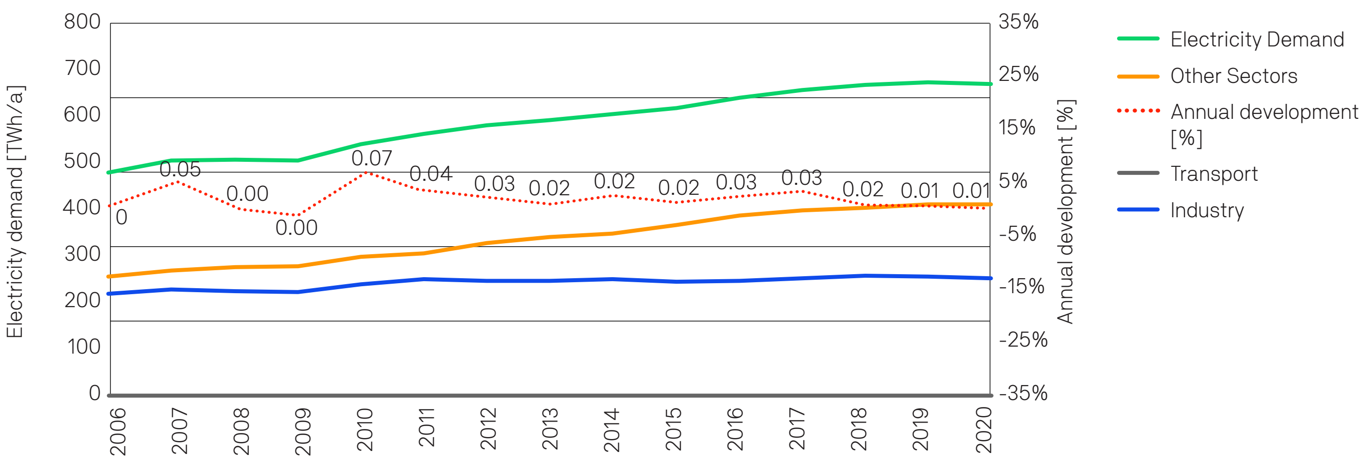
Figure 4: Final energy demand development in Africa from 2005 to 2019



The electricity demand has increased significantly faster than the final energy demand. By 2019, the annual electricity demand was close to 676 billion kilowatt-hours (675.6 TWh/a), up from 480.8 TWh/a in 2006 (Figure 5), growing by a factor of close to 1.4. Again, the residential sector grew fastest, followed by the industry sector, and the electricity demand for transport was almost negligible. However, with the increased electrification of vehicles, the electricity demand for transport is expected to increase significantly.

27 IEA 2022, Advanced World Energy Balances, Africa.

Figure 5: Electricity demand development in Africa from 2005 to 2020



However, Africa's electricity demand is currently 486 kWh per capita, one of the lowest in the world (IBN 2011),[28] whereas global average consumption is 2,500 kWh per annum.[29]

2.3.1 Energy supply

The primary energy supply is dominated by biomass (over 47% in 2020), used mainly for cooking and heating, whereas electricity is supplied by both fossil energy sources (49%) and renewable energy sources, such as hydropower and solar (51%), as shown in Table 5. If the primary energy supply continues to develop as it has over the past 15 years (by approximately 1%–2% annually), the primary energy demand is projected to increase from 31,140 PJ/a in 2020 to 37,664 PJ/a by 2050.

Table 5: Africa's primary energy supply between 2006 and 2019 (IEA World Energy Balances 2021)

Primary supply	Units	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Annual development		-	3.4%	4.2%	2.3%	1.7%	1.7%	5.3%	3.0%	0.2%	0.8%	2.0%	0.2%	1.5%	2.5%
Primary energy	[PJ/a]	24,094	24,919	25,970	26,572	27,025	27,475	28,942	29,814	29,866	30,106	30,717	30,781	31,231	32,023
Net Export (–) /Import (+)	**[PJ/a]**	**-13**	**-16**	**-16**	**-19**	**-14**	**-21**	**-30**	**-34**	**-37**	**-27**	**-31**	**-27**	**-24**	**0**
Fossil fuels	[PJ/a]	11,714	12,235	12,896	13,089	13,429	13,618	14,631	15,270	15,160	15,176	15,457	15,295	15,499	15,953
Coal	[PJ/a]	3,518	3,588	3,887	3,813	3,629	3,483	3,627	3,754	3,969	3,686	3,762	3,757	3,920	4,032
Lignite	[PJ/a]	2	2	2	2	3	4	4	3	4	3	4	4	4	4
Oil	[PJ/a]	4,965	5,138	5,438	5,697	6,005	6,058	6,537	7,025	7,291	7,400	7,372	7,344	7,316	7,324
Gas	[PJ/a]	3,228	3,508	3,569	3,577	3,792	4,074	4,464	4,487	3,897	4,086	4,319	4,190	4,259	4,592
Nuclear	[PJ/a]	109	123	142	140	132	147	130	154	150	133	164	155	126	145
Total renewables	**[PJ/a]**	**11,660**	**11,843**	**12,166**	**12,474**	**12,675**	**12,998**	**13,412**	**13,688**	**13,835**	**14,037**	**14,296**	**14,518**	**14,749**	**15,082**
Biomass	[PJ/a]	11,321	11,493	11,807	12,103	12,263	12,583	12,985	13,239	13,351	13,538	13,781	13,974	14,136	14,412
Hydro	[PJ/a]	332	342	349	359	395	396	408	424	442	435	432	449	487	508
Solar (A)	[PJ/a]	1	1	2	2	4	5	5	6	11	17	29	37	52	76
Wind	[PJ/a]	3	4	5	6	9	9	9	13	20	31	38	42	55	67
Geothermal	[PJ/a]	4	4	4	5	4	5	5	6	11	16	16	17	18	19
Renewables share:	**[%]**	**48.4%**	**47.5%**	**46.8%**	**46.9%**	**46.9%**	**47.3%**	**46.3%**	**45.9%**	**46.3%**	**46.6%**	**46.5%**	**47.2%**	**47.2%**	**47.1%**

(A) Solar is not zero because it is used for various on- and off-grid applications. However, the overall energy generated is < 0.1 PJ/a.

28 IBN. (2011). *Africa's electricity demand*. IBN Publications

29 World Bank Database 2019, https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?locations=IN-PK-BD-LK-NP-AF&name_desc=true

Definition of renewable energy

The IPCC is the leading international body assessing climate change. In its Special Report on Renewable Energy Sources and Climate Change Mitigation,[30] 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, hydropower, 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 residential energy demand

To develop a projection for the residential electricity demand in Africa over the coming 30 years in order to achieve the Africa 1.5°C (AF-1.5°C) scenario, a bottom-up electricity demand analysis was performed.

The AF-1.5°C scenario 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, according to 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

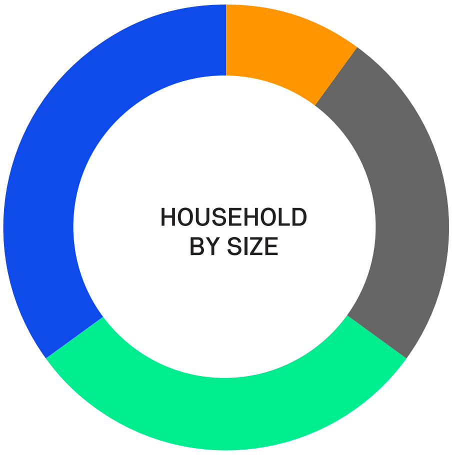
The current and future developments of the electricity demand for Africa's households were analysed from the second half of 2021 onwards under the leadership of Power Shift Africa. The future development of the household demand has been discussed in a multiple-stakeholder dialogue with representatives from Africa's academia, civil society, and government.

Figure 6 shows the breakdown of Africa's households by size and type (UN-ES 2019).[31] The current average electricity demand of Africa's households is significantly lower than those of OECD countries.

30 Arvizu 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, Yamba F, Zwickel T (2011) Technical Summary. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P, Kadner S, Zwickel T, Eickemeier P, Hansen G, Schlömer S, von Stechow C (eds), Cambridge University Press, Cambridge, UK and New York, NY, USA.

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

Figure 6: Africa – households by size and type



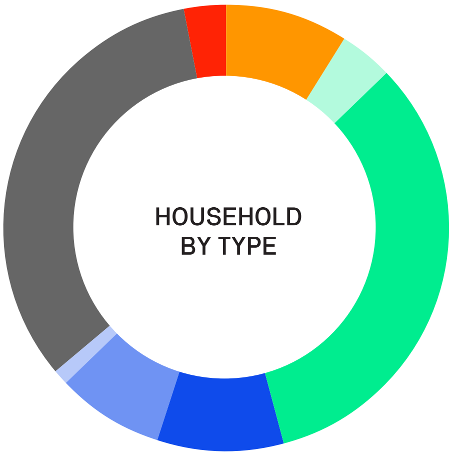


Table 6 shows the electricity demands and the electrical appliances used by households in Africa in 2020 and the projected '*phases*', with increased demand in the case of increased electrification. It is assumed that households with an annual consumption indicated under the household type in 'phase 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 those of households with very basic needs, such as light and mobile phone charging, to a household standard equivalent to that in 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 have two groups: one for the basic level of electrification and one for the more-advanced level. The households will develop over time, from the basic group towards the more advanced group.

Table 6: Household types used in all scenarios and their assumed annual electricity demands

Africa – Annual household electricity demands			
Household type	**Group**		**Annual electricity demand [kWh/a]**
Rural	Phase 1	Very-low-income rural household Low-income rural household	687
	Phase 2	Lower-middle-income rural household	984
	Phase 3	Upper-middle-income rural household	1,675
Semi-urban	Basic	Low-to-middle-income semi-urban household	2,092
	Advanced	Middle-income semi-urban household	2,383
Urban	Single	Low-to-middle-income urban household (apartment)	968
	Shared apartment	Middle-income urban household (apartment)	981
	Basic	Middle-income urban household (house)	1,353
	Advanced	Middle-to-high-income urban household (house)	2,004

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 and liquefied pressurised gas (LPG) for cooking is particularly important in decarbonising Africa's household energy supply. A staged transition towards electrical cooking is assumed.

The typical household electricity demands are compared with:

i) regional countries in South Asia: India, Sri Lanka, Pakistan, and Bhutan;

ii) an example of an 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 7 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 representation of the energy-efficient and highly electrified households in the OECD countries. In predicting the future development of Africa's electricity demand, we assume that the level of electrification and household appliances used will be similar to those in industrialised countries. Although the electricity demands 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 demands provides an orientation for the future demands in developing countries.

Table 7: 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]	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, 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/Schweiz, https://www.energieschweiz.ch/stories/energieeffiziente-elektrogeraete/

The development of the continent-wide shares of the electricity demand in Africa according to the various household types is presented in Table 8. Electrification starts with basic household types, such as rural, semi-urban, and urban (apartments or houses) and moves to better-equipped households. Thus, the proportion of fully equipped households grows 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 Africa's households to close the gap between households in the OECD countries and countries in the global south, to achieve greater equity.

Table 8: Household types – development of household shares of the electricity demand continent-wide in Africa

	Continent-wide electricity shares [%] (rounded)			
Household type	2020	2030	2040	2050
No access to electricity	10.00%	4.00%	2.00%	0%
Rural – phase 1	75.00%	72.00%	65.00%	55.00%
Rural – phase 2	4.00%	8.00%	9.00%	15.00%
Rural – phase 3	0.00%	3.00%	4.00%	10.00%
Semi-urban – basic	10.00%	4.00%	3.00%	5.00%
Semi-urban – advanced	0.00%	2.00%	0.00%	0.00%
Urban apartment – basic	0.00%	0.00%	0.00%	0.00%
Urban apartment – advanced	0.00%	4.00%	8.00%	10.00%
Urban house – basic	0.00%	2.00%	5.00%	1.00%
Urban house – advanced	1.00%	1.00%	4.00%	4.00%
Total	**100%**	**100%**	**100%**	**100%**

Source: CDP, REB, DESCO, and UTS-ISF research

According to the most recent data in *The African Energy Outlook 2022 Report* published in May 2023 (IEA 2022),[32] over 57% of Africa's households have access to electricity. However, only 72% of households have access to reliable and uninterrupted electricity (World Bank 2017).[33] 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. Minigrids have proven a successful technology option for remote areas, bringing energy services to remote communities, helping villages develop local economies, and providing alternative opportunities for young people to establish careers outside the metropolitan areas.

2.4.2 Household fuel demand – cooking

The main energy demand for Africa's households is for cooking (Bhandari et al. 2018). 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.

Table 9 shows the variety of cooking fuels used for cooking. Firewood and LPG markedly dominate, whereas electricity is used in less than 5.6% of all Africa's households. Table 10 provides an overview of the most important cooking technologies and their key technical and economic parameters (WFC 2019).[34] 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 [SHS] or in a mini grid context) using high-efficiency appliances could make cooking even cheaper than it is many households currently using firewood and charcoal. The World Bank's bottom-up research from across sub-Saharan Africa indicated that households use on average US$1–31 per month on cooking fuels (World Bank 2014).[35] With slow cookers and pressure cookers allowing household cooking costs of US$15–21/month for SHS 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).

Table 9 Distribution of cooking fuels in households[36]

		Biomass	Charcoal	Coal	Electricity	Gas	Kerosine	Other	Total
Urban	[%]	22.25	29.48	0.50	9.12	29.81	4.83	4.01	100
Rural	[%]	75.49	6.46	0.11	2.71	11.08	1.75	2.40	100
Africa	[%]	52.37	15.06	0.34	5.60	20.51	3.60	2.52	100

Source: Bhandari et. al. 2018[37]

Based on current cooking energy usage, a transition scenario from fuel-based cooking to electric cooking (e-cooking) has been developed for the AF-1.5°C scenario (Table 11). In the past, Africa replaced inefficient stoves with more-efficient ones, which has had a positive effect on (indoor) air pollution and reduced the need for fuel for each cooking stove. However, with an increasing population and a growing number of households, the overall fuel demand is likely to remain at high levels, and a phase-out of emissions and fuel demand cannot be achieved with this measure.

32 IEA 2022, African Energy Outlook, 2023, Available at: https://iea.blob.core.windows.net/assets/220b2862-33a6-47bd-81e9-00e586f4d384/AfricaEnergyOutlook2022.pdf

33 World Bank 2017, Multi-Tier Framework for Measuring Energy Access 2017. NPL_2017_MTF_v01_M doi: https://doi.org/10.48529/r1sn-zg95, Energy Sector Management Assistance Program (ESMAP)

34 WFC 2019, Beyond fire – How to achieve electric cooking. Couture TD (E3 Analytics); David Jacobs D (IET– International Energy Transition GmbH), Matser E and Clemens H (Hivos), Skowron A (WFC), and Thomas J (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

35 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

36 World Health Organization, 2024, Available at: https://www.who.int/data/gho/data/themes/air-pollution/cooking-fuel-and-technology-database-by-fuel-category

37 Bhandari R, Pandit S. 2018, Electricity as a Cooking Means in Nepal – A Modelling Tool Approach. Sustainability 10:2841. https://doi.org/10.3390/su10082841

Table 10: Basic data on technologies and energy use

Appliance	Cost of the stove (in EUR)	Median cost (EUR)	Watts (range)	Approximate daily household consumption (in Wh/day for electric options and in kg/day for solid and gas-based fuels)	Approximate daily household consumption (in MJ)
Three stones (wood)	0	0.00	N/A	4.15–20.76 kg/day	68.48–342.54
Traditional cooking stove (wood)	0–5	2.50	N/A	3.32–8.3 kg/day	54.78–136.95
Improved cooking stove (wood)	5–65	35.00	N/A	2.08–5.53 kg/day	34.32–91.25
Three stones (charcoal)	0	0.00	N/A	1.92–4.81 kg/day	54.72–137.09
Traditional cooking stove (charcoal)	0–10	5.00	N/A	1.6–4.01 kg/day	45.60–114.29
Improved cooking stove (charcoal)	5–65	35.00	N/A	1.2–2.4 kg/day	34.20–68.40
Improved cooking stove (wood-based biomass pellets)	16–80	48.00	N/A	1.76–3.96 kg/day	30.41–68.43
Improved cooking stove (agro-waste pellets)	16–80	48.00	N/A	2.42–5.44 kg/day	30.49–68.54
Single burner hot plate	8–35	21.50	600–2000	1200–4000 Wh/day	4.32–14.40
Induction hot plate	45–95	67.50	1000–2300	2000–4600 Wh/day	7.20–16.56
Slow cooker/rice cooker/crock pot	10–130	70.00	120–300	175–700 Wh/day	0.63–2.52
Electric pressure cooker	19–140	79.50	500–1000	160–340 Wh/day	0.58–1.22
Microwave oven	50–100	75.00	600–1200	100–1200 Wh/day	0.36–4.32
Gas stove (single burner)	20–60	40.00	N/A	0.3 kg/day	13.7
Gas stove (double burner)	30–90	60.00	N/A	0.3 kg/day	13.7
Gas stove (four burners)	40–100	70.00	N/A	0.3 kg/day	13.7

Source: (WFC 2019)

Table 11: Cooking energy demand by household type in 2021 in Africa

Household	Fuel	Demand per month [MJ/month]	Demand per year [MJ/year]	Persons per household	Demand per person and year [MJ/person/a]
Rural	Firewood	2,100	25,200	5.9	4,271
Semi-urban	Firewood	2,100	25,200	4.3	5,860
Urban	Firewood	2,100	25,200	3.5	720
Rural	LPG	300	3,600	5.9	610
Semi-urban	LPG	350	4,200	4.3	977
Urban	LPG	400	4,800	3.5	1,371

The monthly and annual energy demands for the two main fuel-based cooking technologies are shown in Table 11. Based on these, a scenario for transitioning from fuel-based cooking to electricity-based cooking was developed (Table 12).

On average, 3.3% of all 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.

Table 12: Transition scenario from fuel-based to electricity-based cooking in Africa under the AF-1.5°C pathway

Phase-out of fuel-based cooking 2020–2050											
Share of households with 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
2020	100%	[MJ/a HH]	25,920	25,920	25,920	16800	15960	4800	4800	4800	4800
2025	83%	[MJ/a HH]	21,513	21,513	21,513	14000	13300	4000	4000	4000	4000
2030	67%	[MJ/a HH]	17,366	17,366	17,366	11200	10640	3200	3200	3200	3200
2035	50%	[MJ/a HH]	12,960	12,960	12,960	8400	7980	2400	2400	2400	2400
2040	33%	[MJ/a HH]	8,553	8,553	8,553	5600	5320	1600	1600	1600	1600
2045	17%	[MJ/a HH]	4,406	4,406	4,406	2800	2660	800	800	800	800
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**
2020	0%	[kWhelectric/a HH]	0	0	0	0	0	0	0	0	0
2025	17%	[kWhelectric/a HH]	122	122	122	122	122	122	122	122	122
2030	33%	[kWhelectric/a HH]	243	243	243	243	243	243	243	243	243
2035	50%	[kWhelectric/a HH]	365	365	365	365	365	365	365	365	365
2040	67%	[kWhelectric/a HH]	487	487	487	487	487	487	487	487	487
2045	83%	[kWhelectric/a HH]	608	608	608	608	608	608	608	608	608
2050	100%	[kWhelectric/a HH]	730	730	730	730	730	730	730	730	730

Therefore, e-cooking can be supplied from renewable energy sources and will be emissions-free.

However, there are several 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.

There are already numerous electric cooking devices on Africa'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 *Promotion of Sustainable Electric Cooking in Africa* initiative is dedicated to fostering the adoption of electric cooking technologies across the continent. With around 900 million people in sub-Saharan Africa reliant on biomass fuels, transitioning to electric cooking offers significant environmental, health, and economic advantages. This initiative is in collaboration with governments, NGOs, and the private sector to disseminate crucial information about advances in electric cooking and infrastructure. The efforts focus on raising awareness regarding the affordability and efficiency of electric stoves, including modern solutions such as induction cookers and electric pressure cookers, which help reduce the indoor air pollution associated with traditional biomass and charcoal stoves.

Through partnerships with programmes such as the Modern Energy Cooking Services (MECS), the *Promotion of Sustainable Electric Cooking in Africa* addresses barriers to its adoption by providing resources and support tailored to both urban and rural areas. Initiatives like the Global eCooking Coalition (GeCCo), launched in 2023, aim to transition 10 African countries to electric cooking by 2030, contributing to Sustainable Development Goal 7 for clean energy. Supported by organisations such as *SEforALL* and *Energising Development*, these efforts focus on policy support and resource mobilisation, targeting areas heavily reliant upon polluting fuels. Together, these initiatives seek to improve access to clean cooking solutions while addressing environmental concerns, including deforestation and carbon emissions.

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).
- Concern exists around the quality and stability of the electricity supply.

Technical challenges that e-cooking poses for 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-fuel-powered vehicles will further increase the electric loads and will 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. Moreover, the technical standard of household wiring is low; cables are often not properly installed, or the lack of protective earthing compromises electrical safety.

Policy and social challenges in promoting electric cooking

Local-level governments in Africa have not yet formulated 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. Therefore, the development of clean cooking programmes is lagging the actual targets. Finally, the general awareness of the benefits of e-cooking is still low – particularly in rural areas – because there is no access to the necessary information. 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 programmes for retail staff are required.

2.5 Industry and business demand

The analysis of Africa's economic development is based on a breakdown of the fiscal year 2019. It 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, industry (including construction) contributed strongly (by 25%) to the growth in GDP (in the basic price), whereas machinery and transport equipment contributed the least. The contribution of the manufacturing industry to economic growth rate in that fiscal year was 11%, and the contribution of food, beverages, and tobacco was 18%. Figure 8 presents the annual GDP growth rate from 2005 to 2020.

Figure 7: Contributions of sub-sectors to GDP growth

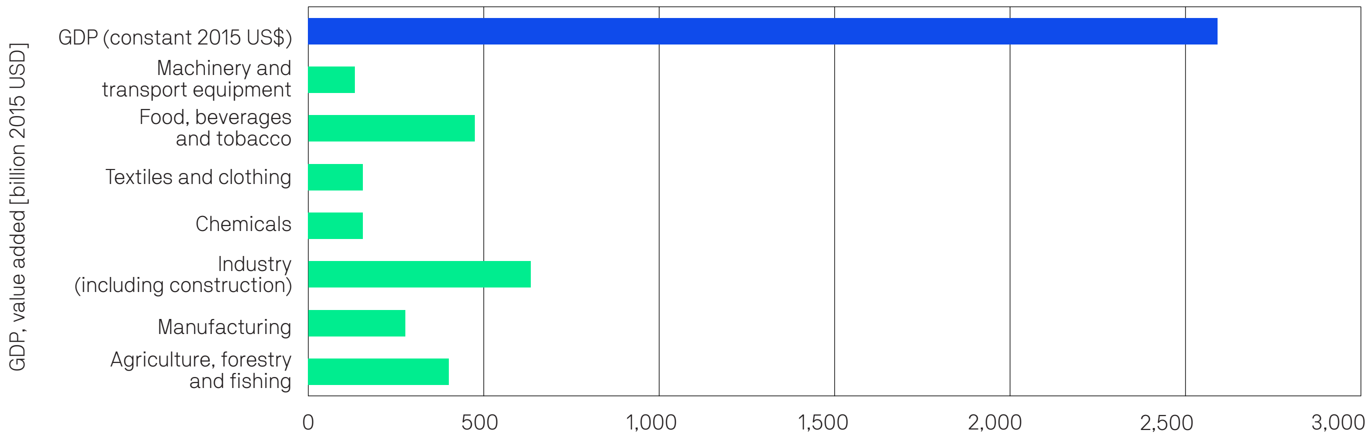
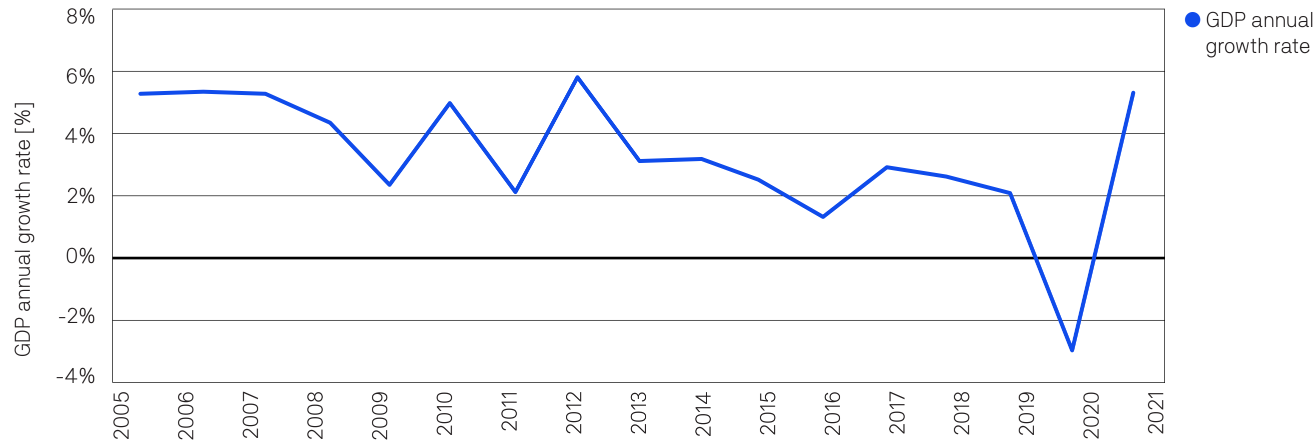


Figure 8: Gross domestic product (GDP) growth rate



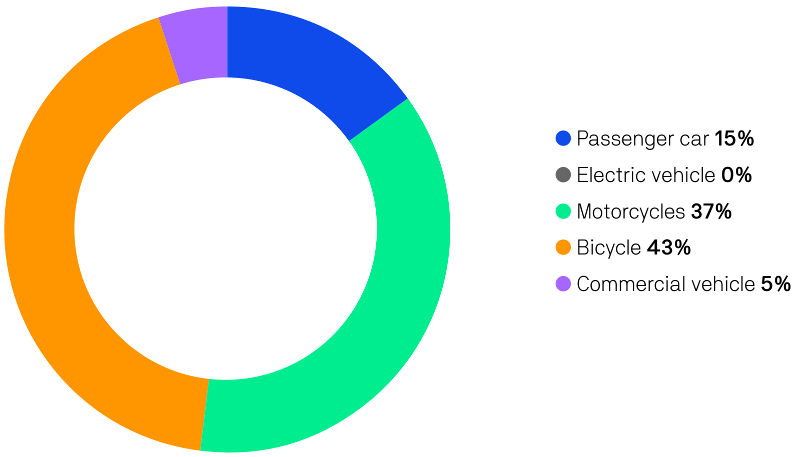
More details of the historical developments in GDP and the calculation methodology for the projections are documented in Appendices A and B.

2.6 Transport demand

The 2025 vehicle market on the African continent includes diverse categories with significant distributions across various types. Among the 6,169,940 vehicles registered, motorcycles (37.1%) and bicycles (42.9%) represent the largest proportions, reflecting high demand for two-wheeled transportation. Passenger cars, which include a range from mini and small cars to SUVs, pickup trucks, and full-sized vans, account for 15.1% of the total. Commercial vehicles, encompassing light commercial vehicles, buses, and trucks, make up 4.8%, whereas electric vehicles (EVs), consisting of battery electric and plug-in hybrid electric vehicles, represent a smaller segment at 0.04%. This breakdown highlights the diverse market, with traditional vehicles leading, although there is a growing, although still minimal, presence of electric and commercial options (Figure 9).[38]

The total number of cars in Africa is estimated to be around 38 million. Over the scenario period up to 2050, it is assumed that all vehicles will be converted to electric drives, or that vehicles with internal combustion engines (ICEs) will be replaced with EVs.

Figure 9: Categories of registered vehicles, with the percentages of the total numbers of registered vehicles (financial year 2023/2024)



Source: Vehicles Africa (Unit Sales 2024), Statista

To develop a future transport scenario, the technical parameters of all vehicular options are required in order 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 of vehicles – 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 an important role 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 around 20 kW to > 200 kW.

Furthermore, drive trains can use a range of fuels, from gasoline, diesel, and biodiesel 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.

38 Statista 2024, Unit sales of vehicles – Africa, available at: https://www.statista.com/outlook/mmo/passenger-cars/africa

2.6.1 Technical parameters – individual transport

Passenger transport by road is the commonest and most important form of travel (TUMI 2021).[39] 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 aims for high technological resolution, simplifications are required. Table 13 shows the energy intensities for the main vehicle types (electric and those with ICEs), and forms the basis for the energy scenario calculations.

Table 13: Energy intensities of individual transport – road transport

Individual transport			Passengers: Average passengers per vehicle	Passengers: Assumed occupation rate	Vehicle demand average	Consumption per passenger average	Energy demand assumption for scenario calculation
		Fuel			**litre/100 km**	**litre/100 pkm**	**[MJ/pkm]**
Scooters and motorbikes	2-wheeler	Gasoline	1	1	3.0	3.0	1.21
		Electricity			**kWhel/100 km**	**kWhel/100 pkm**	**[MJ/pkm]**
E-bikes	2-wheeler	Battery	1	1	1.0	1.0	0.04
Scooters	2-wheeler	Battery	1	1	1.8	1.9	0.06
Motorbikes	2-wheeler	Battery	1	1	4.8	4.8	0.17
Rickshaw	3-wheels	Battery	3	2	8.0	4.0	0.14
		Fuels	**0**	**0**	**litre/100 km**	**litre/100 pkm**	**[MJ/pkm]**
Cars	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			**kWhel/100 km**	**kWhel/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

39 TUMI (2021), Teske, S., Niklas, S., Langdon, R., (2021), TUMI Transport Outlook 1.5°C – A global scenario to decarbonize transport; Report prepared by the University of Technology Sydney for the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH; published by TUMI Management, Deutsche Gesellschaft für International Zusammenarbeit (GIZ) 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 from 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 100 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 per 100 km, 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 14 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 14: Energy intensities for public transport – road and rail transport

Public transport			Passengers		Vehicle demand average	Consumption per passenger average	Energy demand assumption for scenario calculation
			Average passengers per vehicle	Assumed occupation rate			
		Fuels			**litre/100 km**	**litre/100 pkm**	**[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**	**kWhel/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
		Fuels	**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**	**kWhel/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 tonne-km (tkm). The average energy intensities per tkm used in the scenarios are shown in Table 15 and are largely consistent with those from other sources in the scientific literature (EEA 2021).[40] The assumed energy intensities for electric and fuel cell/hydrogen freight vehicles are only estimates because these technologies are still in the demonstration phase. Therefore, none of the scenarios factor in large shares of electric freight transport vehicles before 2035.

Table 15: Energy intensities for freight transport – road and rail transport

Freight transport			Maximum load capacity (tonnes)	Assumed utilisation rate	Vehicle demand average	Consumption per tonne average	Energy demand assumption for scenario calculation
Trucks		**Fuels**			**litre/100 km**	**litre/tkm**	**[MJ/tkm]**
	3.5 t	Diesel	3.5	40%	11	7.9	3.16
	3.5 t	Bio	3.5	40%	11	7.9	2.57
	7.5 t	Diesel	7.5	40%	20	6.5	2.61
	7.5 t	Bio	7.5	40%	20	6.5	2.13
	12.5 t	Diesel	12.5	40%	25	5.0	2.01
	12.5 t	Bio	12.5	40%	25	5.0	1.64
		Electricity			**kWhel/100 km**	**kWhel/ton-km**	**[MJ/tkm]**
	3.5 t	Battery	3.5	40%	19	13.6	1.34
	3.5 t	Fuel Cell	3.5	40%	46	33.2	1.33
	7.5 t	Battery	7.5	40%	41	13.6	0.49
	7.5 t	Fuel Cell	7.5	40%	100	33.2	1.19
	12.5 t	Battery	12.5	40%	68	13.6	0.49
	12.5 t	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			**kWhel/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 a projection into the future. No up-to-date surveys are available. The annual passenger–kilometres (pkm) and tonne–kilometres (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 (average of 1.5 MJ/pkm), and SUVs and pick-up trucks (energy demand of 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. More statistical data about Africa's land transport is documented in Appendix C. However, the transport statistics for African countries are largely incomplete and are often based on estimates, rather than the documentation of actual data. The data presented in Table 16 have been calculated on the basis of the total transport energy demand divided by the average energy intensity per kilometre.

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

Table 16: Africa – projected passenger and freight transport demands under the 1.5°C scenario

		2019	2020	2025	2030	2035	2040	2045	2050
Road: passenger transport demand	[PJ/a]	3,433	3,187	3,429	3,429	3,255	3,917	3,203	4,778
Annual passenger kilometres	[billion pkm]	46,515	47,002	47,002	47,002	53,425	58,768	64,644	71,109
Average energy intensity – passenger vehicles	[MJ/pkm]	2	2	2	2	2	2	2	2
Annual demand variation	[%/a]	0%	0%	0%	0%	5%	10%	10%	10%
Road: freight transport demand	[PJ/a]	1,471	1,366	1,470	2,252	1,115	1,255	1,460	1,797
Annual freight kilometres	[million tkm]	70,552	53,232	50,403	50,403	53,232	53,232	53,232	53,232
Average energy intensity – freight vehicles	[MJ/tkm]	2	2	2	2	1	1	1	1
Annual demand variations	[%/a]	0%	0%	0%	0%	5%	5%	5%	5%

The total amount of passenger and freight kilometres is 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 that the transport demand will increase with population growth and GDP.

It is assumed that the annual passenger kilometres will increase by 3% annually until 2050, whereas the freight transport demand will increase by 2% annually. All assumptions and calculated energy demands are shown in Table 16. 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 passenger kilometre to 1.07 MJ/pkm in 2030 and to 0.54 MJ/pkm 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

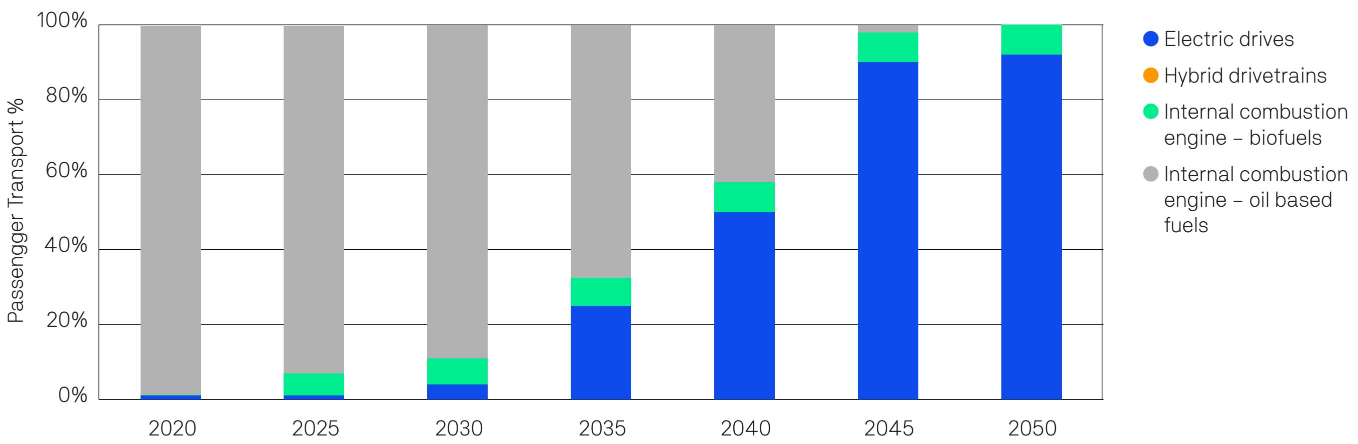
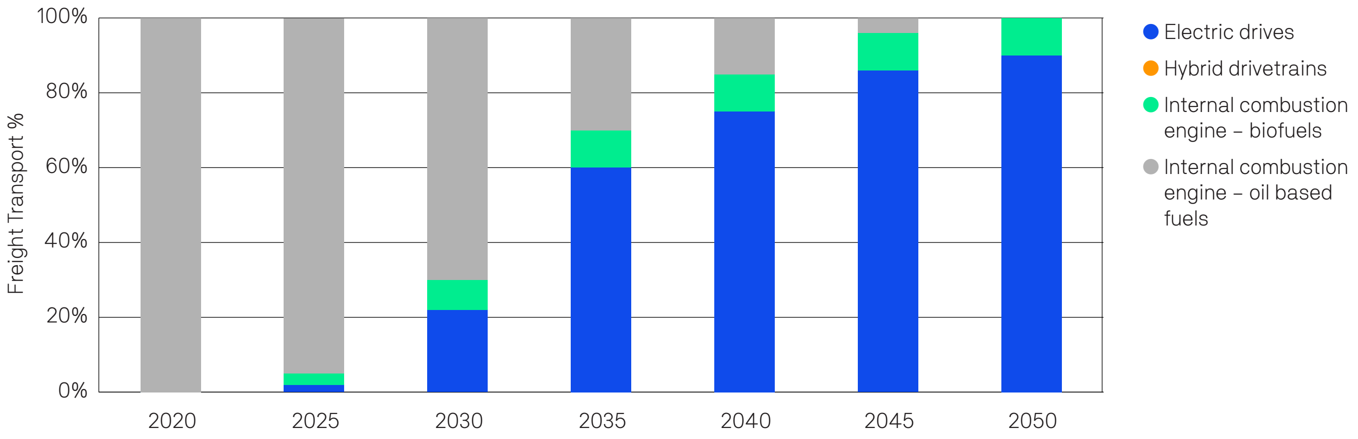


Figure 11: Freight transport – drive trains by fuel



The assumed trajectory for the transport sector (Figure 10 and Figure 11) is consistent with the Nationally Determined Contribution (NDC 2022)[41] report to the UNFCCC in July 2022. Several countries in Africa are aligning their transport sector strategies with the goals outlined in their NDCs. A significant focus is on enhancing the rail infrastructure, which is viewed as a more sustainable alternative to road transport. This commitment to developing rail systems aims to reduce GHG emissions and promote eco-friendly transportation options across the continent.

Countries such as Malawi are setting ambitious targets, aiming to achieve substantial reductions in emissions – such as a 51% reduction by 2040 compared with the business-as-usual scenario. This broader strategy is supported by significant investments in sustainable transport initiatives, indicating a regional push towards greener transport solutions that will benefit both the environment and public health.

Given that the majority of current vehicle/transportation sales within Africa are of bicycles and motorbikes, and given the life spans of these vehicles, a continent-wide overall market share of electric drives for the entire existing car fleet may not exceed 5% by 2030 for passenger and freight cars, given their high cost. In the long term, it can be expected that electric drive vehicles, whether they be electric-powered motorcycles or cars, will decrease in price as economies of scale increase, thus making these transportation options more viable because transport-kilometres increase with the increasing use of motorised transport.

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 upon the progress of electricity services. However, the decarbonisation of Africa'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 will be essential.

41 NDC 2023, Nationally determined contributions under the Paris Agreement. Synthesis report by the secretariat, Available at: https://unfccc.int/documents/632334

2.7 Technology and fuel cost projections

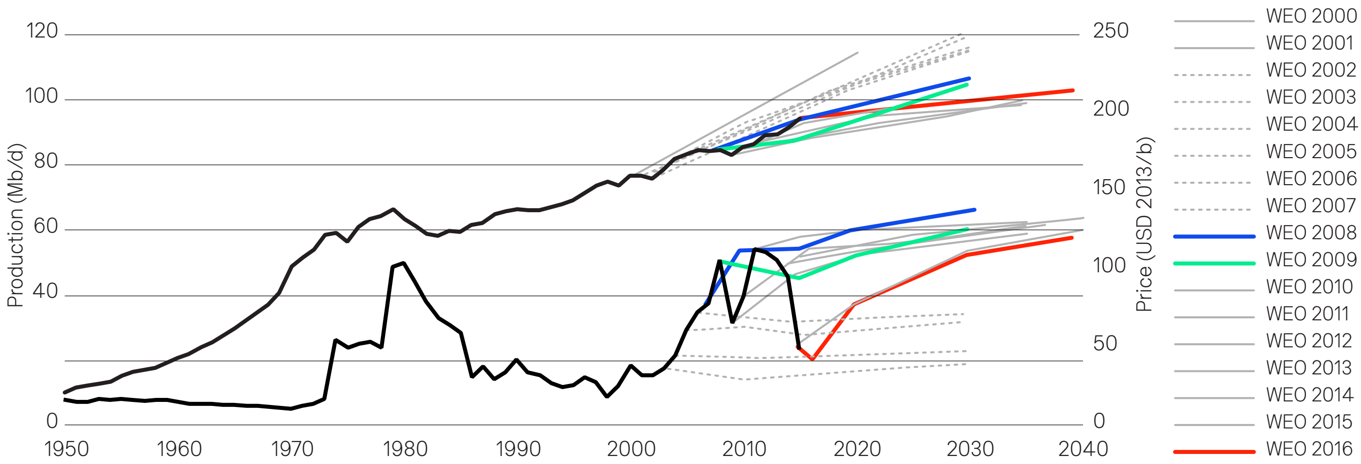
All cost projections in this analysis are based on a publication by Teske et al. (2019).[42] Section 5.2 is based on Chapter 5 of that book, written by Dr. Thomas Pregger, Dr. Sonja Simon, and Dr. Tobias Naegler of the German Aerospace Center/ DLR. The parameterisation of the models requires many assumptions 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. The projection of these costs is vital for our scenarios, 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, which 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 avoided electricity consumption 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).[43] Therefore, fossil fuel price projections have also seen considerable variations (IEA 2017;42 IEA 2013[44]) 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)

42 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.

43 IEA (2017): IEA (2017) World Energy Outlook 2017. International Energy Agency, Organization for Economic Co-operation and Development, Paris.

44 IEA 2013: IEA (2013) World Energy Outlook 2013. International Energy Agency, Organization for Economic Co-operation and Development, Paris.

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).[45] An evaluation of the oil price projections of the IEA since 2000 by Wachtmeister et al. (2018)[46] showed that price projections have varied significantly over time. Whereas the IEA's oil production projections seem comparatively accurate, 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 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 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 bioenergy 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[47]; Rubin et al. 2015[48]). Therefore, the reliability of cost projections largely depends upon the uncertainty of future markets and the availability of historical data.

Fossil fuel technologies provide a large cost data set 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, hydropower 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. However, 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, so cost assumptions must be made with particular care.

Furthermore, many technologies have only relatively small markets, such as geothermal, modern bioenergy 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 calculated internally, 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.

45 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. Accessed 10.9.2018 2018.

46 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

47 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

48 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

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),[49] which were based on a variety of studies, including the European-Commission-funded New Energy Externalities Development for Sustainability (NEEDS) project (NEEDS 2009), projections of the European Renewable Energy Council (Zervos et al. 2010),[50] 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 investments in the power sector and its 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.

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),[51] 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 17 summarises the cost trends for power technologies derived from the assumptions discussed above for Africa. It is important to note that the cost reductions are, in reality, not a function of time but of cumulative capacity (production of units), so dynamic market development must achieve a significant reduction in specific investment costs. Therefore, overall, we might underestimate the costs of renewables in the REFERENCE scenario relative to the With the Existing Measures (WEM) scenario and the AF-1.5°C scenario (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 at advanced stages of their 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. Hydropower 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.

49 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.

50 Zervos A, Lins C, Muth J (2010) RE-thinking 2050: A 100% Renewable Energy Vision for the European Union. European Renewable Energy Council (EREC).

51 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.

Table 17: Investment cost assumptions for power generation plants in US dollars (US$/kW) and the local currency (R/kW) until 2050

Assumed investment costs for power generation plants	2020	2025	2030	2040	2050
Technology	US$/kW	US$/kW	US$/kW	US$/kW	US$/kW
Coal power plants	2,018	2,018	2,018	2,018	2,018
Diesel generators	908	908	908	908	908
Gas power plants	504	504	504	504	676
Oil power plants	938	918	898	865	827
Hydropower plants*	2,674	2,674	2,674	2,674	2,674
PV power plants	989	744	736	565	474
Onshore wind	1,594	1,559	1,523	1,463	1,412
Offshore wind	3,723	3,097	2,472	2,295	2,119
Bioenergy power plants	2,371	2,346	2,320	2,220	2,129

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

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 the heat demand from renewable sources are still under development and rather expensive. Market barriers will slow the further implementation and cost reductions of 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 18 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/kWthermal (shallow) to €3,000/kWthermal (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 Africa. 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$1,450/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 to 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 are US$500–1,300/kW, and large biomass heating systems are assumed to reach their cheapest 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, at US$680/kW, by 2050. The cost 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 18: Specific investment cost assumptions (in US$2015) for heating technologies in the scenarios until 2050

Investment costs for heat generation plants		2020 US$/kW	2030 US$/kW	2040 US$/kW	2050 US$/kW
Solar collectors	Industry	820	730	650	550
	In heat grids	970	970	970	970
	Residential	1,010	910	800	680
Geothermal		2,270	2,030	1,800	1,590
Heat pumps		1,740	1,640	1,540	1,450
Biomass heat plants		580	550	510	480
Commercial biomass heating systems	Commercial scale	810	760	720	680
Residential biomass heating stoves	Small scale/Rural	110	110	110	110

2.7.3 Renewable energy costs in Africa in 2021

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

Table 19: Solar home systems – estimated costs

Solar home systems	US$	US$/kWpeak
10 W	46	4,572
20 W	86	4,322
50 W	159	3,186
55 W	173	3,152
60 W	184	3,059
80 W	210	2,629
100 W	250	2,495
Institutional solar power systems	**US$**	**US$/kWpeak**
1,000 W	2,277	2,277
2,000 W	3,816	1,908

Source: UTS-ISF own research, September 2024

Table 20: Solar dryers – estimated costs

Solar dryers [1 sqft = 0.0929 m²]	US$/m²
3–6 sqft (household)	617
10–15 sqft (household)	505
> 21 sqft (institutional)	464

Source: UTS-ISF own research, September 2024

Table 21: Solar cookers – estimated costs

Solar cookers	US$
Parabolic: household	196
Parabolic: institutional	1,200

Source: UTS-ISF own research, September 2024

Table 22: Biomass stoves – estimated investment costs

Biomass stoves	US$
Institutional improved stove – type 1	389
Institutional improved stove – type 2	408
Institutional improved stove – type 3	485
Natural draft stove	35
Forced draft stove	71
Improved metallic stove	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 2017* (IEA 2017). Beyond 2040, we extrapolated the price developments between 2035 and 2040 and present them in Table 23. Although these price projections are highly speculative, they provide prices consistent with our investment assumptions. Fuel prices for nuclear energy are based on the values in the Energy [R]evolution report 2015 (Teske et al. 2015) corrected by the cumulative inflation rate for the Eurozone between 2012 and 2015 of 1.82%.

Table 23: Development projections for fossil fuel prices in US$2015 (IEA 2023)

Development projections for fossil-fuel prices – all scenarios		2020	2021	2022	2025	2030	2035	2040	2045	2050
Crude oil	US$/GJ	10.72	10.73	10.74	10.78	10.55	10.11	9.44	8.11	6.67
Natural gas	US$/GJ	8.30	8.42	8.54	8.90	9.55	10.24	10.98	8.67	6.85
Hard coal	US$/GJ	2.46	2.45	2.45	2.44	2.33	2.22	2.00	1.89	1.78
Brown coal	US$/GJ	2.71	2.82	2.93	3.27	3.53	3.41	3.67	3.96	4.26
Uranium	US$/GJ	0.97	0.99	1.01	1.07	1.18	1.29	1.42	1.56	1.72
Biomass	US$/GJ	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33	8.33
Biofuel	US$/GJ	10.72	10.73	10.74	10.78	10.55	10.11	9.44	8.11	6.67
Synthetic fuels and Hydrogen	US$/GJ	16.67	16.67	16.67	16.67	9.55	10.24	10.98	8.67	6.85
Fossil fuel prices in historical units		**2020**	**2021**	**2022**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Crude oil	US$/barrel	66	66	66	66	65	62	58	50	41
Natural gas import	US$/Mbtu	8	8	8	8	9	10	10	8	7
Steam coal	US%/tonne	70	70	70	70	66	63	57	54	51

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)[52] 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.[51] 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).

Bioenergy prices in Africa in 2021

Table 24: Biogas prices – small quantities – average for African region

Biogas	2 m³ US$	4 m³ US$	6 m³ US$	8 m³ US$
Household – low-cost assumption	411	587	676	756
Household – average cost	481	647	749	817
Household – high-cost assumption	551	707	821	877

Source: UTS-ISF own research–September 2024

Table 25: Biogas prices – medium quantities – average for African region

Biogas	12.5 m³ US$	40 m³ US$	60 m³ US$	100 m³ US$
Household – low-cost assumption	2,171	6,255	8,304	12,112
Household – average cost	2,377	6,641	9,555	13,922
Household – high-cost assumption	2,582	7,027	10,806	15,731

Source: UTS-ISF own research, September 2024

52 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://doi.org/10.1111/gcbb.12162

3 Africa’s renewable energy potential

The solar and wind potentials of African countries were 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 Africa's renewable energy resources (solar and wind). It was also used in the regional analysis of geographic and demographic parameters and of the available infrastructure that could be leveraged in developing the scenarios. Mapping was performed with the software ESRI ArcGIS10.8, which performs spatial analyses and maps the results. It was used to allocate solar and wind resources and for the demand projections for each country. Projections of population density, access to electricity infrastructure, and economic development are also key input parameters in the region-specific analysis of Africa's future energy situation, to clarify the requirements for additional power grid capacities and/or microgrids.

The [R]E Space methodology is part of the OECM methodology used to map solar energy potential and onshore energy potential.[53] Open-source data and maps from various sources were collected and processed to visualise the continent. 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 26.

Table 26: Africa – [R]E space GIS-mapping – data sources

Data	Assumptions	Source
Land cover	Land cover classes suitable for solar energy and wind energy production were identified from Copernicus Global Land Cover 2019.	Copernicus Global Land Cover 2019
Digital elevation model (DEM)	For both wind and solar analyses, any land with a slope of > 30% was excluded from all scenarios.	SRTM 90m Digital Elevation Database v4[54]
Population and population density	Population data were derived from the United Nations Standard Population Database. Population density spatial dataset for 2020 was derived from the Socioeconomic Data and Application Center (SEDAC).	United Nations Standard Population Database Gridded Population of the World, Version 4 (GPWv4)[55]
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
Transmission lines and networks	Solar and wind potential of areas ≤ 10 km from transmission lines were considered (Scenario 2).	Africa – Electricity Transmission and Distribution Map (2017)[56]
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[57]
Wind speeds	Wind speeds ≥ 5 m/s at a height of 100 m were considered.	Global Wind Atlas[58]

The [R]E mapping procedure is summarised in Figure 13. The land areas available for potential solar and wind power generation were calculated and visualised at the national and provincial levels with ArcGIS. The land-cover map, elevation (digital elevation model, DEM), solar irradiation (direct normal irradiation, DNI), and wind speed data were obtained from the websites cited above as raster data, and were converted into binary maps (0 = area not suitable as a potential area, 1 = area suitable as a potential area) against all the assumptions in Table 26. They were then combined into one binary map by overlaying all the raster data. This map integrates all the criteria listed cited above into one map with a value of 1 (land included in the areas with potential) or a value of 0 (land not included in the areas with potential).

53 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

54 SRTM Digital Elevation Data Version 4: https://srtm.csi.cgiar.org/

55 Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11: Gridded Population of the World, Version 4 (GPWv4).

56 World Bank, Africa–Electricity Transmission and Distribution Map (2017): https://datacatalog.worldbank.org/search/dataset/0040465/Africa---Electricity-Transmission-and-Distribution-Grid-Map

57 Global Solar Atlas: https://globalsolaratlas.info/map

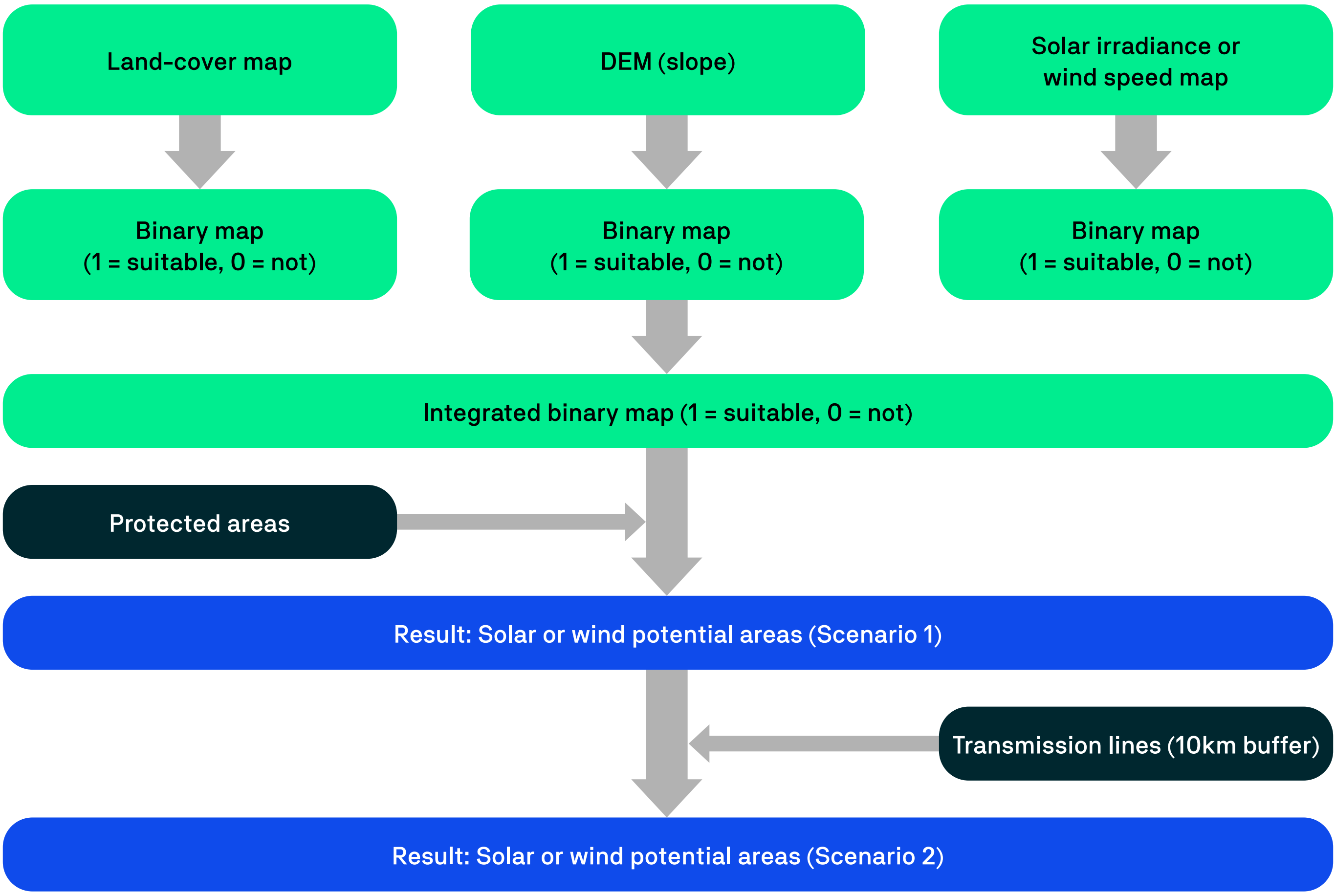
58 Global Wind Atlas: https://globalwindatlas.info/en

Data on transmission lines and protected areas exist as vector data. All protected areas were excluded from the above value 1 areas in the integrated raster data using a mask layer generated from the 'erase' function. For the continental scale, the output map was generated with 1 km resolution.

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 Africa, 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



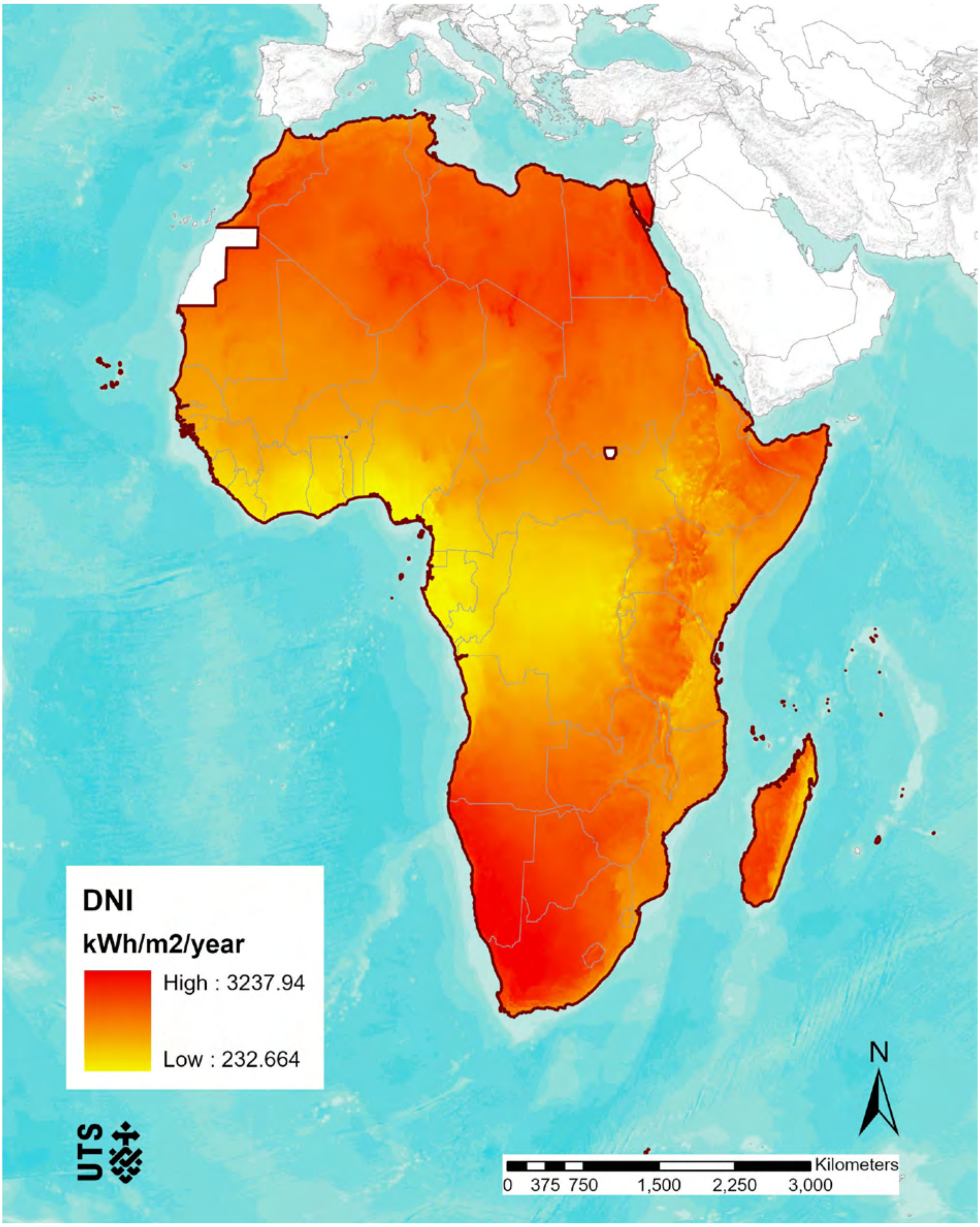
3.2 Mapping Africa

Africa has large untapped potential for renewable energy. As discussed in Section 2.3.1 Energy Supply, biomass is used extensively across the continent as a primary energy source for activities such as cooking and heating. This source of energy leads to a renewable energy share of > 45% across the historical period. This high share of renewable energy in the overall final and primary demands does not translate to a share of electrical power generation, because biomass plays a negligible role in electricity generation. Therefore, historically, renewable electricity generation has relied on hydropower. Thanks predominantly to the generation of hydropower, Africa was able to produce 22% of its electricity from renewable sources in 2020, with 147 TWh of hydropower helping to supply an electrical demand of 834 TWh (IEA 2022).

3.2.1 Solar potential

The average annual solar irradiation (DNI) levels across the African continent are shown in Figure 14, with DNI ranging between 233 and 3,238 kWh/m^2 per year. The higher end of that range is in the southwest, and central north of the continent.

Figure 14: Solar irradiation (DNI) levels in Africa



Source: generated from Global Solar Atlas data

Africa’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:** Scenario 1, with the additional restriction that excludes areas over 10 km from existing transmission lines (PT10).

Table 27: Africa’s potential for solar photovoltaic

	1. LU + PA + S30		2. LU + PA + S30 + PT10	
Scenarios	**Solar area (km²)**	**Solar potential (GW)**	**Solar area (km²)**	**Solar potential (GW)**
LDCs				
Angola	697,089	17,427	44,879	1,122
Benin	60,854	1,521	15,802	395
Burkina Faso	227,156	5,679	104,367	2,609
Burundi	19,776	494	12,105	303
Central African Republic	206,388	5,160	1,134	28
Chad	1,056,756	26,419	3,244	81
Comoros	297	7	-	-
Congo	33,266	832	5,245	131
Djibouti	19,086	477	4,762	119
Eritrea	83,977	2,099	6,552	164
Ethiopia	754,136	18,853	125,416	3,135
Gambia	8,518	213	2,118	53
Guinea	149,846	3,746	27,739	693
Guinea-Bissau	15,513	388	5,726	143
Lesotho	14,979	374	7,017	175
Liberia	2,535	63	527	13
Madagascar	414,259	10,356	7,338	183
Malawi	67,165 (68,619)*	1,679 (1,715)*	32,305 (32,413)*	808 (810)*
Mali	1,149,618	28,740	52,987	1,325
Mauritania	1,028,761	25,719	106,718	2,668
Mozambique	410,199	10,255	115,751	2,894
Niger	975,275	24,382	82,966	2,074
Rwanda	16,034 (16,177)*	401 (404)*	11,582 (15,540)*	290 (388)*
Sao Tome and Principe	29	1	-	-
Senegal	133,396 (133,225)*	3,335 (3,331)*	64,538 (64,182)*	1,613 (1,605)*
Sierra Leone	33,269	832	7,098	177
Somalia	616,777	15,419	20,804	520
South Sudan	465,927	11,648	67,610	1,690
Sudan	1,795,797	44,895	95,802	2,395
Togo	35,266	882	15,586	390
United Rep. of Tanzania	417,241 (434,985)*	10,431 (10,875)*	108,435 (109,290)*	2,711 (2,732)*
Uganda	153,298	3,832	131,635	3,291
Zambia	332,605	8,315	89,744	2,244

Scenarios	1. LU + PA + S30		2. LU + PA + S30 + PT10	
	Solar area (km²)	Solar potential (GW)	Solar area (km²)	Solar potential (GW)
Non-LDCs				
Algeria	1,029,229	25,731	46,121	1,153
Botswana	406,380	10,160	82,920	2,073
Cabo Verde	1,849	46	-	-
Cameroon	156,941	3,924	41,071	1,027
Dem Rep of the Congo	585,072	14,627	54,247	1,356
Cote d'Ivoire	115,051	2,876	36,854	921
Egypt	807,352	20,184	44,667	1,117
Equatorial Guinea	99	2	84	2
Eswatini (former Swaziland)	10,874	272	6,926	173
Gabon	5,275	132	560	14
Ghana	116,262	2,907	34,954	874
Kenya	457,923 (468,229)*	11,448 (11,706)*	59,195 (140,247)*	1,480 (3,506)*
Libya	1,608,519	40,213	73,102	1,828
Mauritius	126	3	–	–
Morocco	171,479	4,287	32,643	816
Namibia	482,397	12,060	295,856	7,396
Nigeria	584,197	14,605	184,779	4,619
Seychelles	–	–	–	–
South Africa	953,397	23,835	348,305	8,708
Tunisia	140,132 (139,748)*	3,503 (3,494)*	25,740 (30,032)*	644 (751)*
Zimbabwe	262,803	6,570	50,248	1,256
Africa total	**19,290,445**	**482,261**	**2,795,804**	**69,895**

*Note: The results provided in the country reports for Kenya, Malawi, Rwanda, Senegal, Tanzania, and Tunisia are provided in brackets. The results for Scenario 2 differ to a significant extent when the transmission network map data used in the country report reflect an updated or more detailed transmission network than the granularity provided on the continent-wide file.

Scenario 1: The results differ slightly between these country analyses and this continental-scale analysis because of differences in the map projections and the cell sizes used in the analyses, which are the basis for area calculations using GIS (250 m for the country analyses and 1 km for the continental-scale analysis).

Scenario 2: The results can differ significantly in Kenya, Rwanda, and Tunisia because of differences in the data sources used for the transmission lines for two different analyses. The country-scale dataset includes the detailed mapping of transmission lines, which results in larger potential areas and higher renewable energy potentials.

Figure 15: Africa – Areas of solar potential (Scenario 1: LU + PA + S30)

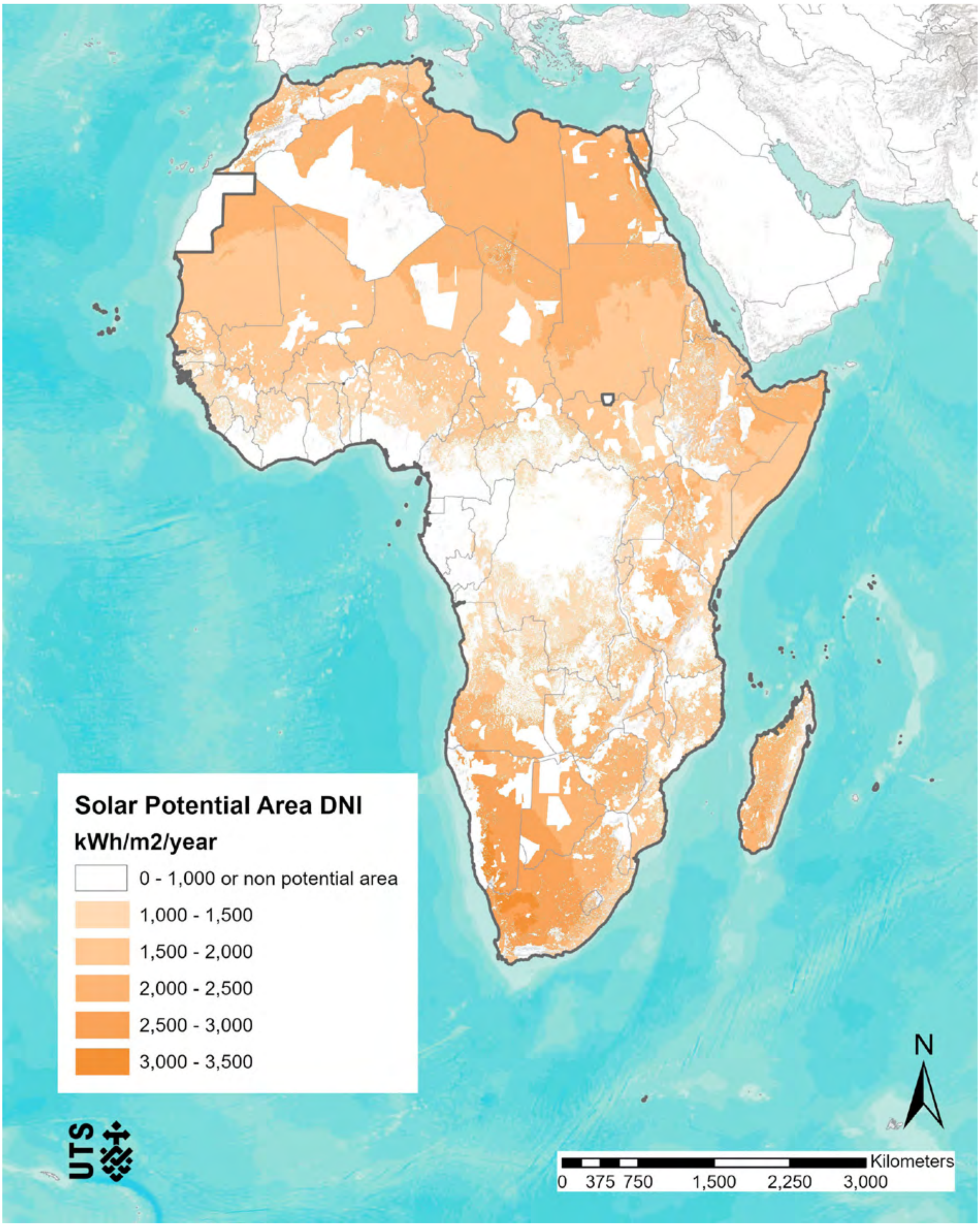
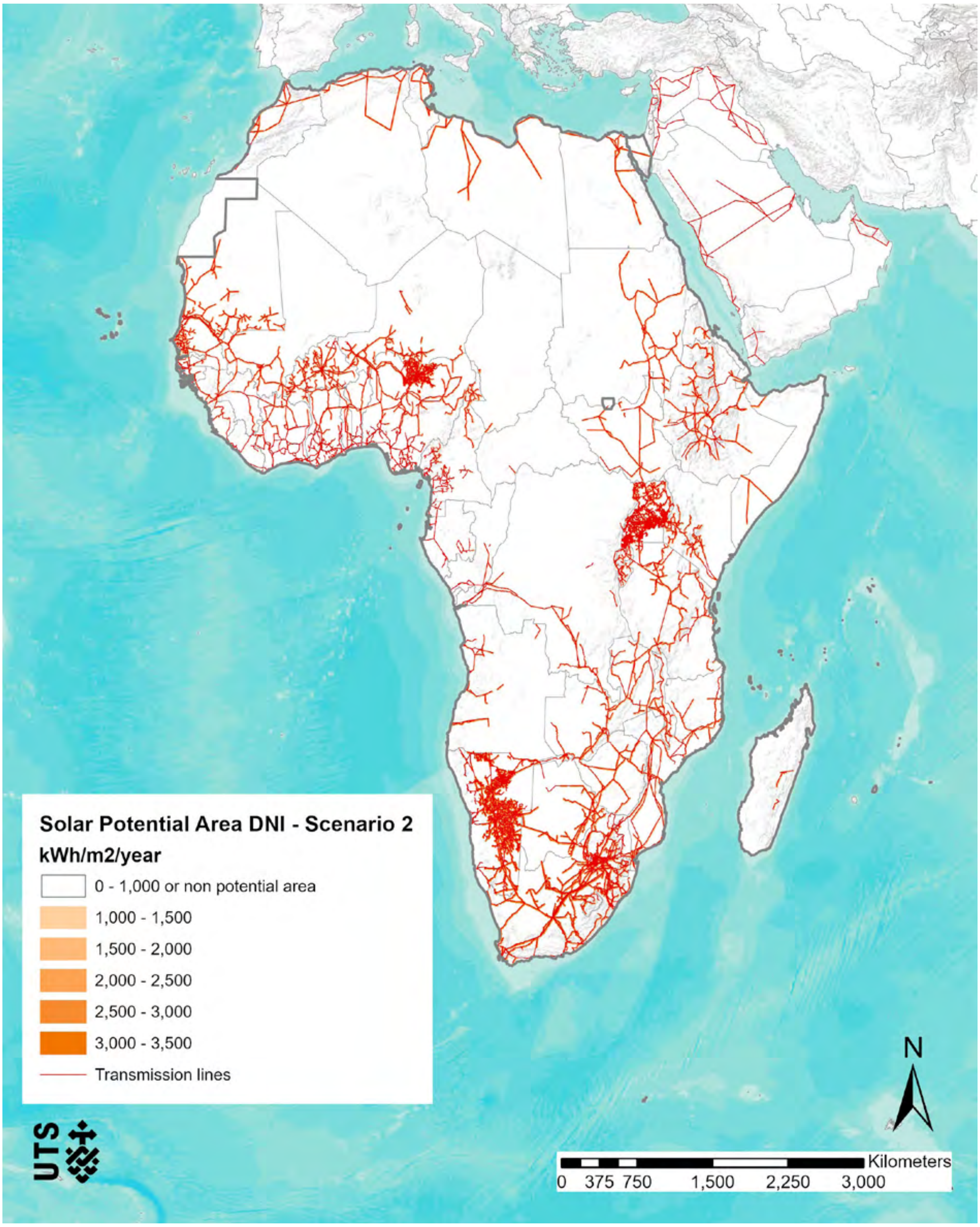


Figure 15 shows the results of a spatial analysis of the solar potential areas under Scenario 1 (LU + PA + S30). This scenario provides 19.3 million km^2 of areas with solar potential and a total potential for solar PV capacity of 482,261 GW. Scenario 1 excludes all protected areas and areas with slopes > 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 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 16 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 2.8 million km^2 in the total African countries. Under Scenario 2, utility-scale solar farms in Africa can potentially harvest 69,895 GW of solar PV.

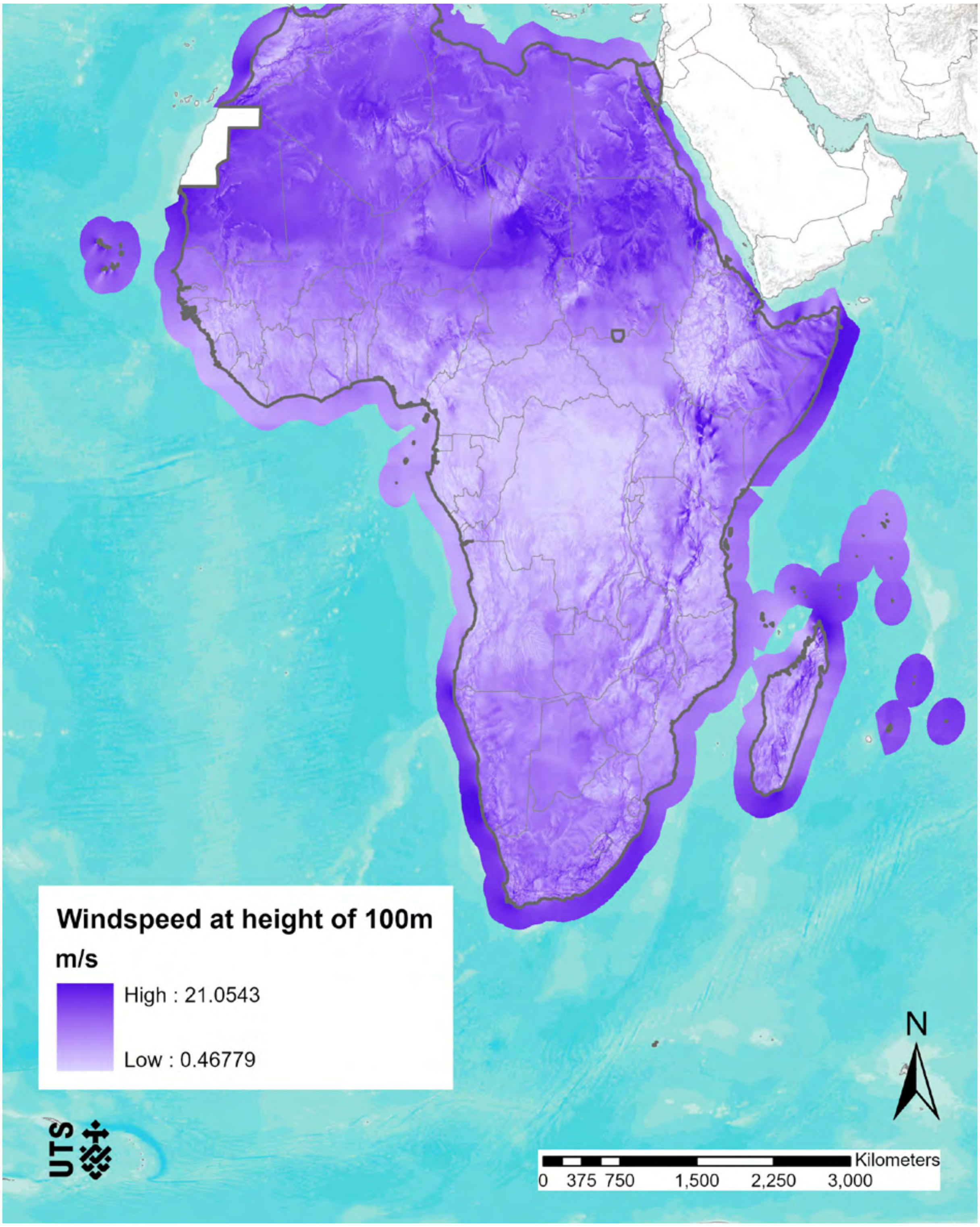
Figure 16: Africa – Areas of solar potential (Scenario 2: LU + PA + S30 + PT10)



3.2.2 Africa's Wind Potential

In Africa, the overall wind resources on land are significantly smaller than the solar potential. The wind speeds in Africa range from 0.5 to 21 m/s at 100 m height and are shown below in Figure 17 (Global Wind Atlas).

Figure 17: Africa – Windspeeds (at height of 100 m)



Source: generated from Global Wind Atlas data

In this analysis, we have included only areas with an average annual wind speed at 100 m height of ≥ 5 m/s. The wind potential of African countries has been mapped under:

- **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:** Scenario 1, with the additional restriction excluding areas more than or equal to 10 km from existing transmission lines (PT10).

The land-use classes 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 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 28 shows that the overall total onshore wind potential under all restrictions is 71,778 GW (14.4 million km^2) for Scenario 1. The spatial analysis identified wind potential of 8,738 GW (1.7 million km^2) in Africa under Scenario 2.

Table 28: Africa's potential for utility-scale wind power

	1. LU + PA + S30		2. LU + PA + S30 + PT10	
Scenario	**Wind area (km^2)**	**Wind potential (GW)**	**Wind area (km^2)**	**Wind potential (GW)**
LDCs				
Angola	176,749	884	6,040	30
Benin	28,274	141	9,958	50
Burkina Faso	185,207	926	85,943	430
Burundi	1,200	6	656	3
Central African Republic	18,187	91	-	-
Chad	900,416	4,502	1,062	5
Comoros	13	0	-	-
Congo	1,464	7	124	1
Djibouti	17,124	86	4,465	22
Eritrea	54,035	270	2,250	11
Ethiopia	355,121	1,776	30,910	155
Gambia	7,962	40	1,658	8
Guinea	5,840	29	1,085	5
Guinea-Bissau	1,451	7	808	4
Lesotho	8,555	43	3,503	18
Liberia	3	0	2	0
Madagascar	216,710	1,084	3,346	17
Malawi	38,852 (39,036)*	194 (195)*	16,715 (16,521)*	84 (83)*
Mali	1,058,651	5,293	32,502	163
Mauritania	1,028,384	5,142	106,436	532
Mozambique	175,387	877	54,439	272
Niger	972,038	4,860	81,719	409
Rwanda	288 (289)*	1 (1)*	196 (285)*	1 (1)*
Sao Tome and Principe	-	-	-	-
Senegal	117,686 (116,728)*	588 (584)*	60,055 (59,447)*	300 (297)*
Sierra Leone	248	1	53	0
Somalia	603,143	3,016	20,661	103
South Sudan	125,028	625	15,868	79
Sudan	1,728,566	8,643	91,884	459

Scenario	1. LU + PA + S30		2. LU + PA + S30 + PT10	
	Wind area (km²)	Wind potential (GW)	Wind area (km²)	Wind potential (GW)
United Rep. of Tanzania	152,704 (157,725)*	764 (789)*	46,215 (46,358)*	231 (232)*
Togo	10,658	53	6,483	32
Uganda	6,916	35	4,946	25
Zambia	197,054	985	58,922	295
Non-LDCs				
Algeria	984,128	4,921	33,853	169
Botswana	377,364	1,887	68,187	341
Cabo Verde	1,793	9	-	-
Cameroon	26,478	132	13,966	70
Dem Rep of the Congo	26,794	134	6,132	31
Cote d'Ivoire	20,550	103	7,402	37
Egypt	793,255	3,966	40,277	201
Equatorial Guinea	-	-	-	-
Eswatini (former Swaziland)	6,617	33	3,779	19
Gabon	871	4	57	0
Ghana	26,392	132	15,875	79
Kenya	322,028 (326,908)*	1,610 (1,635)*	13,428 (53,930)*	67 (270)*
Libya	1,605,588	8,028	72,102	361
Mauritius	208	1	-	-
Morocco	102,732	514	14,606	73
Namibia	439,207	2,196	272,469	1,362
Nigeria	370,229	1,851	122,609	613
Seychelles	61	0	-	-
South Africa	788,555	3,943	262,600	1,313
Tunisia	133,036 (132,165)*	665 (661)*	22,843 (26,525)*	114 (133)*
Zimbabwe	135,712	679	28,426	142
Africa total	**14,355,512**	**71,778**	**1,747515**	**8,738**

*Note: The results provided in country reports for Kenya, Malawi, Rwanda, Senegal, Tanzania, and Tunisia are provided in brackets, with results for Scenario 2 differing to a significant extent when the transmission network map data used in the country report reflect an updated or more detailed transmission network than the granularity provided on the continent-wide file.

Scenario 1: The results differ slightly between these country analyses and the continental-scale analysis because of differences in the map projections and the cell sizes used in the analyses, which are the basis for the areas calculated with GIS (250 m for country analyses and 1 km for the continental-scale analysis).

Scenario 2: The results can differ significantly in Kenya, Rwanda,. and Tunisia because of differences in the data sources for transmission lines used for two different analyses. The country-scale dataset includes detailed mapping of transmission lines, which resulted in larger potential areas and higher renewable energy potentials.

Figure 18: Africa – Areas of onshore wind potential (Scenario 1: LU + PA + S30)

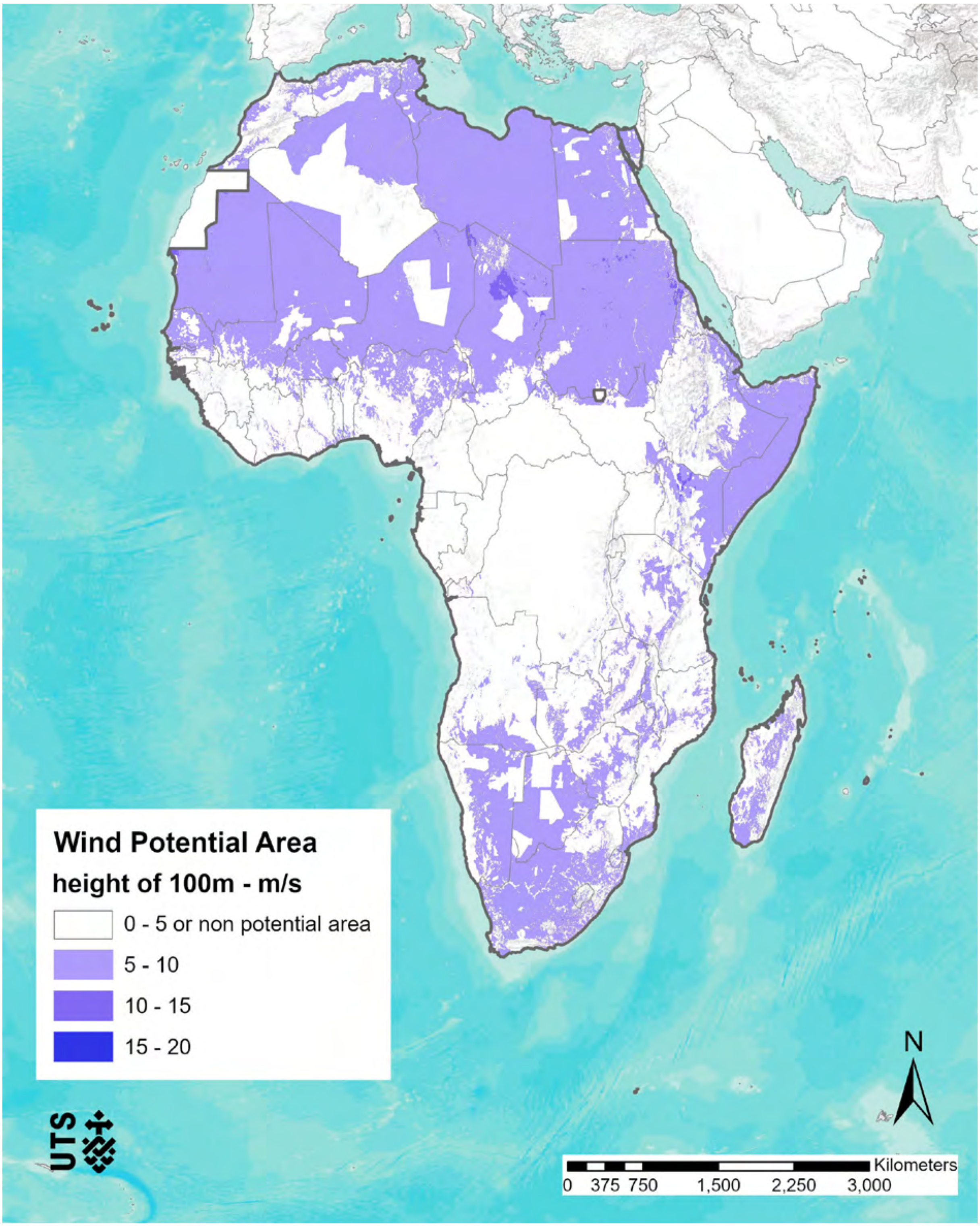
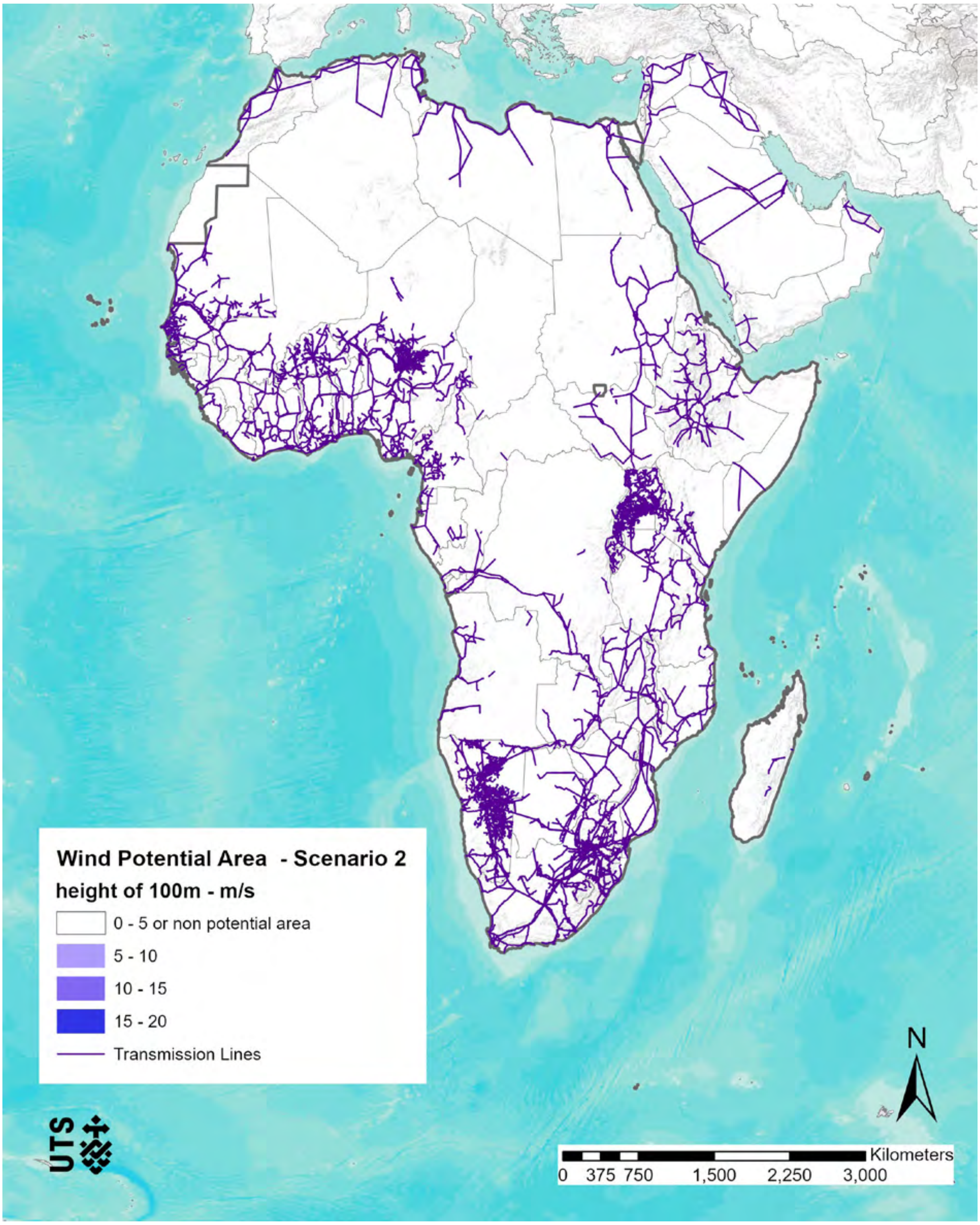


Figure 19: Africa – Average wind speed and existing power transmission lines under [R]E-Space Scenario 2: LU + PA + S30 + PT10



3.2.3 Land use assessment

The above sections of Chapter 3 outline the mapping of Africa's renewable potentials, and demonstrate that Africa has sufficient untapped renewable potential to power its sustainable development ambitions. The analysis in this section contextualises both the results of mapping the renewable potentials and the generation capacities outlined in the AF-1.5°C scenario (further details in Section 5.2.2).

Table 29 collates the total installed capacity under the AF-1.5°C scenario, the land use required to achieve the installed generation capacity, the percentage of generator land use relative to the suitable potential area for the generator type, using Scenario 1 as the reference point (outlined in Sections 3.2.1 and 3.2.2), and the percentage of the capacity land-use area relative to all of Africa's land mass. The land-use requirements for solar capacity were calculated with land-use factors of 40 km^2/GW for solar generation and 200 km^2/GW for onshore wind. The outcome shows that < 1% of Africa's total landmass will be required to achieve the AF-1.5°C scenario based on the assumptions outlined above and in Chapter 2.

Table 29: Africa – areas required for three types of renewable energy technologies under the most ambitious AF-1.5°C scenario

Technology		Units	2030	2040	2050
Solar PV	Total installed capacity under AF-1.5°C scenario	GW	190	946	2,615
	Land use required for installed solar capacity	km^2	7,603	37,820	104,600
	Percentage of solar potential area	%	0.04%	0.20%	0.54%
	Percentage of Africa's landmass	%	0.03%	0.12%	0.34%
Wind onshore	Total installed capacity under AF-1.5°C scenario	GW	38	174	562
	Land use required for installed wind capacity	km^2	7,553	34,838	112,374
	Percentage of onshore wind potential area	%	0.05%	0.24%	0.78%
	Percentage of Africa's landmass	%	0.02%	0.11%	0.37%

3.2.4 Assumptions for hydrogen and synthetic fuel production

In the AF-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 that will be supplied by extra renewable power production capacity, predominantly solar PV and hydropower. 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 possible.
- The transport sector will also rely increasingly on hydrogen as a renewable fuel, when battery-supported electric vehicles reach their limits and when 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 AF-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 Estimation of the ‘off-grid’ population in Africa

In the African continent, a sizeable percentage of the population still live without access to electricity. The number of people without access to electricity was estimated using spatial datasets of population density and transmission lines.

4.1 Methodology

A spatial analysis was conducted with the software ESRI ArcGIS10.8. Population density projection data (projection for 2020; persons/km^2) from the Socioeconomic Data and Applications Center (SEDAC)[59] and African continental-scale electricity transmission line data from the World Bank (2017)[60] were the key input data for this analysis. Population density is mapped in Figure 20, and the electricity transmission line network across the continent is mapped in Figure 21.

In this analysis, people who live more than 10 km from mapped transmission lines (including low-voltage to high-voltage lines) are considered the potential 'off-grid' population, i.e., people who live without access to electricity. The mean population density (persons/km^2) in the off-grid area by country was calculated with GIS, and simply multiplied by the land area of the off-grid area (km^2) to obtain estimated size of the off-grid population by country.

The limitations of this analysis are directly related to the availability of accurate data and the quality of the original input data. For example, the significant difference in the mapping details of transmission lines among countries could affect the results considerably.

Table 30: Estimated populations living > 10 km from transmission lines in Africa

	Country area (km^2)	'Off-grid' area (> 10 km from transmission lines) (km^2)	Mean population density (persons/km^2)	Estimate 'Off-grid' population	Comparison with UN population data (2020)[61]
LDC countries					
Angola	1,318,470	1,188,280	17.3	20,546,797	62.4%
Benin	119,470	82,230	64.1	5,271,059	40.9%
Burkina Faso	288,176	155,759	56.1	8,740,293	41.2%
Burundi	27,110	10,199	348.5	3,554,676	28.6%
Central African Republic	632,971	618,001	7.1	4,398,781	88.7%
Chad	1,380,390	1,266,260	12.4	15,751,200	93.0%
Comoros	1,731	1,647	522.9	861,310	100.0%
Congo	346,984	323,466	7.3	2,358,617	41.5%
Djibouti	22,761	16,155	23.4	378,736	34.5%
Eritrea	130,337	112,222	28.8	3,229,391	99.0%
Ethiopia	1,164,850	945,355	68.0	64,243,722	54.8%
Gambia	11,399	7,783	106.9	832,140	33.5%
Guinea	254,599	200,554	35.2	7,054,110	53.4%
Guinea-Bissau	35,401	23,144	46.8	1,084,178	54.5%
Lesotho	40,551	18,797	37.9	712,157	32.0%
Liberia	97,705	75,946	26.7	2,027,734	39.8%
Madagascar	669,475	581,000	41.0	23,795,601	83.2%
Malawi	126,126	74,521	106.0	7,900,069	41.0%
Mali	1,390,830	1,196,820	11.6	13,849,370	64.8%
Mauritania	1,188,630	928,995	1.5	1,438,336	31.7%

59 Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11: Gridded Population of the World, Version 4 (GPWv4).

60 World Bank, Africa – Electricity Transmission and Distribution Map (2017): https://datacatalog.worldbank.org/search/dataset/0040465/Africa---Electricity-Transmission-and-Distribution-Grid-Map

61 UN Population Division, World Population Prospects 2024, demographic indicators by region, sub-region, and country, annually for 1950–2100.

	Country area (km²)	'Off-grid' area (> 10 km from transmission lines) (km²)	Mean population density (persons/km²)	Estimate 'Off-grid' population	Comparison with UN population data (2020)[61]
Mozambique	871,244	610,155	28.3	17,238,861	56.8%
Niger	1,307,500	1,093,170	12.5	13,690,634	58.7%
Rwanda	25,481	8,737	406.3	3,549,685	27.5%
Sao Tome and Principe	997	990	219.4	217,208	100.0%
Senegal	210,488	114,646	31.5	3,613,460	21.8%
Sierra Leone	74,499	58,083	70.1	4,074,131	52.1%
Somalia	647,027	612,064	16.2	9,896,908	60.6%
South Sudan	658,039	251,140	25.8	6,486,892	61.4%
Sudan	2,020,350	1,748,000	18.2	67,214,855	68.8%
United Rep. of Tanzania	959,839	794,298	38.7	30,732,127	51.2%
Togo	58,353	30,718	94.2	2,892,413	33.8%
Uganda	243,281	65,827	45.8	3,016,906	6.9%
Zambia	800,282	617,430	17.0	10,481,620	55.8%
Non-LDCs					
Algeria	2,999,670	2,249,630	13.5	30,377,818	69.5%
Botswana	678,650	485,249	2.7	1,315,245	56.0%
Cabo Verde	4,421	4,063	132.6	538,641	100.0%
Cameroon	473,560	366,137	33.6	12,294,933	47.5%
Dem Rep of the Congo	2,363,240	2,226,170	40.0	88,952,170	94.2%
Cote d'Ivoire	329,893	212,343	55.0	11,685,751	40.9%
Egypt	1,238,260	936,142	36.4	34,094,838	31.4%
Equatorial Guinea	27,048	17,857	54.2	966,988	57.0%
Eswatini (former Swaziland)	21,789	6,180	48.4	299,342	25.3%
Gabon	264,788	234,987	7.4	1,743,287	75.9%
Ghana	245,226	141,902	66.0	9,363,403	29.7%
Kenya	590,959	510,342	51.6	26,352,214	51.0%
Libya	2,053,420	1,542,800	3.2	4,904,510	70.1%
Mauritius	2,285	2,004	636.8	1,275,980	99.3%
Morocco	576,215	366,016	46.3	16,930,727	46.5%
Namibia	968,500	451,990	0.5	244,624	9.1%
Nigeria	942,383	618,252	147.7	91,287,298	43.1%
Seychelles	446	436	230.1	100,361	84.4%
South Africa	1,606,070	786,788	13.9	10,919,845	18.2%
Tunisia	227,362	128,399	43.1	5,537,023	46.6%
Zimbabwe	439,759	330,812	27.9	9,228,452	59.9%
Africa total		**25,450,891**		**720,026,473**	**50.2%**

Figure 20: Africa – Population density

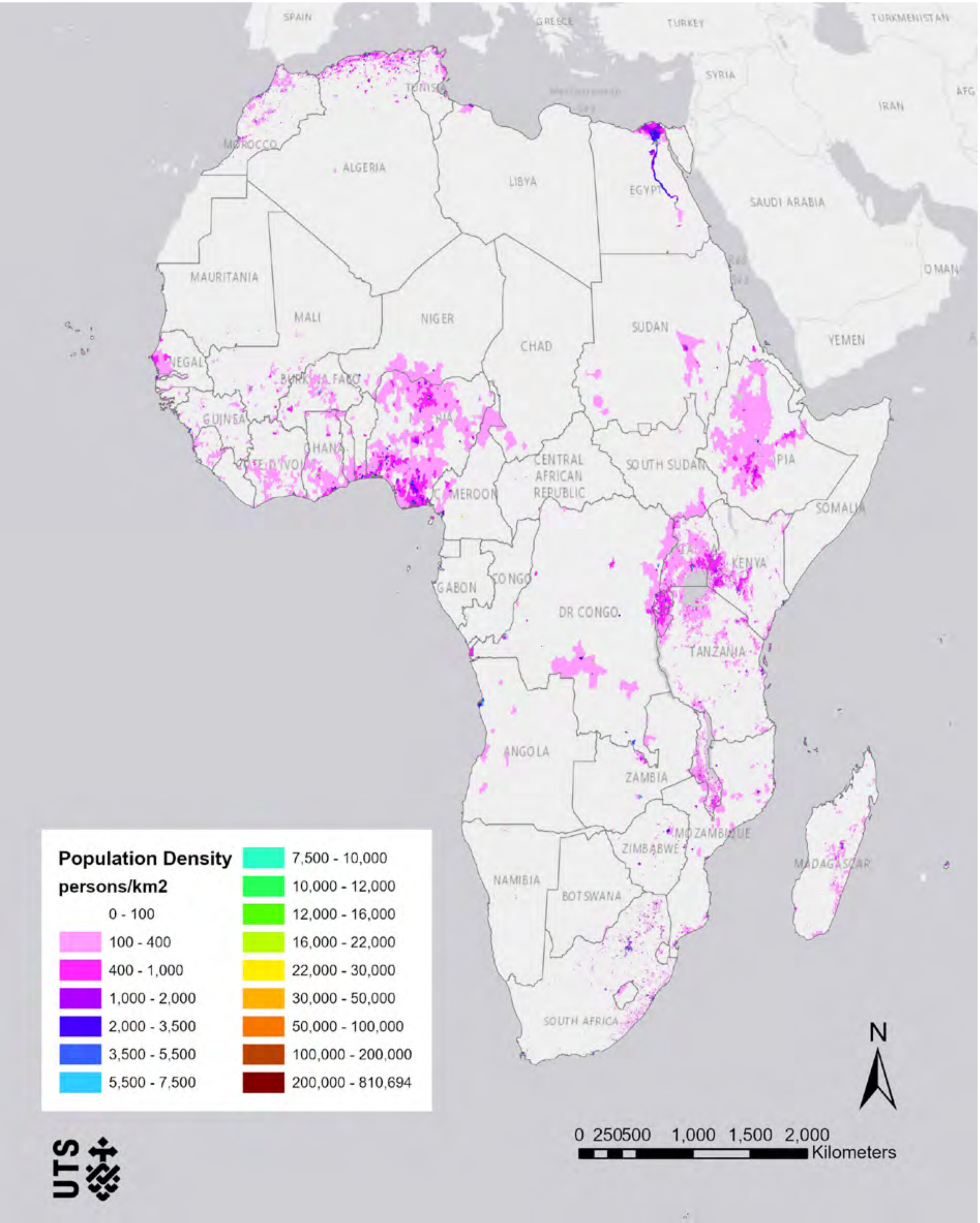
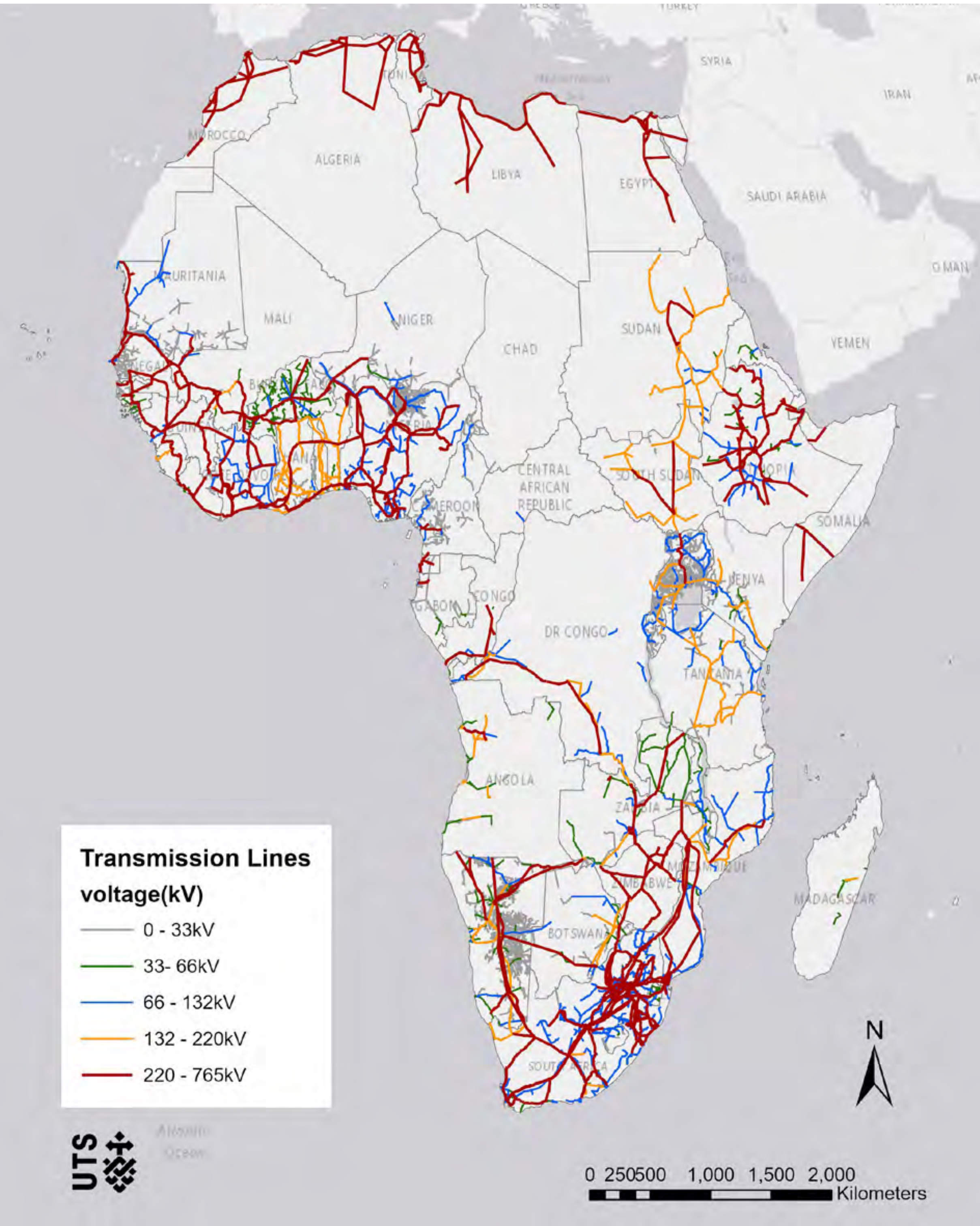


Figure 21: Africa – Existing transmission lines



4.2 Estimation of 'off-grid' population

Our analysis estimates that approximately 720 million people are living in areas far from transmission lines. This is the population that is assumed to live without access to electricity. The sizes of the estimated 'off-grid' populations are summarised by country and compared with the UN population data in Table 30.

4.3 Estimation of 'stand-alone-grids' market potential

Providing access to electricity services for over half a billion people
Access to electricity services can be achieved either by expanding the central grid or by building off-grid generation capacity close to consumers. Although various technical options are possible, there are two main options: grid expansion and decentralised island grids with distributed generation.

4.3.1 Bottom-up electrification

Grid expansion – the top-down approach
Expanding the existing electricity grid is the conventional way of ensuring access to modern energy services. For a village that is not yet electrified, connecting to the grid is considered the preferred option, because it is then directly integrated into the central grid and the country's electricity company – often organised as a monopoly – can be contracted to provide it. However, in Africa, the central grid supply is often insufficient to meet all the demand, and small rural connections are often cut in favour of supplying cities and industries, leading to frequent power outages. Another problem is that centralised grid operators often do not know exactly how much electricity is being used or where in the system it is used due to a lack of metering equipment and rampant energy theft. This makes it difficult to control power quality, e.g., maintaining voltage and frequency within normal operating limits. Moreover, in some cases, rural communities cannot afford the connection costs even if grid expansion is the cheaper option.

Off-grid power generation – the bottom-up approach
Stand-alone grids with distributed renewable generation and storage support are a way to move from rural electrification to a fully integrated grid while promoting renewable energy. Stand-alone grids can be sized in different capacities, from a few kilowatts to several megawatts. The main advantage of island grids is that they can be implemented in different locations at the same time – no central planning is required. Furthermore, these stand-alone grids can be interconnected later. Thus, interconnected stand-alone grids can form a nationwide electricity grid over time – bottom-up grid expansion.

Stand-alone grids that can switch between stand-alone and grid operation represent a particularly interesting case. These stand-alone grids are distribution networks that can be developed with a bottom-up approach, such as home energy systems and off-grid systems that use local renewable energy sources to meet local demand. However, unlike these stand-alone systems, the power supply is more flexible and reliable, with the option to source from local or central generation depending on availability and price. This allows cheap power to be sourced from the grid during periods of low demand, while during power outages on the main grid, the local supply can be activated to meet local needs. Furthermore, microgrids can manage the balance between local supply and demand, thereby manipulating the flow of power at the common interconnection point with the grid. This allows the microgrid to assist the larger grid in managing the power quality and the security of supply by injecting or consuming active or reactive power as needed and assisting with black starts (start of the electricity supply after a total back-out).

Technical definitions – various sizes of stand-alone grids

1. Energy homes systems

Home energy systems are for the basic electrification of a single household or building. They consist of a small generator, often solar PV or wind powered, with a battery and a charge controller. This type of system is designed to be connected directly to DC loads of 15–150 Watt_{peak}, such as lamps, radios, televisions, and refrigerators. For AC loads, an inverter is necessary. The charge controller connects the generator to the battery and controls the state of charge. The battery will often have 3–5 days storage capacity.

2. Off-grid distribution systems

Off-grid distribution systems are essentially a small version of the central grid. They connect several loads with several generation sources and a central controller manages the supply–demand balance. These systems are often used for powering remote communities where the cost of extending the central grid is considered too high. There are many systems in operation around the world and they are well suited to the exploitation of local renewable energy resources. However, due to the seasonal fluctuations in and the weather dependence of many of these sources, it is best to use a combination of energy sources to ensure a continuous supply. For example, variable sources, such as solar, wind, and run-of-river hydro, should be coupled to batteries, or biomass-based generators that can adapt quickly to fluctuating conditions. These are called ‘hybrid systems’ and can be designed as DC systems or mixed DC/AC systems.

3. Microgrids

Microgrids are distribution systems consisting of loads and generators balanced with a controller, as with the off-grid distribution system, but connected to the grid at a single point of connection – called the ‘point of common coupling’. The unique feature of microgrids, in this sense, is the ability to switch between grid-connected and island operation modes. This allows flexible operation to access grid supply at times when local demand is high, exceeding the local generation capacity, or when the grid power prices are low, while using local generation when there is a supply shortage in the central grid or when the grid power prices are high. This increases the reliability of supply to microgrid customers while simultaneously supporting the central grid by creating a generation/demand block, which can be controlled to act as a load or a generator and maintain the voltage at the point of common coupling. It may also be possible for the microgrid to contribute to black starting the central grid.

4. Distributed generation systems

Distributed generation systems are small-scale generators connected to the distribution network of the central grid. Electrically, they act to reduce the distribution load that the central grid sees at the point of common coupling. Because reactive power can also be injected, voltage support can be offered to a certain extent. However, unlike microgrids, distributed generation is not made to balance the local demand by a central controller and cannot run disconnected from the central grid.

There are strengths and weaknesses of each of the documented stand-alone systems versus the centralised grid approach.

Table 31: Strengths and weaknesses of different energy access options

Energy Access Alternatives	Pros	Cons
Stand-alone Hybrid Energy Sources (HES) (island)	– Lowest capital cost due to small unit size – No transmission or distribution lines must be built – Fast and simple construction – No change in regulation required – Reliable supply can be sustained when grid is down	– Supply accessible to only one user – (No benefit from economy of scale)
Minigrid system (island)	– No transmission lines must be built – Supply can be shared between multiple users – No change in regulation required – Reliable supply can be sustained when grid is down	– Distribution lines must be built – Requires localised balancing control – Effective payment structure must be established – Minigrid operator must be established
Microgrid system (island ↔ grid)	– Investment in transmission extension can be delayed until it is economically justified – Supply can be shared between multiple users – Reliable supply can be sustained when grid is down – Supply from grid can be accessed when energy is cheaper and/or during local generation outage – Excess local supply can be fed to the grid – Microgrid can support grid voltage and black start operation	– Distribution lines must be built – Requires localised balancing control – Requires an effective independent payment structure until grid access is available – An operator of the island grid must be established until grid access is available – Requires communication and control equipment to switch between operation modes – Requires review of protection equipment and regulation
Grid extension with distributed generation (DG) (grid)	– Access to economies of scale – Access to centralised balancing control – No change in regulation required – No new payment structure must be developed for consumers	– Transmission and distribution lines must be built – Reliability of supply is dependent upon centralised system (small villages are unlikely to become high-priority areas for maintaining delivery of high-quality reliable supply) – Small load on a long feeder is prone to voltage problems
Distributed generation (grid)	– Supply can be shared between multiple users – Access to centralised balancing control – Can support grid voltage and black start operation – No new payment structure must be developed for consumers	– Highest capital cost because transmission and distribution lines must be built as well as generation units – Reliability of supply is dependent upon centralised system (small villages are unlikely to become high-priority areas for maintaining delivery of high-quality reliable supply) – Requires review of regulation – Power purchase agreements must be established

Source: ‘e[r] cluster’ for a smart energy access – The role of microgrids in promoting the integration of renewable energy in India. Martensen N, Kuwahata R, Ackermann T, Teske S et al., May 2012

4.3.2 Estimated market potential of stand-alone-grids

The potential investment in stand-alone grids was estimated based on the number of people that live further than 10 km from a power grid, the projected residential electricity demand (see Section 5.2.2), and the calculated average electricity generation costs (see Section 5.2.7). Table 32 provides an overview of the assumptions and the key results.

Table 32: Key parameters – stand-alone grids

		2020	2025	2030	2035	2040	2045	2050
Population	[x 10^6]	1,361	1,530	1,711	1,899	2,093	2,290	2,485
No access to power grid	[x 10^6]	720	811	736	627	481	298	12
Persons with no electricity access	[%]	53%	53%	43%	33%	23%	13%	1%
Progress ratio	[%/a]			2.0%	2.0%	2.0%	2.0%	2.5%
Potential NEW stand-alone grid customers	[x 10^6]	0	0	75	184	329	513	798
Residential electricity demand	[TWh/a]	410	474	551	652	781	949	1,179
Average residential electricity demand per person	[kWh/a]	640	659	565	512	484	476	477
Stand-alone grid–supply	[TWh/a]			43	94	160	245	381
Average electricity costs–stand-alone grids	[US$ cent/kWh]	0.09	0.09	0.13	0.11	0.09	0.11	0.10
Total electricity value–stand-alone grids	[million US$/a]	0	0	54	108	150	264	396
Investment in stand-alone grids	[million US$/a]			51	103	142	250	376

Under the assumptions that the average electricity demand per person supplied by stand-alone grids is similar to that in grid-connected areas and that electricity generation costs are at the same level as the grid-connected system, stand-alone grids will reach an annual electricity supply market volume of around US$250 million per year in 2030 and grow to just over US$375 billion by 2050.

A detailed investment plan to implement an African stand-alone power-generation network that supplies over 500 million people was not within the scope of this research. However, the high-level cost estimate (see cost assumptions documented in Section 2.7) means that the investment required in power generation and stand-alone grid equipment will be around US$6.2 billion between 2025 and 2050, equivalent to an annual average investment of US$250 million.

5 Key results – Africa’s long-term scenario

Africa 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 and offshore 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 2023.[62]

Africa 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 relative to those in countries with more stable policies.

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

- **Policy stability:** This research assumes that Africa 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, namely 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 rooftop 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:** The three scenarios are based on the same population and GDP assumptions. Projections of population growth are taken from the *World Population Review*,[63] whereas the GDP projections have been estimated based on a detailed assessment of over 50 African countries and projected under the assumption that all African countries will successfully develop towards middle-income countries. Further details are documented in Appendices 10 and 11.
- **Cost assumptions:** The cost assumptions are documented in Section 2.

Three energy scenarios have been developed for the African continent: the REFERENCE scenario, the AF-Pledges scenario, and the AF-1.5°C scenario. The corresponding assumptions are documented in the following section.

5.1 Assumptions for the REFERENCE scenario

The REFERENCE scenario for Africa is based on the Stated Policies Scenario (STEPS) scenario published in the International Energy Agencies' World Energy Outlook (IEA WEO) 2024.[64] IEA's STEPS scenario is further broken down into world regions, one of which is 'Africa'. Whereas the IEA documents all assumptions, it takes the basic assumptions – such as the development of the energy supply mix for electricity, and the heat and fuels required for transport and industry – into account, the estimation of GDP differs to reflect the overarching research goal of transitioning all African countries towards middle-income countries. Therefore, the growth rates of Africa's GDP development until 2050 are higher than in the IEA STEPS scenario, which leads to significantly higher energy demands across all sectors (buildings, transport, and industry). The REFERENCE scenario follows the IEA STEPS scenario in terms of increasing energy-related CO_2 emissions until 2050.

62 REN21 – Global Status report 2023.

63 World Population Review, online database, viewed August 2024, https://worldpopulationreview.com/

64 International Energy Agency – World Energy Outlook 2024, https://www.iea.org/reports/world-energy-outlook-2024

5.1.2 Assumptions for the African Pledges scenario

The Africa-Pledges (AF-Pledges) scenario is based on the IEA's Announced Pledges Scenario (APS) – also published in October 2024 as part of the World Energy Outlook (IEA WEO 2024). The APS examines what would happen if all national energy and climate targets made by governments, including net-zero goals, are met in full and on time. Again, the regional part of Africa in the APS scenario has been recalculated with the assumption of a higher GDP, but the same 'scenario logic'. Whereas the global implementation of the IEA STEPS scenario would lead to a global temperature rise of around +2.5°C, the IEA APS would lead to +2.0°C.

5.1.3 Assumptions for the Africa 1.5°C scenario

The Africa 1.5°C (AF-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 AF-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 renewables industry:** Dynamic growth in new capacities for renewable heat and power generation is assumed based on current knowledge of the potentials, 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 local populations, 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. Coal power plants will be phased out early, followed by gas power plants.
- **Future power supply:** The capacity of large hydropower will remain flat in Africa over the entire scenario period, whereas the quantities of bioenergy 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 contributions of bioenergy and wind energy. The figures for solar PV combine rooftop 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 hydropower, and hydro pump storage.
- **Sustainable biomass levels:** Africa's sustainable level of biomass use is assumed to be limited. However, the estimates of sustainable bioenergy potentials for Africa vary significantly between 200 PJ/year and over 20,000 PJ/year. The assessment report *Biomass Potential in Africa*,[65] published by the International Renewable Energy Agency (IRENA) in co-operation with the German Biomass Research Centre (DBFZ), provides a detailed overview about different bioenergy resources and their potentials. However, the use of low-tech biomass, such as inefficient household wood burners, is largely replaced in the AF-1.5°C scenario by state-of-the-art technologies, primarily highly efficient heat pumps and solar collectors.
- **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 scenario assumes the limited use of biofuels for transportation, given the limited supply of sustainable biofuels.

65 Biomass Potential in Africa, International Renewable Energy Agency (IRENA) and German Biomass Research Centre (DBFZ) 2013, https://www.irena.org/publications/2013/Aug/Biomass-Potential-in-Africa

- **Hydrogen and synthetic fuels:** Hydrogen and synthetic fuels generated by electrolysis using renewable electricity will be introduced as a third renewable fuel in the transport 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 and liquid fuels, depending upon the economic benefits (storage costs versus additional losses) and the technological and market development in the transport sector (combustion engines versus fuel cells). Because Africa’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.

Africa’s 1.5°C scenario (AF-1.5°C) takes an ambitious approach to transforming Africa’s entire energy system to an accelerated new renewable energy supply. However, under the AF-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 latter sector, there will be a strong role for storage technologies, such as batteries, synthetic fuels and hydrogen.

The resulting final energy demand for transportation will be lower than that under the With the Existing Measures (WEM) scenario, based on the assumptions that:

- future vehicles, and particularly electric vehicles, will be more efficient; and
- there will be a greater improvement in the public transport system in (AF-1.5°C).

Under the AF-1.5°C scenario, the share of electric and fuel-cell vehicles will increase. This scenario also relies on a greater production of synthetic fuels from renewable electricity, for use in the aviation, marine transport, and industry sectors. Renewable hydrogen will be converted into synthetic hydrocarbons, which will replace the remaining fossil fuels, particularly for process heat generation for the industrial sector, the chemical industry, and steel production – 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 Africa’s energy plan because the costs in the early developmental stages are relatively high.

It is assumed that synthetic fuels and hydrogen will not enter Africa’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 developing countries. 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 this scenario, assuming that power from renewable energy sources will be the future’s main ‘primary energy’.

The AF-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. The increased implementation of a district heating infrastructure (interconnections of buildings in central business districts), bioenergy-based heat generation, and solar collectors and heat pumps for office buildings and shopping centres in larger cities are assumed, leading to a growth in the electricity demand that partly offsets the efficiency savings in these sectors. A rapid expansion of solar and geothermal heating systems is also assumed.

The increasing share of variable renewable power generation, principally solar PV, will require the implementation of smart grids and the fast interconnection of micro- and minigrids 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.

5.2 Africa – energy pathway until 2050

The following section provides an overview of the key results of the three different energy scenarios for Africa. The energy scenarios by no means claim to predict the future. Instead, they provide useful tools to describe and compare potential development pathways from the broad range of possible 'futures'. The AF-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 serve as a reliable basis for further analyses of the possible concepts and actions required to implement technical pathways to achieve measurable results.

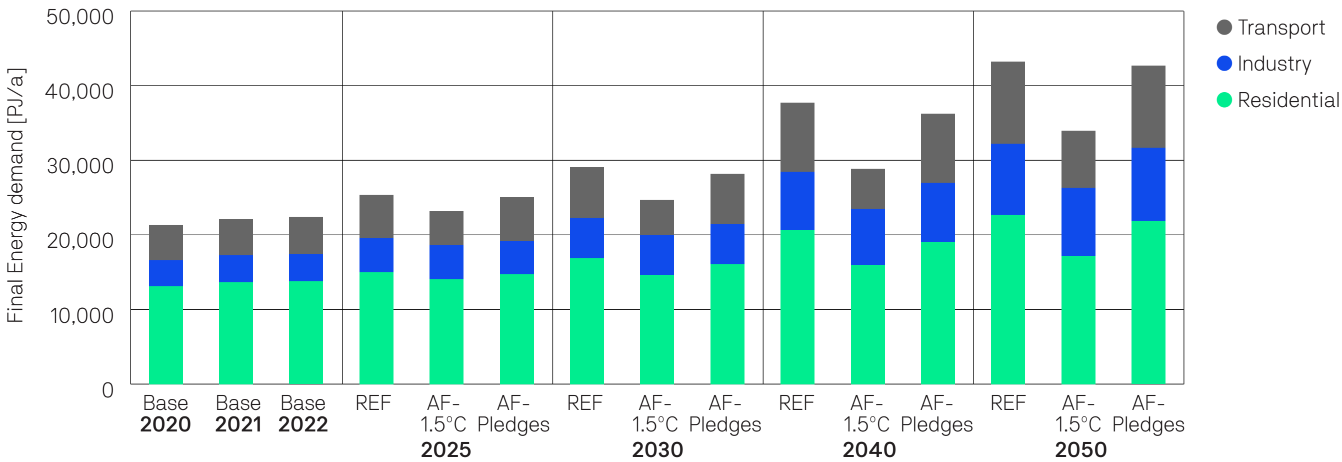
5.3 Africa – Final energy demand

The projections of population development, GDP growth, and energy intensity were combined to project the future development pathways for Africa's final energy demand. These are shown in Figure 22 for the 'REFERENCE', the 'AF-Pledges' and the AF-1.5°C scenarios. In the REFERENCE scenario, the total final energy demand will almost double from 23 EJ/a to 43 EJ/a in 2050. The AF-1.5°C scenario will lead to an increase in the final energy demand of only 50% to 34 EJ/a – mainly due to higher electrification rates in transport, process heating (industry), and cooking for the residential sector.

As a result of the projected continued annual GDP growth of 4.5% on average until 2025 and 5.5% thereafter until 2050, the overall energy demand is expected to grow under all three scenarios (Figure 22). The residential sector will remain dominant in Africa's energy demand, but the energy demand of the industry sector will increase constantly. By 2050, industry will consume at least four times more energy than in 2020, making this sector the second highest consumer after transport in all three scenarios.

The energy demand of the transport sector will double by 2050 under the REFERENCE scenario, whereas it will increase by 50% under the AF-1.5°C scenario. The main reason for the significant difference in these growth projections is the high rates of electrification in the latter pathway. The large efficiency gains achieved in the AF-1.5°C pathway are attributable to the high electrification rates, mainly in the cooking and transport sectors, because combustion processes with high losses will be significantly reduced.

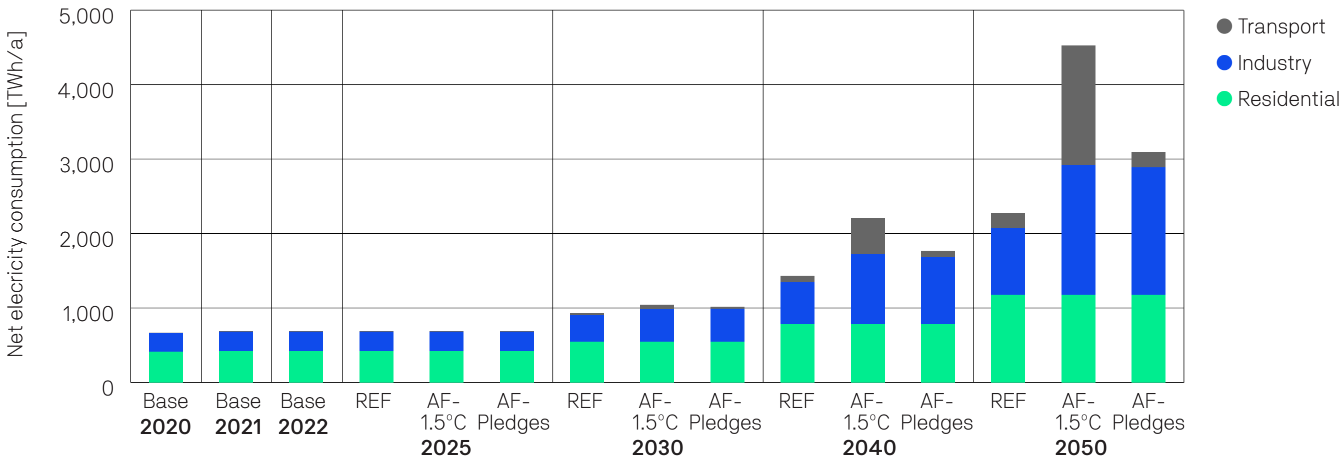
Figure 22: Africa– Projection of the total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)



The increased projected electrification of the heating, cooking, and transport sectors, especially under the AF-1.5°C scenario, will lead to a significantly increased electricity demand. The AF-1.5°C pathway will accelerate the electrification of the heating, cooking, and transport sectors more than the other pathways, and aims to replace more fossil and biofuels with electricity. By 2050, Africa's electricity demand will increase to 4,500 TWh per year.

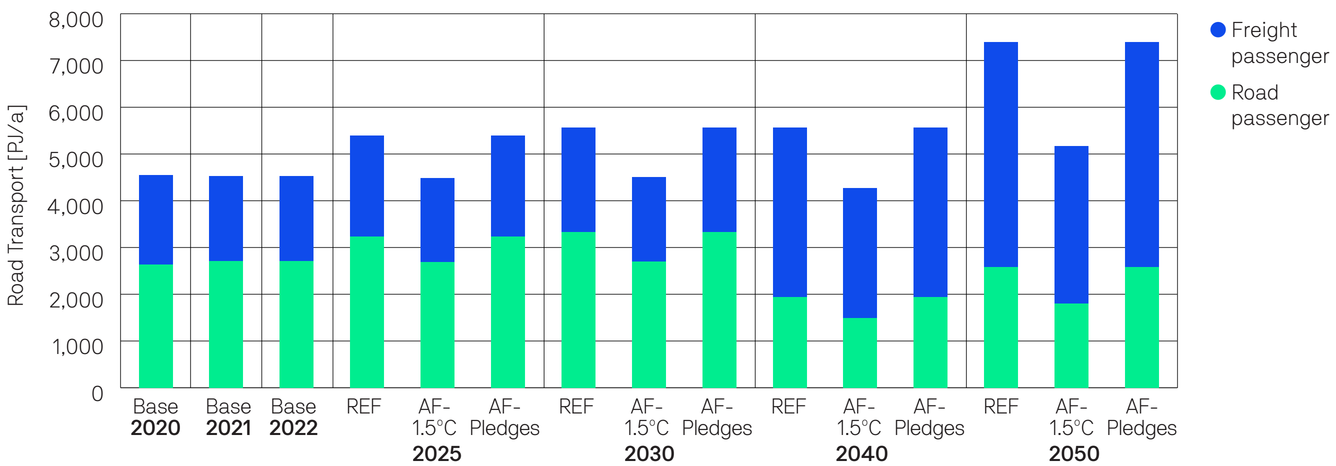
Electricity will become the major renewable 'primary' energy, not only for direct use for various purposes, but also for the generation of a limited amount of synthetic fuels to substitute for fossil fuel in providing industrial process heat. Under AF-1.5°C, around 1,600 TWh will be used for electric vehicles and rail transport in 2050, whereas under the REFERENCE and AF-Pledges, only 200 TWh will be used annually for the transport sector.

Figure 23: Development of electricity demand by sector under all three scenarios



The projected development of the road transport sector differs significantly between the different scenario for Africa. More details of the assumptions made for the transport sector projections, broken down into freight and passenger transport, are documented in Section 2.6.

Figure 24: 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 AF-1.5°C scenario will greatly benefit new renewables, whereas hydropower will continue to generate bulk electricity for industry and export. By 2030, the share of new renewable electricity production will reach 46% – compared with 23% in 2023 – and increase to 90% by 2040 under the AF-1.5°C scenario. The installed capacity of new renewables will reach about 306 GW in 2030 – compared to 80 GW in 2023. A 100% electricity supply from new renewable energy resources under the AF-1.5°C scenario by 2050 will lead to around 3,500 GW of installed generation capacity in 2050.

Figure 25: Breakdown of electricity generation by technology

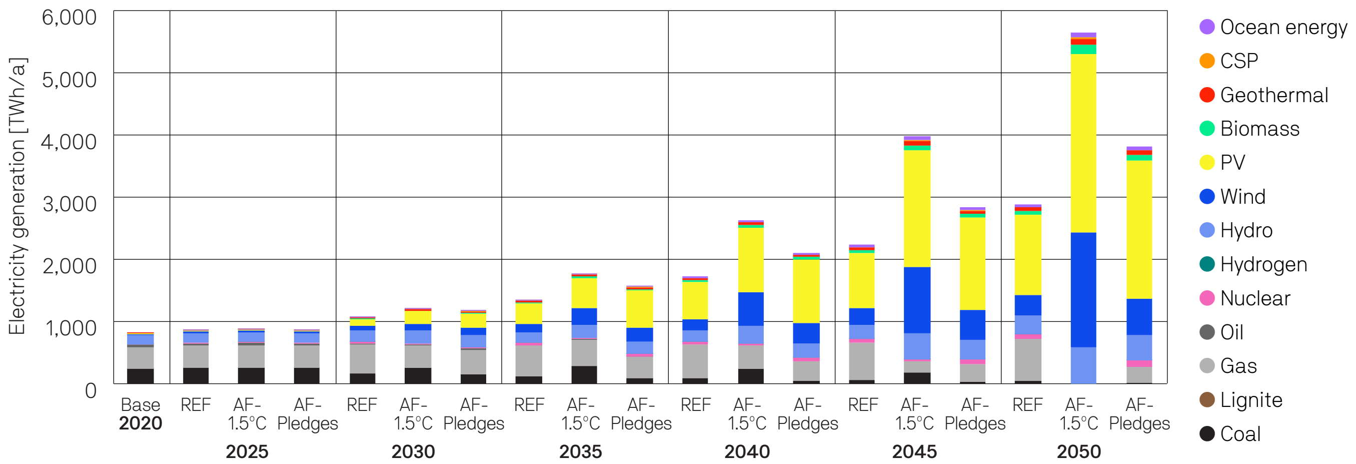


Table 33 shows the comparative evolution of Africa's power generation technologies over time. Hydro will remain the main power source until 2030. However, just after 2035, solar PV will overtake hydropower in installed capacity. After 2045, the continuing growth of solar PV and additional wind power capacities will lead to a total capacity of over 1 TW combined, compared with 182 GW hydropower under the AF-1.5°C scenario. This 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 hydropower. 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.

Table 33: Projection of renewable electricity generation capacities

Generation capacity [GW]		2020	2030	2035	2040	2050
Hydro	REFERENCE	53	58	53	58	91
	AF-1.5°C		65	70	89	182
	AF-Pledges		63	61	71	124
Biomass	REFERENCE	0	2	3.7	6	16
	AF-1.5°C		2	5	10	32
	AF-Pledges		2.0	75.9	7.9	21.9
Wind	REFERENCE	10	27	45	56	103
	AF-1.5°C		40	96	192	625
	AF-Pledges		45.3	80.1	114.5	192.4
PV	REFERENCE	10	103	310	559	1,173
	AF-1.5°C		190	443	946	2,615
	AF-Pledges		205.2	550.5	933.1	2,014.2
Total	**REFERENCE**	**270**	**403**	**627**	**905**	**1,670**
	AF-1.5°C		**493**	**838**	**1,443**	**3,519**
	AF-Pledges		**503**	**856**	**1,274**	**2,505**

Table 34 shows the annual power capacity changes across Africa under the three calculated scenarios. The AF 1.5°C phases out all fossil-fuel-based power generation until 2050. The majority of gas and coal power plants will go off-line between 2040 and 2050.

The solar PV market must grow to 177 GW annually by 2030, 755 GW/a by 2040, and 1,700 GW per year by 2050. In comparison, the global solar PV market in 2023 was 447 GW.

Therefore, Africa must develop a large solar PV market and the manufacture of solar systems should also take place in Africa.

The wind market will increases to 28 GW by 2030, 135 GW by 2040, and 387 GW by 2050. In comparison, the global wind market in 2023 was 116 GW. Therefore, by 2040, the African wind power market alone should be as large as the global wind market in 2023. The regional manufacture of all-important components for the wind industry has significant costs and logistical advantages.

Table 34: Power generation capacity changes in 2025–2050

Power generation capacity changes		2025–2030			2031–2040			2041–2050		
		REFERENCE	AF-1.5°C	AF-Pledges	REFERENCE	AF-1.5°C	AF-Pledges	REFERENCE	AF-1.5°C	AF-Pledges
Coal power plant	[GW]	-16.64	-0.39	-20.69	-15.44	-1.03	-20.63	-8.08	-50.39	-6.35
Lignite power plant	[GW]	-0.05	-0.05	-0.05	0.00	0.00	0.00	0.00	0.00	0.00
Gas power plant	[GW]	36.21	0.39	12.80	26.01	4.46	-6.56	47.45	-129.31	-19.25
Oil power plant	[GW]	-8.16	-7.30	-7.40	-8.45	-9.50	-9.21	0.00	0.00	0.00
Nuclear power plant	[GW]	2.15	0.25	2.48	3.45	0.97	4.79	3.17	-2.80	6.80
Biomass	[GW]	1.30	1.50	1.45	4.61	7.85	5.93	9.74	22.38	14.01
Hydro large	[GW]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydro small	[GW]	7.53	14.16	12.74	-0.33	24.16	7.99	33.30	92.98	52.39
Wind onshore	**[GW]**	**15.00**	**28.28**	**33.43**	**18.18**	**136.42**	**57.53**	**23.29**	**387.68**	**50.22**
Wind offshore	[GW]	1.89	1.89	1.89	10.66	14.86	11.61	23.97	45.66	27.68
PV power plant	**[GW]**	**90.41**	**177.27**	**192.48**	**455.45**	**755.44**	**727.93**	**614.95**	**1669.49**	**1081.08**
Geothermal	[GW]	2.16	2.51	2.42	1.54	3.61	2.32	2.67	7.35	4.17
Concentrated solar power	[GW]	0.31	0.50	0.46	1.61	1.81	1.75	3.85	7.72	5.23
Ocean energy	[GW]	1.73	2.07	1.99	8.11	13.78	10.42	10.14	25.31	15.14

5.2.3 Energy supply for cooking and industrial process heat

Today, bioenergy meets around 70% of Africa's energy demand for fuel-based cooking and heating. Dedicated support instruments are required to ensure dynamic development, particularly of electric cooking stoves, renewable heating technologies for buildings, and renewable process heat production. Under the AF-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 bioenergy (firewood), the efficiency of which is low. Under AF-1.5°C, the use of heat pumps as one of the leading new heating supply technologies will accelerate, especially between 2025 and 2035.

- Energy efficiency measures, especially building standards, will help to reduce the currently growing energy demand for heating.
- 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 26: Projections of heat supply by energy carrier (REFERENCE, Pledges and AF-1.5°C scenarios)

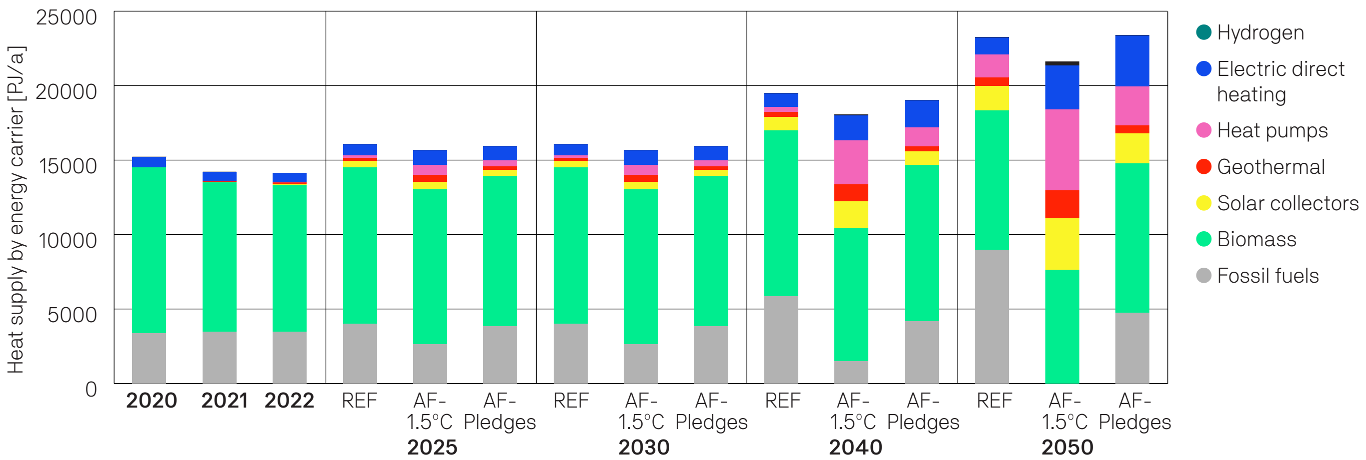


Table 35: Projections of renewable heat supply (cooking and process heat)

Africa – Development of renewable heat supply under three scenarios [PJ/a]		**2020**	**2025**	**2030**	**2040**	**2050**
Biomass	REFERENCE	11,112	10,514	10,514	11,162	9,351
	AF-1.5°C		10,399	10,399	8,900	7,651
	AF-Pledges		10,088	10,088	10,516	10,034
Solar	REFERENCE	8	420	420	888	1,649
	AF-1.5°C		488	488	1,828	3,465
	AF-Pledges		420	420	909	1,982
Heat pumps	REFERENCE	0	159	159	351	1,564
	AF-1.5°C		672	672	2,974	5,450
	AF-Pledges		397	397	1,272	2,598
Geo	REFERENCE	0	207	207	334	550
	AF-1.5°C		483	483	1,119	1,861
	AF-Pledges		207	207	334	550
Electric	REFERENCE	696	760	760	906	1,131
	AF-1.5°C		960	960	1,658	2,934
	AF-Pledges		960	960	1,823	3,418
Total	**REFERENCE**	**15,224**	**16,086**	**16,086**	**19,514**	**23,277**
	AF-1.5°C		**15,672**	**15,672**	**18,052**	**21,603**
	AF-Pledges		**15,948**	**15,948**	**19,051**	**23,387**

Table 35 shows the development of different renewable technologies for heating in Africa over time. Biomass will remain the main contributor, with increasing investments in highly efficient modern biomass technology. 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 AF-1.5°C scenario includes many efficient heat pumps, which can also be used for demand-side management and load flexibility.

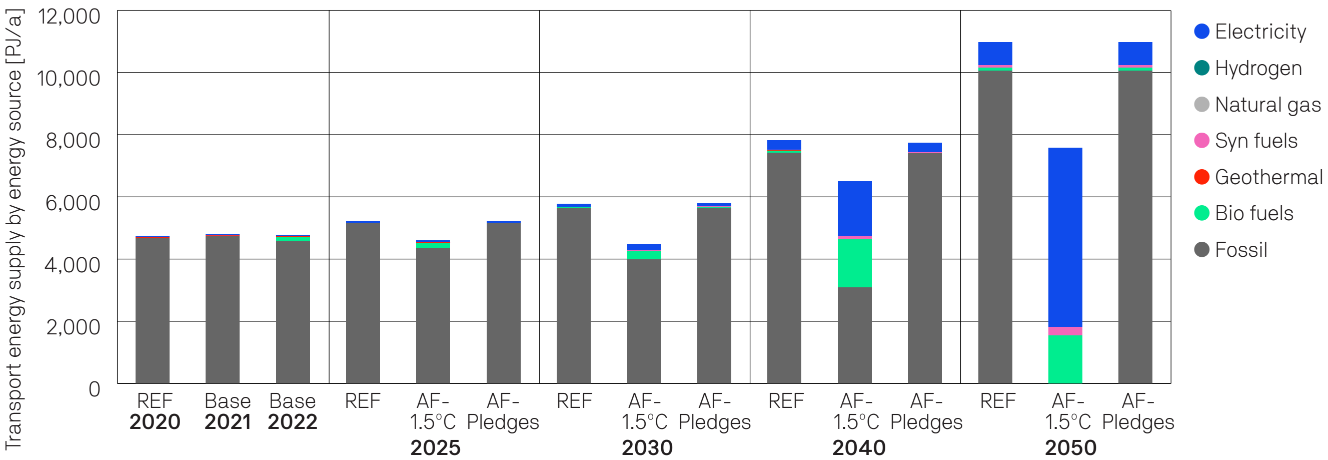
5.2.4 Transport

A key target in Africa 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 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. By 2030, electricity will provide 4.4% of transport under the AF-1.5°C scenario. The AF-1.5°C scenario will achieve the total decarbonisation of the transport sector in Africa by 2050. More details about the assumptions made to calculate the transport demand and supply development are documented in Section 2.6.

Table 36: Projection of transport energy demands by mode

Transport mode [PJ/a]		2020	2025	2030	2035	2040	2050
Rail	REFERENCE	62	81	90	114	141	310
	AF-1.5°C		81	90	114	141	310
	AF-Pledges		81	90	114	141	310
Road	REFERENCE	4,553	5,020	5,563	6,418	7,393	9,964
	AF-1.5°C		4,394	4,265	4,369	5,172	6,575
	AF-Pledges		5,020	5,563	6,418	7,393	9,964
Domestic aviation	REFERENCE	57	57	66	102	158	394
	AF-1.5°C		57	66	102	158	394
	AF-Pledges		57	66	102	158	394
Total	**REFERENCE**	**4,742**	**5,201**	**5,769**	**6,712**	**7,815**	**10,972**
	AF-1.5°C		**4,576**	**4,472**	**4,664**	**5,593**	**7,583**
	AF-Pledges		**5,201**	**5,769**	**6,712**	**7,815**	**10,972**

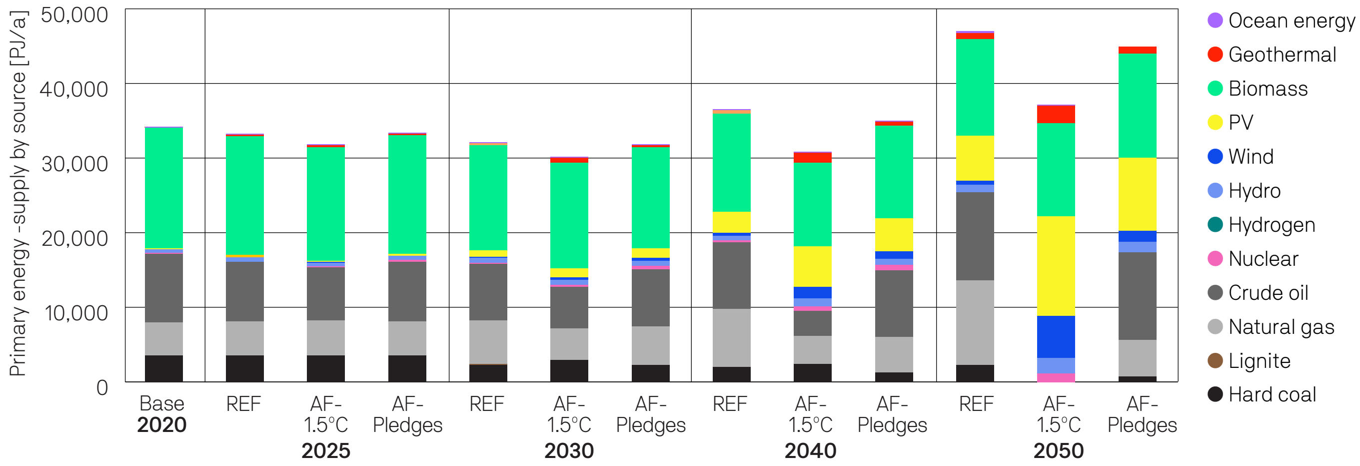
Figure 27: Final energy consumption by transport under three calculated scenarios



5.2.5 Primary energy consumption

Based on the assumptions discussed above, the resulting primary energy consumption from the AF-1.5°C scenario is shown in Figure 28. The AF-1.5°C scenario will result in primary energy consumption of around 36,400 PJ in 2050 – almost the same primary energy demand as today – due to the high electrification rate. In comparison, under the REFERENCE scenario, the primary energy demand will increase to 48,000 PJ/a, while providing the same level of transport services and economic development. The AF-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 57% in 2030, 69% in 2040, and 100% in 2050 under the AF-1.5°C scenario (excluding non-energy consumption).

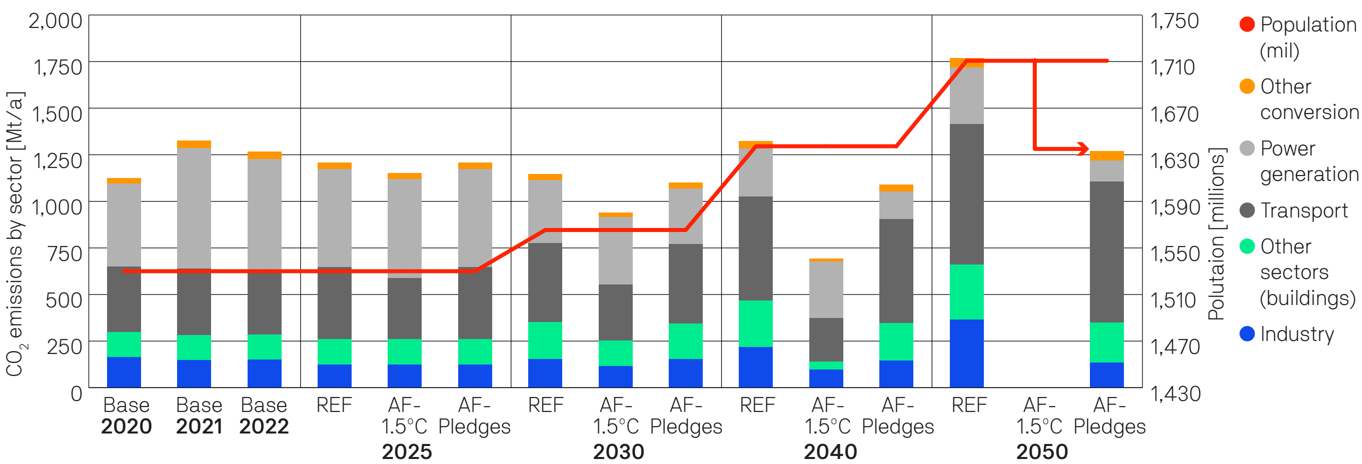
Figure 28: Projection of total primary energy demand by energy carrier (including electricity import balance)



5.2.6 CO_2 emissions trajectories

The AF-1.5°C scenario will reverse the trend of increasing energy-related CO_2 emissions after 2025, leading to a reduction of about 16% relative to 2020 by 2030 and of about 38.5% by 2040. Full decarbonisation of Africa's energy sector will be achieved in 2050 under the AF-1.5°C scenario. Under the AF-1.5°C scenarios, the cumulative emissions will sum to 23 Gt and Africa's energy-related per capita CO_2 emissions will remain at around 1 tonne until 2030. They will then decline until full decarbonisation is achieved in 2050.

Figure 29: Development of CO_2 emissions by sector



5.2.7 Cost analysis

Future costs of electricity generation

Figure 30 shows that introducing new generation capacities will increase the average electricity generation arising from new investments, and consequently, additional capital costs will be incurred.

The Africa scenario will increase the total installed capacity of solar PV from around 15 GW in 2023 to around 2,600 GW by 2050. Furthermore, the wind power capacity will increase from 9 GW to 625 GW in 2050 – the additional capacity will include some from offshore wind, but the majority is expected to be from onshore wind. Moreover, power plants fuelled with sustainable biomass will increase to 32 GW, whereas new hydro power plants – all run-of-river with no dams – are expected to increase from just over 50 GW in 2023 to 182 GW in 2050 under the AF-1.5°C scenario. The reason for the high generation capacity is the far-reaching electrification strategy to replace fossil fuels with electricity for cooking, heating, and transport.

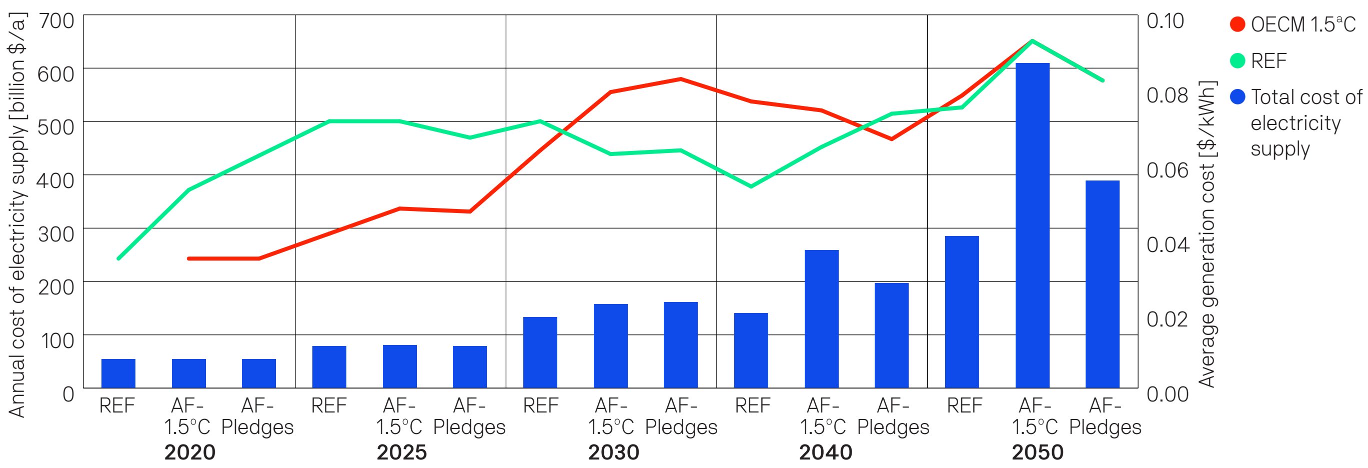
In comparison, the REFERENCE and AF-Pledge scenarios will lead to total power generation capacities of 1,670 GW and 2,500 GW, respectively, whereas the AF-1.5°C scenario will require a power generation capacity of 3,500 GW in 2050.

The AF-1.5°C scenario will lead to slightly greater power generation costs of around additional 2–3 cents per kWh between 2030 and 2040 due to significantly higher investment in new power generation capacities. However, electricity will replace fuels for (process) heating and in the transport sector.

The higher electricity generation costs for the first 10 years will level out with the REFERENCE scenario by 2040 and cost advantages will be reached in response to the accelerated investment in renewable electricity. The full cost of generation will be about 8 US$cents/kWh under the AF-1.5°C scenario, when no consideration is given to the integration costs for storage or other load-balancing measures.

Africa's total electricity supply costs will increase with the increasing electricity demand. The AF-1.5°C scenario will have the highest total electricity costs, but these will directly replace the of costs natural gas and oil fuel.

Figure 30: Development of total electricity supply costs and specific electricity generation costs



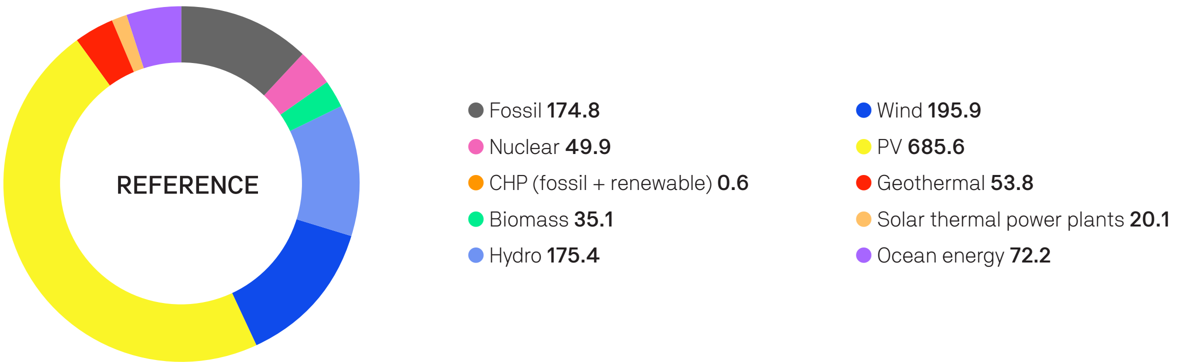
Investments in power generation

Africa will invest over US$3.3 trillion – around US$110 billion annually in new power generation under the AF-1.5°C scenario until 2050. In comparison, the REFERENCE scenario will require a total investment of less than half that (US$1.4 trillion), whereas the AF-Pledges scenario will lead to an investment of US$2.2 trillion. Most of this investment will go into solar PV, followed by onshore wind. The AF-1.5°C scenario will not invest in new nuclear power plants after 2025 due to the significant cost advantages of renewable power generation. The infrastructure for renewables is also much faster to build and can therefore follow the increasing electricity demand from year 1 onwards, whereas nuclear power plants require a construction period of around 10 years. During this time, no electricity is produced, whereas significant costs are incurred during the early phase of construction.

Africa has significant solar and wind potential throughout all countries. Solar power stand-alone grids can supply electricity to remote villages, which are unlikely to acquire grid connections over the next 10–15 years. Therefore, solar electricity systems are the premier choice to provide access to modern energy services (see also Section 4.3).

However, wind energy systems can and should play a role in many areas across the African continent. The generation pattern is different 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 31: Cumulative investment shares in power generation



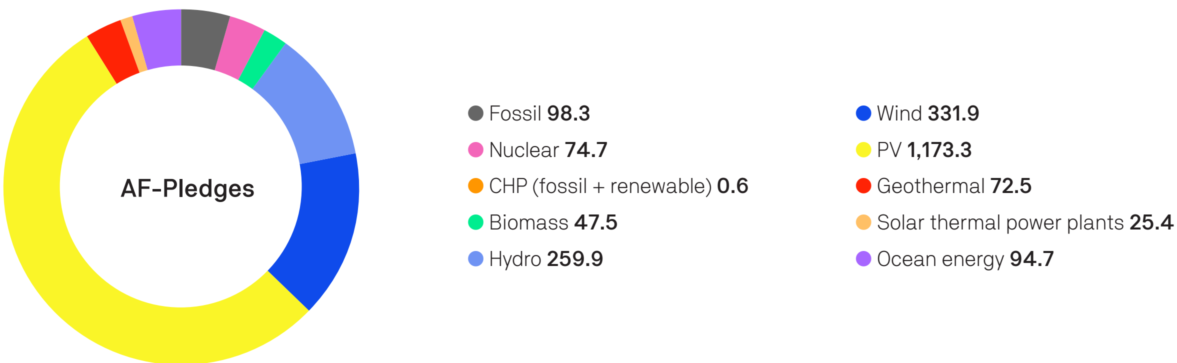


Table 37: Africa – Investment costs in new power in 2020–2050 under three scenarios

AF-1.5°C	2020–2050 [billion USD]	Average annual [billion USD/yr]
Fossil	120.2	4.0
Nuclear	15.5	0.5
CHP (fossil + renewable)	0.6	0.0
Biomass	69.8	2.3
Hydro	417.0	13.9
Wind	970.8	32.4
PV	1,476.0	49.2
Geothermal	105.9	3.5
Solar thermal power plants	33.8	1.1
Ocean energy	133.6	4.5
Total investment AF-1.5°C	**3,343.2**	**111.4**
REFERENCE		
Fossil	174.8	5.8
Nuclear	49.9	1.7
CHP (fossil + renewable)	0.6	0.0
Biomass	35.1	1.2
Hydro	175.4	5.8
Wind	195.9	6.5
PV	685.6	22.9
Geothermal	53.8	1.8
Solar thermal power plants	20.1	0.7
Ocean energy	72.2	2.4
Total investment REFERENCE	**1,463.4**	**48.8**
AF-Pledges		
Fossil	98.3	3.3
Nuclear	74.7	2.5
CHP (fossil + renewable)	0.6	0.0
Biomass	47.5	1.6
Hydro	259.9	8.7
Wind	331.9	11.1
PV	1,173.3	39.1
Geothermal	72.5	2.4
Solar thermal power plants	25.4	0.8
Ocean energy	94.7	3.2
Total investment AF-Pledges	**2,178.8**	**72.6**

Future investments in the heating sector

The main difference between the AF-1.5°C scenario and the other two scenarios is its significant investment in heat pumps and the diversification of heating technologies. The AF-1.5°C scenario will lead to an investment of US$1.9 trillion in heat pumps between 2020 and 2050, more than the investments made in the REFERENCE scenario (US$0.7 trillion) and AF-Pledges (US$1 trillion) combined. Electrical heat pumps, geothermal heat pumps, and solar thermal applications for space and water heating and drying will lead to a considerable reduction in the use of biogas and solid biomass, and therefore reduce the fuel costs. Figure 32 shows the shares of cumulative investments in the heating sector between 2020 and 2050.

Table 37 shows the cumulative investment in heat generation under the AF-1.5°C, AF-Pledges, and REFERENCE scenarios. The investments in favour of electrification (heat pumps) – and 'fuel-less' technologies (solar thermal) – especially under the AF-1.5°C, are significantly higher than under the more 'fuel-based' technology scenarios. However, fuel costs will decrease and refinance those investment over the technical life-times of those applications.

Figure 32: Cumulative investment in the heating technologies (generation) under the scenarios

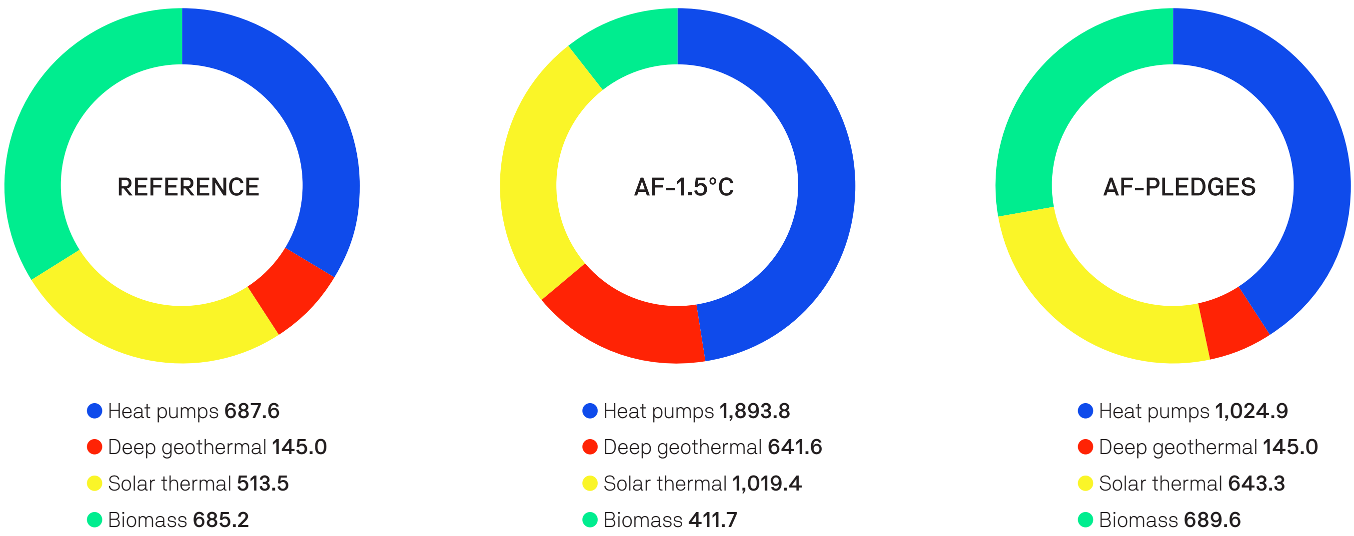


Table 38: Africa – Accumulated investment costs for heat generation under three scenarios

	Cumulative investment costs in billion US$: 2020–2050	Average annual investment costs in billion US$/a	Cumulative investment costs in billion US$: 2020–2050	Average annual investment costs in billion US$/a	Cumulative investment costs in billion US$: 2020–2050	Average annual investment costs in billion US$/a
	Reference		AF-Pledges		AF-1.5°C	
Heat pumps	688	22.9	1,025	34.2	1,894	63.1
Deep geothermal	145	4.8	145	4.8	642	21.4
Solar thermal	514	17.1	643	21.4	1,019	34.0
Biomass	685	22.8	690	23.0	412	13.7
Total	**2,031**	**67.7**	**2,503**	**83.4**	**3,966**	**132.2**

5.2.8 Investments and fuel cost savings

Finally, the fuel costs for the power, heating, and transport sectors are presented. All three scenarios have very low fuel costs for the power sector because generation is based mainly on solar and wind power, which need no fuels under the AF-1.5°C scenario. However, the remaining fuel costs for the AF-1.5°C scenario over the entire scenario period (2020–2050) will add up to US$10.6 trillion. In comparison, the REFERENCE scenario will require US$18.9 trillion and the 'AF-Pledges' US$16.6 trillion. Although increased electrification will lead to higher investment costs in power generation and higher overall electricity supply costs for Africa, fuel costs will decrease significantly.

Table 39: Total fuel costs across all sectors between 2020 and 2050 under three difference scenarios

Fuel supply costs (excluding non-energy use and conversion losses)							
REFERENCE	**Units**	**2021–2030**	**2031–2040**	**2041–2050**	**2020–2050**	**Units**	**Annual average 2020–2050**
Oil	billion US$	1,062.4	4,298.5	3,468.6	9,149.1	billion US$/a	305.0
Gas	billion US$	429.8	3,317.4	3,235.3	7,120	billion US$/a	237.3
Coal	billion US$	74.3	70.0	52.4	296	billion US$/a	9.9
Lignite/brown coal	billion US$	0.9	2.3	0.5	4	billion $/a	0.1
Biomass	billion US$	1,266.2	193.0	254.0	2,190	billion US$/a	73.0
Hydrogen	billion US$	2	33	73	109	billion US$/a	3.6
Synthetic Fuels	billion US$	0	1	2	2	billion US$/a	0.1
Total fuel costs	**billion US$**	**2,835.7**	**7,915.0**	**7,085.9**	**18,869.6**	**billion US$/a**	**629.0**

Fuel supply costs (excluding non-energy use and conversion losses)							
AF-Pledges	**Units**	**2021–2030**	**2031–2040**	**2041–2050**	**2020–2050**	**Units**	**Annual average 2020–2050**
Oil	billion US$	1,064.0	4,307.0	3,474.6	9,165.2	billion US$/a	305.5
Gas	billion US$	409.6	2,609.3	1,785.0	4,941	billion US$/a	164.7
Coal	billion US$	73.8	64.5	24.4	262	billion US $/a	8.7
Lignite/brown coal	billion US$	0.9	2.3	0.5	4	billion US$/a	0.1
Biomass	billion US$	1,248.0	181.8	253.7	2,161	billion US$/a	72.0
Hydrogen	billion US$	2	33	73	109	billion US$/a	3.6
Synthetic fuels	billion US$	0	1	2	2	billion US $/a	0.1
Total fuel costs	**billion US$**	**2,798.3**	**7,198.7**	**5,613.4**	**16,643.4**	**billion US$/a**	**554.8**

Fuel supply costs (excluding non-energy use and conversion losses)							
AF-1.5°C	**Units**	**2021–2030**	**2031–2040**	**2041–2050**	**2020–2050**	**Units**	**Annual average 2020–2050**
Oil	billion US$	665	2,589	701	4,275	billion US$/a	143
Gas	billion US$	394	2,246	977	3,754	billion US$/a	125
Coal	billion US$	80	92	36	307	billion US$/a	10
Lignite/brown coal	billion US$	1	2	1	4	billion US$/a	0
Biomass	billion US$	1,244	184	235	2,140	billion US$/a	71
Hydrogen	billion US$	2	33	73	109	billion US$/a	4
Synthetic fuels	billion US$	0	2	15	17	billion US$/a	1
Total fuel costs	**billion US$**	**2,386**	**5,148**	**2,038**	**10,606**	**billion US$/a**	**354**

Table 40: Cumulative investment and fuel costs under three scenarios for Africa in 2020–2050

	2020–2050 [billion US$]	Average annual in [billion US$/a]
REFERENCE		
Cumulative heating investment: 2020–2050	2,031	68
Cumulative investment in power generation	1,463	49
Cumulative fuel costs: 2020–2050	18,870	629
Total cumulative costs: 2020–2050	**22,364**	**745**
AF-Pledges		
Cumulative heating investment: 2020–2050	2,503	83
Cumulative investment in power generation	2,178	73
Cumulative fuel costs: 2020–2050	16,643	555
Total cumulative costs: 2020–2050	**21,325**	**711**
AF-1.5°C		
Cumulative heating investment: 2020–2050	3,966	132
Cumulative investment in power generation	3,343	111
Cumulative fuel costs: 2020–2050	10,606	354
Total cumulative costs: 2020–2050	**17,915**	**597**
Costs savings: REFERENCE versus AF-Pledges	**1,039**	**35**
Costs savings: REFERENCE versus AF-1.5°C	**4,449**	**711**

Table 39 shows the cumulative investment costs in power and heat generation and the cumulative fuel costs for the three scenarios for Africa in 2020 and 2050

The AF-1.5°C scenario will require investments of US$3.4 trillion in power generation and US$3.9 trillion in heat generation, almost exactly twice those required in the REFERENCE scenario, which will require US$3.5 trillion investment in power and heat generation combined. Therefore, the AF-1.5°C scenario will require average annual investments in generation of US$243 billion between 2020 and 2050, whereas the REFERENCE scenario will require US$117 billion.

In comparison, the average annual fuel costs for the REFERENCE scenario will amount to US$629 billion, whereas the fuel costs for the AF-1.5°C scenario will be US$354 billion – 44% lower. Therefore, the average annual fuel cost savings of US$275 billion will completely refinance the higher investment costs of the AF-1.5°C scenario.

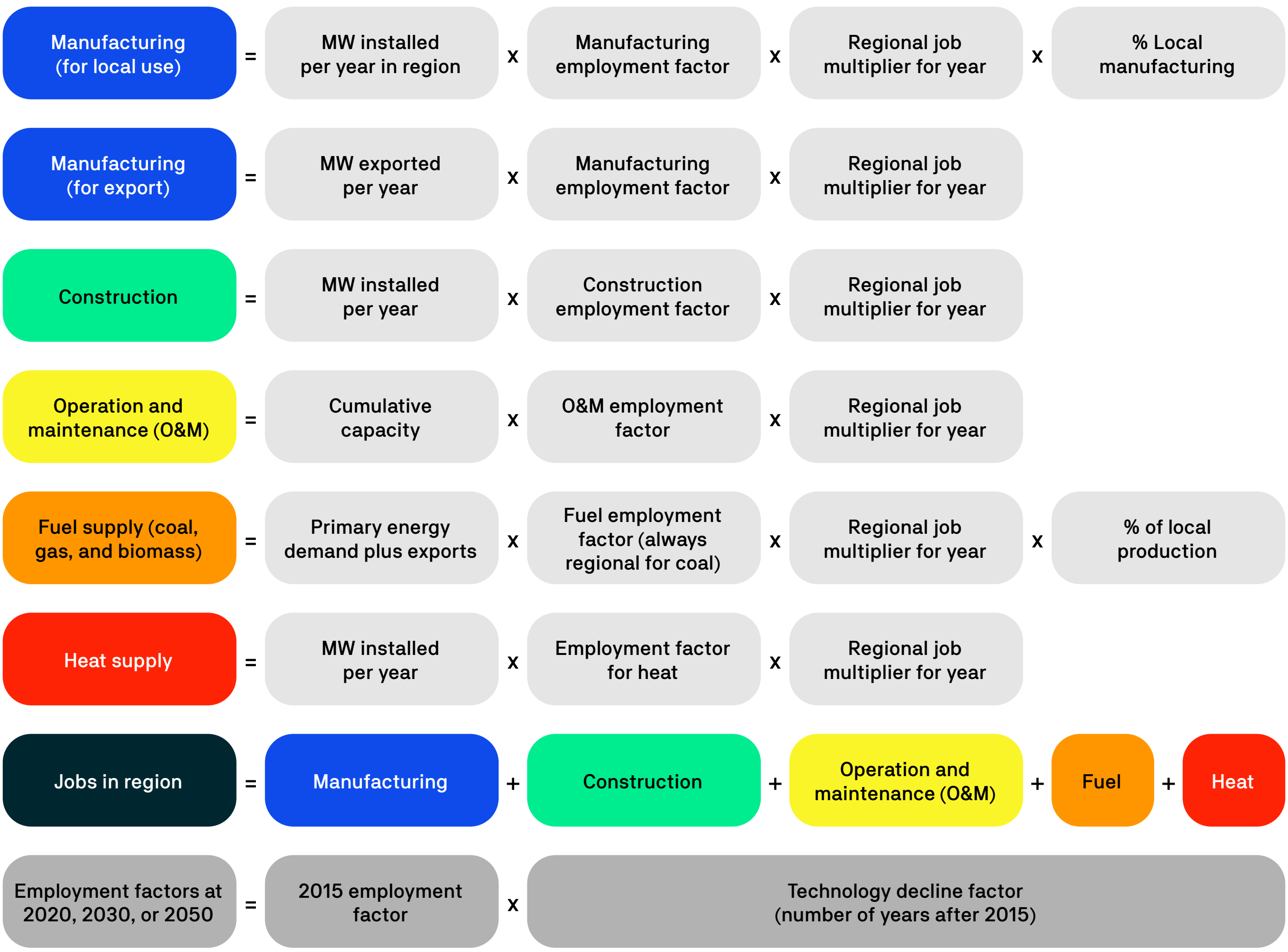
6 Employment

Employment development has been calculated based on the methodology described in Section 6.1 (see below) and the results for the long-term energy scenario documented in Section 5. The figures represent quantitative estimates and have been compared with the current workforces in Africa when information was available.

6.1 Methodology: Employment analysis

The methodology outlined in this section has two dimensions: total employment in the energy sector and occupational breakdown. The methodology used to analyse the total employment in the energy sector was first developed at the University of Technology Sydney, Institute for Sustainable Futures (UTS-ISF) (see Rutovitz et al. 2015; Rutovitz and Atherton 2009). This methodology has been updated for a global energy scenario project by UTS-ISF, in partnership with the German Aerospace Centre (DLR), Institute for Engineering Thermodynamics, and Department of Systems Analysis and Technology Assessment (STB) (Teske 2019). This study projects the total employment in the energy sector under three scenarios: the AF-1.5°C, AF-Pledges, and the REFERENCE scenarios. Employment is projected for the whole continent of Africa under each scenario from 2023 until 2050. The calculations are based on a series of employment multipliers and the projections for energy use and capacity. Only direct employment is included – jobs in construction, manufacturing, operations and maintenance, fuel supply associated with electricity generation, and direct heat provision. An overview of the total employment methodology is given in Figure 33.

Figure 33: Total employment calculation: methodological overview



The main inputs for the quantitative employment calculations are outlined below.

6.1.1 For each scenario (AF-1.5°C, AF-Pledges, and REFERENCE)

- The electrical and heating capacity that will be installed each year for each technology.
- The primary energy demand for coal, gas, and biomass fuels in the electricity and heating sectors.
- The amount of electricity generated per year from oil and diesel.

6.1.2 For each technology

- Employment factors, or the number of jobs per unit of capacity, separated into manufacturing, construction, operation and maintenance, and per unit of primary energy for fuel supply.
- For the 2025, 2030, and 2050 calculations, a 'decline factor' for each technology, which reduces the employment factor by a certain percentage per year. This reflects the fact that employment per unit will decrease as technology efficiencies improve.

The figures for the increase in electrical capacity and energy use for each scenario are multiplied by the employment factor for each of the technologies and then adjusted for the regional labour intensity and the proportion of fuel or manufacturing that occurs locally. A range of data sources were used for the model inputs, including the International Energy Agency, US Energy Information Administration, BP Statistical Review of World Energy, US National Renewable Energy Laboratory, International Labour Organization, World Bank, industry associations, national statistics, company reports, academic literature, and the UTS-ISF's own research. These calculations only consider direct employment, e.g., the construction team required to build a new wind farm. They do not include indirect employment; for example, the extra services provided in a town to accommodate the construction team.

The calculations do not include jobs in energy efficiency because this is beyond the scope of this research. The large number of assumptions required to make these calculations means that the employment numbers are only estimates, especially for regions for which few data exist. However, within the limits of data availability, the figures presented are representative of the employment levels under the given scenarios.

6.1.3 Employment factors

Employment factors were used to calculate the number of jobs required per unit of electrical or heating capacity, or per unit of fuel. The employment factors differ depending on whether they involve manufacturing, construction, operation and maintenance, or fuel supply. Information about these factors usually comes from OECD countries because they are where most data are collected, although local data were used wherever possible. The employment factor for Africa was used, as shown in Table 41.

Table 41: Summary of employment factors

	Construction and installation	Manufacturing	Operations and maintenance	Fuel – primary energy demand
	Job years/MW	Job years/MW	Job years/MW	
Coal	11.4	5.1	0.14	Regional supply
Gas	1.8	2.9	0.14	Regional supply
Biomass	14.0	2.9	1.5	2.5 jobs/PJ
Hydro, large	7.5	3.9	0.2	
Hydro, small	15.8	11.1	4.9	
Wind onshore	3.0	3.4	0.3	
Wind offshore	6.5	13.6	0.15	
Photovoltaic	3.2	1.5	0.7	
Geothermal	6.8	3.9	0.4	
Solar thermal	8.9	4.0	0.7	
Ocean	10.3	10.3	0.6	
Geothermal – heat	6.9 jobs/MW (construction and manufacturing)			
Solar – heat	8.4 jobs/MW (construction and manufacturing)			
Combined heat and power	CHP technologies use the factor for the technology, i.e., coal, gas, biomass, geothermal, etc., increased by a factor of 1.5 for operations and maintenance only.			

6.1.4 Coal fuel supply

The employment factors for coal are particularly important at the regional level, because employment per tonne varies significantly across world regions and because coal plays a significant role in energy production in many countries. The calculation of coal and gas employment per petajoule (PJ) is based on data from national statistics and company reports, combined with production figures from the BP Statistical Review of World Energy 2018 (BP-SR 2018) and other sources. Data were collected for as many major coal-producing countries as possible, and coverage was obtained for 90% of the world coal production.

Table 42: Employment factors used for coal fuel supply (mining and associated jobs)

	Employment factor Jobs per PJ	Tonnes per person per year (coal equivalent)
World average	36.2	943
Africa	13.7	2,482

6.1.5 Regional adjustments

The employment factors used in this model for energy technologies other than coal mining were usually for OECD regions, which are typically wealthier than other regions. A regional multiplier was applied to make the jobs per MW more realistic for other parts of the world. In developing countries, there are generally more jobs per unit of electricity because those countries have more labour-intensive practices. The multipliers change over the period of interest, consistent with the projections for GDP per worker. This reflects the fact that as prosperity increases, labour intensity tends to fall. The multipliers are shown in Table 43.

Table 43: Regional multipliers used for the quantitative calculation of employment

	2020	2030	2040	2050
OECD (Europe, North America)	1.0	1.0	1.0	1.0
Latin America	3.4	3.4	3.1	2.8
Africa	3.1	3.0	2.9	2.7
Middle East	1.5	1.4	1.4	1.2
Eastern Europe/Eurasia	2.4	2.2	2.0	1.8
India	5.5	3.7	2.7	2.2
Developing Asia	5.2	4.1	3.5	3.1
China	2.2	1.6	1.3	1.2

Source: Derived from ILO (2013) Key Indicators of the Labour Market, eighth edition software, with growth in GDP per capita derived from IEA World Energy Outlook 2023 and World Bank data.

For this analysis, the regional factors and multipliers for Africa were used. Due to the huge diversity of the 54 African countries, the results are indicative.

6.2 Results: employment analysis

Employment development was calculated based on the methodology described and the results for the long-term energy scenarios documented in Section 5. The figures represent quantitative estimates and have been compared with the current workforces across Africa when information was available. The renewable energy employment data for the base year (2020) was taken from IRENA (2024).[66]

Table 44 shows the projected development of employment in the energy sector in Africa. Under the REFERENCE scenario, employment in the energy sector – across all technologies and energy sources – will more than double from around 1.5 million in 2023 to 3.2 million in 2050. Under the AF-Pledges case, employment is estimated to grow to 4.0 million by 2050, whereas the AF-1.5°C scenario will create the highest number of jobs at 5.4 million.

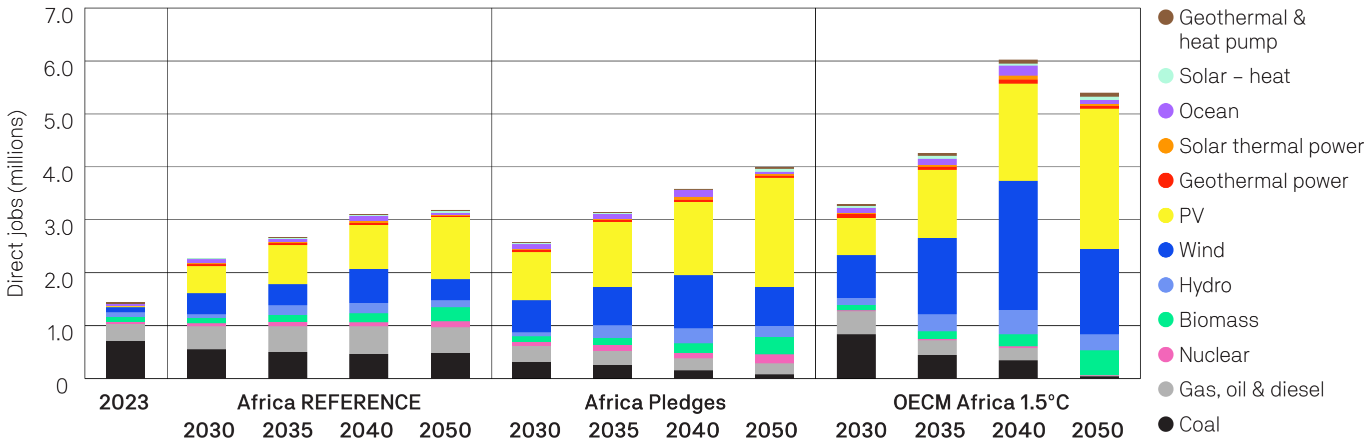
Table 44: Africa – Development of employment in the energy sector

Africa		REFERENCE				AF-Pledges				AF-1.5°C			
Thousand jobs	**2023**	**2030**	**2035**	**2040**	**2050**	**2030**	**2035**	**2040**	**2050**	**2030**	**2035**	**2040**	**2050**
Coal	711	555	508	468	485	320	264	153	83	841	449	212	43
Gas, oil, and diesel	327	432	480	634	489	300	259	233	211	426	273	108	21
Nuclear	36	63	91	103	110	75	118	99	163	27	26	39	8
Renewable	379	1,236	1,602	2,629	2,106	1,878	2,502	3,104	3,534	2,003	3,513	8,033	5,329
Total jobs	**1,453**	**2,286**	**2,681**	**3,835**	**3,191**	**2,573**	**3,143**	**3,588**	**3,990**	**3,297**	**4,261**	**8,392**	**5,401**
Construction and installation	101	521	558	624	413	764	812	874	759	1,082	1,255	1,851	955
Manufacturing	115	440	523	679	304	577	700	858	533	887	1,192	1,850	664
Operations and maintenance	427	627	914	1,121	1,636	782	1,225	1,553	2,374	762	1,218	1,825	3,551
Fuel supply (domestic)	606	476	459	454	546	446.5	403	301	247	495.1	487	387	88
Coal and gas export	204	221	227	225	235	3	2.7	1.8	1.1	3	2.7	1.8	1.1
Total jobs (thousands)	**1,453**	**2,286**	**2,681**	**3,103**	**3,191**	**2,573**	**3,143**	**3,588**	**3,990**	**3,297**	**4,261**	**6,030**	**5,401**

66 IRENA and ILO (2024), Renewable energy and jobs: Annual review 2024, International Renewable Energy Agency, Abu Dhabi, and International Labour Organization, Geneva.

Table 44 shows the changes in job numbers under all scenarios for each technology between 2023 and 2050. The development of employment in the renewable energy industry will be from around 350,000 currently to 2 million under the REFERENCE scenario, but to 3.5 million under the AF-Pledges scenario and 5.3 million under the AF-5°C scenario. Therefore, the employment losses in the fossil-fuel industry will be overcompensated by employment in the renewable energy sector between 2030 and 2035 under the AF-1.5°C scenario.

Figure 34: Total employment in Africa's energy sector in 2023–2050



7 Resources

The mineral resource requirements for the One earth Climate Model (OECM) 1.5°C pathway for Africa were calculated based on the methodology described in Section 7.1 (see below) and the results for the long-term energy scenario documented in Section 5. The figures represent quantitative estimates and have been compared with the current resource demand globally and in Africa. However, the published access data for Africa's mineral resources are incomplete and more research is required in the future.

7.1 Methodology: Mineral Resource requirements

The mineral resource requirements for the energy pathways in OECM AF-1.5°C are calculated on the basis of the following five main parameters:

1. Technology sector: generation, storage, application
2. Technology group: generation technologies, storage technologies, electric mobility (application)
3. Technology type
4. Quantity of technology
5. Resource intensity per unit quantity.

Table 45 shows the calculation matrix used for the assessment of mineral resource requirements under the energy scenarios. Although not all technology groups are listed, it shows all the parameters.

Table 45: Calculation matrix for the assessment of mineral resources required under the energy scenarios (example)

Technology				Market share of technology variation		Quantity of technology			Resource Intensity – base year			Projected future resource intensity			Total material required under the calculated scenario		
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Sector	Technology group	Technology type	Technology type variation and/or component	Status quo [%]	Estimated development until 2030/2050 [%]	By quantity [1]	By capacity [GW]	By energy unit [GWh/a]	By quantity [tonne/unit]	By capacity [tonne/GW]	By energy unit [tonne/ GWh]	By quantity [tonne/unit]	By capacity [tonne/GW]	By energy unit [tonne/ GWh]	Base year [tonne/year]	2050 [tonne/year]	Development [%/a]
Generation	Solar PV	c-Si		X%	X% ± Y%		●			●		± X%	± X%	± X%	●	●	+/- X%
		CIGS		X%	X% ± Y%		●			●		± X%	± X%	± X%	●	●	+/- X%
		CdTe		X%	X% ± Y%		●			●		± X%	± X%	± X%	●	●	+/- X%
	Concentrated solar	Parabolic trough		X%	X% ± Y%		●			●		± X%	± X%	± X%	●	●	± X%
		Central tower		X%	X% ± Y%		●			●		± X%	± X%	± X%	●	●	± X%
	Onshore wind	Direct-drive excited synchronous generator		X%	X% ± Y%		●			●		± X%	± X%	± X%	●	●	± X%
		Doubly fed induction generator		X%	X% ± Y%		●			●		± X%	± X%	± X%	●	●	± X%
	Offshore wind	Direct-driven permanent synchronous generator		X%	X% ± Y%		●			●		± X%	± X%	± X%	●	●	± X%
		Permanent magnet synchronous generator		X%	X% ± Y%		●			●		± X%	± X%	± X%	●	●	± X%
Storage	Batteries	Lithium ion	Mobile storage applications	30%	33% +10%			●		●	●	± X%	-20%	± X%		●	± X%
		Lithium-ion phosphate	Mobile storage applications	X%	X% ± Y%			●		●	●	± X%	± X%	± X%		●	± X%
		Lithium nickel-cobalt-aluminium-oxide	Mobile storage applications	X%	X% ± Y%			●		●	●	± X%	± X%	± X%		●	± X%
		Vanadium redox flow	Stationary storage	X%	X% ± Y%			●		●	●	± X%	± X%	± X%		●	± X%
		Lithium sulphur	Stationary storage	X%	X% ± Y%			●		●	●	± X%	± X%	± X%		●	± X%
	Hydrogen	Electrolyser	Alkaline electrolyser	X%	X% ± Y%		●	●		●	●	± X%	± X%	± X%	●	●	± X%
			PEM electrolyser	X%	X% ± Y%		●	●		●	●	± X%	± X%	± X%	●	●	± X%
		Fuel cell	PEM Fuel cells	X%	X% ± Y%		●	●		●	●	± X%	± X%	± X%	●	●	± X%
Application	Electric vehicles	Permanent magnet		X%	X% ± Y%	●	●	●	●	●	●	± X%	± X%	± X%	●	●	± X%

Calculation example:

To calculate the mineral resource intensity of a storage technology, the specific technology type must be defined. In this example, we chose 'lithium-ion batteries' marked in yellow). The market share of this technology type within all installed batteries in the base year is 30% (parameter in column E) and is assumed to increase to 40% (column F).

The installed battery capacity in the base year was 300 GWh – the market share was 33%, leading to 100 GWh of lithium ion batteries.

The overall battery market is assumed to increase to 3,000 GWh by 2050 and the market share of lithium-ion batteries is assumed to increase to 43% (column F), leading to an overall storage capacity of this specific technology type of 1,290 GWh. The analysed material quantity, e.g., lithium per storage capacity in the base year is 118.5 tonnes per GWh (column I) and is assumed to decrease by 20% (column N) to 94.8 tonnes per GWh in 2050.

The lithium requirement for lithium-ion batteries in the **base year** in this example would be:

100 GWh x 118.5 tonnes/GWh = 11,850 tonnes of lithium

In 2050, the projected market size of battery storage capacity is 3,000 GWh, whereas the projected market share of lithium-ion batteries will increase to 43%, leading to a lithium-ion capacity of 1,290 GWh. At the same time, the resource intensity is projected to decrease to 94.8 tonnes per GWh.

Therefore, the quantity of lithium needed to produce the batteries required in 2050 under this scenario would be:

1290 GWh x 94.8 tonnes/GWh = 122,292 tonnes of lithium

Although the calculation of a single technology type is simple, the interaction of different developments in terms of the overall sector (e.g., storage), the market size of a specific technology type (e.g., lithium ion), and the development of the resource intensity increases the calculation complexities.

Various generation technologies and applications (e.g., electric vehicles) are also calculated.

Furthermore, the recycling rates for specific technologies may increase over time, and although this might not lead to reductions in future material requirements, it may reduce the quantity of a particular mineral that must be mined.

The quantity of recycled materials is not only dependent upon the recycling rate, but also upon the average lifetime of the application. For example, the silver used for solar PV modules will remain in the product for an average of 25 years – the average lifetime of solar PV modules.

7.2 Key assumptions for the calculation of resource requirements

This section provides an overview of the main input assumptions for the calculation of resource requirements. Besides the actual energy scenario – which determines the energy demand, including the current and future utilisation of applications and vehicle types and the energy supply technologies – the market shares of the future technologies and their resource intensities define the material requirements.

7.2.1 Material intensities

The assumed material intensities for all the energy transition technologies analysed are shown in Table 45. There are various types of solar PV systems, onshore and offshore wind power generators, hydrogen electrolysers, and fuel cells, as well as a huge variety of battery technologies. Therefore, the listed material intensities are average values based on literature research.

Table 46: Material Intensities for the minerals analysed

Technology	Resources		Unit	Al	Co	Cu	Gr	Dy	Li	Mn	Nd	Ni	V
Batteries	Lithium Ion	NMC	[tonne/ GWh]	920.50	30.00	1200	975.00	0.00	118.50	144.00	0.00	695.50	0.00
	Lithium-ion Phosphate	LFP	[tonne/ GWh]	1977	0.00	970.00	1056	0.00	102.00	0.00	0.00	0.00	0.00
	Lithium Nickel-Cobalt-Aluminium-Oxide	NCA	[tonne/ GWh]	500.00	33.00	283.00	403.00	0.00	100.00	0.00	0.00	717.00	0.00
	Vanadium Redox Flow	VRFB	[tonne/ GWh]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3160
	Lithium Sulphur	Li-S	[tonne/ GWh]	220.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average EV			[kg/ vehicle]	55	13	53	25	0	9	25	0	40	0
EV batteries	Lightweight		[kg/ vehicle]	264.95	9.15	53.20	30.70	0.00	8.70	0.00	0.00	39.95	0.00
	Battery EV Light Drive Vehicle	BEV LDVs	[kg/ vehicle]	54.50	9.15	53.20	30.70	0.00	8.70	0.00	0.00	39.95	0.00
	Plug-in Hybrid Light Drive Vehicle	PHEV LDVs	[kg/ vehicle]	8.65	1.45	53.20	4.85	0.00	1.40	0.00	0.00	6.35	0.00
	Battery EV Heavy Drive Vehicle	BEV HDVs	[kg/ vehicle]	42.18	19.10	53.20	64.40	0.00	18.30	0.00	0.00	18.51	0.00
	Plug-in Hybrid Heavy Drive Vehicle	PHEV HDVs	[kg/ vehicle]	18.05	3.05	53.20	10.20	0.00	2.90	0.00	0.00	13.25	0.00
EV magnets	BEV/PHEV/ FCEV Vans		[kg/ vehicle]	0.0000	0.0024	0.0000	4.8500	0.1530	0.0000	0.0000	0.0052	0.0000	0.0000
Passenger – Average per vehicle based on assumed market share of vehicle type			[kg/ vehicle]	0	0.0019	0.0000	17.8	0.1274	0.0000	0.0000	0.0043	0.0000	0.0000
	BEV/PHEV/FCEV buses		[kg/ vehicle]	0.0000	0.0033	0.0000	64.4	0.2040	0.0000	0.0000	0.0070	0.0000	0.0000
	BEV/PHEV/FCEV trucks		[kg/ vehicle]	0.0000	0.0049	0.0000	10.2	0.3060	0.0000	0.0000	0.0042	0.0000	0.0000
Freight – Average per vehicle based on assumed market share of vehicle type			[kg/ vehicle]	0.0000	0.0041	0.0000	37.3	0.2550	0.0000	0.0000	0.0056	0.0000	0.0000

Technology	Resources		Unit	Al	Co	Cu	Gr	Dy	Li	Mn	Nd	Ni	V
Solar PV	Crystalline silicon	c-Si	[tonne/GW]	11,174	0	884	0	0	0	0	0	0	0
	Copper indium gallium diselenide solar cell	CIGS	[tonne/GW]	949	0	450	0	0	0	0	0	0	0
	Cadmium telluride	CdTe	[tonne/GW]	0	0	5,181	0	0	0	0	0	0	0
Concentrated solar power	Parabolic trough	Parabolic trough	[tonne/GW]	0.000	0.0	3,200.0	0.0	0.0	0.0	2,000.0	0.0	940.0	1.9
	Central tower	Central tower	[tonne/GW]	11,000	0	1,400	0	0	0	5,700	0	1,800	2
Wind	Non-PMG (permanent magnetic generator)	Direct-drive synchronous generator	[tonne/GW]	1,225	0	4,850	0	0	0	0	28	377	0
		Doubly fed induction generator	[tonne/GW]	1,650	0	3,191	0	3	3	3	12	377	0
	PMG (permanent magnetic generator)	Direct-driven permanent synchronous generator	[tonne/GW]	1,125	0	3,850	0	0	0	0	190	377	0
		Permanent magnet synchronous generator	[tonne/GW]	1,750	0	2,966	0	3	3	3	51	377	0
Hydrogen	Electrolyser	Alkaline electrolyser	[tonne/GW]	0	0	0	0	0	0	0	0	76	0
		PEM electrolyser	[tonne/GW]	0	0	0	0	0	0	0	0	17	0
	Fuel cell	PEM fuel cells	[tonne/GW]	300	0	0	100	0	0	0	0	0	0

7.2.2 Market shares

The development of market shares is based on a Table 46 and Table 47 . which show the technology market shares for all energy transition technologies analysed. The assumed market shares are based on literature reviews and own projections. Scarce minerals, such as cobalt, are assumed to be phased-out due to probable supply chain bottlenecks.

Table 47: Assumed market shares for power generation

Mineral			Market share	2023	2030	2035	2040	2045	2050
Batteries – power supply	Assumption: percentage of total solar PV and wind generation		[%]	0.20%	1.0%	5.0%	7.5%	10.0%	12.5%
Battery technology: market shares for power supply	Lithium ion	NMC	[%]	72.0%	70.0%	60.0%	40.0%	20.0%	10.0%
	Lithium-ion phosphate	LFP	[%]	13.0%	22.0%	32.0%	54.0%	74.0%	84.0%
	Lithium nickel-cobalt-aluminium oxide	NCA	[%]	5.0%	2.5%	2.5%	0.8%	0.8%	0.8%
	Vanadium redox flow	VRFB	[%]	5.0%	1.5%	1.5%	1.2%	1.2%	1.2%
	Lithium sulphur	Li-S	[%]	5.0%	4.0%	4.0%	4.0%	4.0%	4.0%
Battery – electric mobility	Assumption: total electricity required for road transport		[%]	1.00%	2.5%	5.0%	7.5%	10.0%	12.5%
Battery technology: market shares for electric mobility	Lithium ion	NMC	[%]	78.0%	70.0%	60.0%	40.0%	20.0%	10.0%
	Lithium-ion phosphate	LFP	[%]	13.0%	25.0%	32.0%	54.0%	74.0%	84.0%
	Lithium nickel-cobalt-aluminium oxide	NCA	[%]	4.8%	2.5%	3.3%	0.8%	0.8%	0.8%
	Vanadium redox flow	VRFB	[%]	0.8%	0.5%	0.8%	1.2%	1.2%	1.2%
	Lithium sulphur	Li-S	[%]	3.4%	2.0%	4.0%	4.0%	4.0%	4.0%
Solar photovoltaics	Crystalline silicon	c-Si	[%]	97%	97%	98%	97%	98%	99%
	Copper indium gallium diselenide solar cell	CIGS	[%]	1%	1%	1%	1%	1%	1%
	Cadmium telluride	CdTe	[%]	2%	2.0%	1.5%	1.8%	1.5%	1%
Concentrated solar power	Parabolic trough	Parabolic trough	[%]	77%	70%	65%	60%	50%	30%
	Central tower	Central tower	[%]	23%	30%	35%	40%	50%	70%
Wind power (onshore + offshore) – total	Non-PMG (permanent magnetic generator)	Direct-drive excited synchronous generator	[%]	37%	30%	25%	20%	3%	1%
	Non-PMG (permanent magnetic generator)	Doubly fed induction generator	[%]	37%	30%	25%	20%	3%	1%
	PMG (permanent magnetic generator)	Direct-driven permanent synchronous generator	[%]	18%	25%	30%	35%	3%	1%
	PMG (permanent magnetic generator)	Permanent magnet synchronous generator	[%]	8%	15%	20%	25%	91%	97%
Hydrogen	Electrolyser	Alkaline electrolyser	[%]	31%	25%	25%	27%	30%	33%
	Electrolyser	PEM electrolyser	[%]	69.0%	75.0%	75.0%	73.0%	70.0%	67.0%
	PEM fuel cells	Market share	[%]	61%	100%	100%	100%	100%	100%

Table 48: Assumed market shares for battery technologies

Technologies			Units	2023	2030	2035	2040	2045	2050
Electric vehicle – passenger	EV market share – total road transport		[%]	1.0%	4.0%	25.0%	50.0%	90.0%	92.0%
	Manufactured passenger vehicles per year	[Million vehicles per year]		0.04	0.25	0.94	1.6	2.4	2.68
	Lightweight	BEV LW	[kWh/vehicle]	21	21	21	21	21	21
	Battery EV light drive vehicle	BEV LDVs	[kWh/vehicle]	30	30	30	30	30	30
	Plug-in hybrid light drive vehicle	PHEV LDVs	[kWh/vehicle]	75	75	75	75	75	75
	Battery EV heavy drive vehicle	BEV HDVs	[kWh/vehicle]	123	123	123	123	123	123
	Plug-in hybrid heavy drive vehicle	PHEV HDVs	[kWh/vehicle]	123	123	123	123	123	123
	Lightweight	0	[kWh/100 km]	10	10	10	10	10	10
	Battery EV light drive vehicle	BEV LDVs	[kWh/100 km]	15	15	15	15	15	15
	Plug-in hybrid light drive vehicle	PHEV LDVs	[kWh/100 km]	25	25	25	25	25	25
	Battery EV heavy drive vehicle	BEV HDVs	[kWh/100 km]	35	35	35	35	35	35
	Plug-in hybrid heavy drive vehicle	PHEV HDVs	[kWh/100 km]	50	50	50	50	50	50
	Market share – vehicle size								
EV batteries	Lightweight	0	[%]	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
	Battery EV light drive vehicle	BEV LDVs	[%]	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
	Plug-in hybrid light drive vehicle	PHEV LDVs	[%]	40.0%	40.0%	40.0%	40.0%	40.0%	40.0%
	Battery EV heavy drive vehicle	BEV HDVs	[%]	10.0%	10.0%	10.0%	10.0%	10.0%	10.0%
	Plug-in hybrid heavy drive vehicle	PHEV HDVs	[%]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Electric vehicles – freight	EV market share – total freight transport		[%]	1.0%	22.0%	60.0%	70.0%	80.0%	90.0%
	Manufactured freight vehicles per year	[Million vehicles per year]		0.01	0.06	0.23	0.39	0.59	0.65
	Battery EV heavy drive vehicle	BEV HDVs	[kWh/vehicle]	75	75	75	75	75	75
	Plug-in hybrid heavy drive vehicle	PHEV HDVs	[kWh/vehicle]	125	125	125	125	125	125
	Battery EV heavy drive vehicle	BEV HDVs	[kWh/100 km]	150	150	150	150	150	150
	Plug-in hybrid heavy drive vehicle	PHEV HDVs	[kWh/100 km]	50	50	50	50	50	50
	Market share – vehicle size								
	Battery EV heavy drive vehicle	BEV HDVs	[%]	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
	Plug-in hybrid heavy drive vehicle	PHEV HDVs	[%]	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%

7.3 Key results – resource requirements for energy transition technologies

Around 46 million tonnes of silicon will be required between 2020 and 2050, so silicon represents the most important mineral requirement by volume. It is mainly used for solar cells, but also for batteries. Silicon is classified as a metalloid, makes up 27.7% of the Earth's crust by mass, and is the second most abundant element on Earth (oxygen is the first). It does not occur uncombined in nature, but chiefly as the oxide (silica) and as silicates. Forms of the oxide include sand, quartz, rock crystal, amethyst, agate, flint, and opal (Royal Society of Chemistry[67]). The mineral required in the second largest volume is aluminium, which is used for solar module frames for structural support, and for lightweight (electric) vehicle parts and battery components.

Table 49: Key energy transition technologies: resource requirements for main minerals under OECM AF-1.5°C

Mineral – total demand for Africa		Total material	Maximum material recovery		Maximum material volume in tonnes in case of 100% recycling after the technical lifetime – in percent of total material demand between 2020–2050
		Total 2020–2050	Total 2020–2050		
Aluminium	Al	37,072,130	4,168,836	[t]	11%
Cadmium	Cd	2,311	250	[t]	11%
Chromium	Cr	4,261,002	834,077	[t]	20%
Cobalt	Co	225,734	117,266	[t]	52%
Copper	Cu	10,841,265	2,540,595	[t]	23%
Gallium	Ga	135	17	[t]	12%
Graphite	Gr	3,953,834	1,207,973	[t]	31%
Indium	In	1,031	99	[t]	10%
Dysprosium	Dy	3,510	739	[t]	21%
Lithium	Li	689,107	218,410	[t]	32%
Manganese	Mn	1,218,074	405,139	[t]	33%
Neodymium	Nd	60,087	11,741	[t]	20%
Nickel	Ni	2,775,050	972,728	[t]	35%
Silicon	Si	46,205,067	3,224,220	[t]	7%
Silver	Ag	106,764	14,371	[t]	13%
Selenium	Se	1,077	75	[t]	7%
Tellurium	Te	2,609	283	[t]	11%
Vanadium	V	103,296	25,986	[t]	25%
Titanium	Ti	162,985	24,645	[t]	15%

Table 49 and Table 50 show the total cumulative volumes of all the minerals analysed for key energy transition technologies between 2020 and 2050 under the OECM AF-1.5°C scenario in metric tonnes and the maximum proportions recycled. Most of the minerals analysed can achieve maximum shares of recycled materials of around 20% between 2020 and 2050, which is directly related to their estimated technical lifetimes. Therefore, the remaining materials embedded in the energy transition technologies will be available AFTER 2050.

67 Royal Society of Chemistry, online database, viewed March 2025, https://periodic-table.rsc.org/element/14/silicon

Figure 35: Africa's material demands for key energy transition technologies between 2020 and 2050 versus available recycled materials

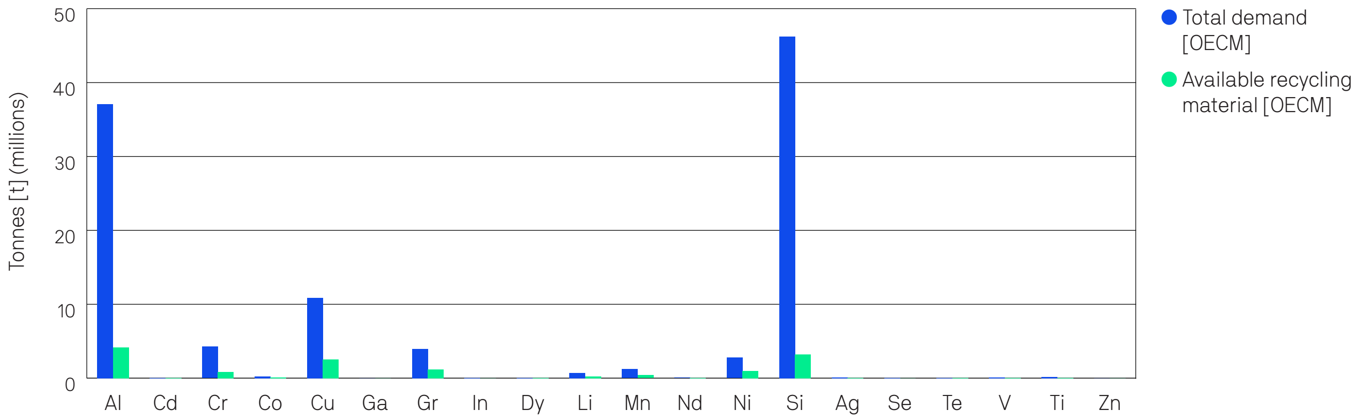
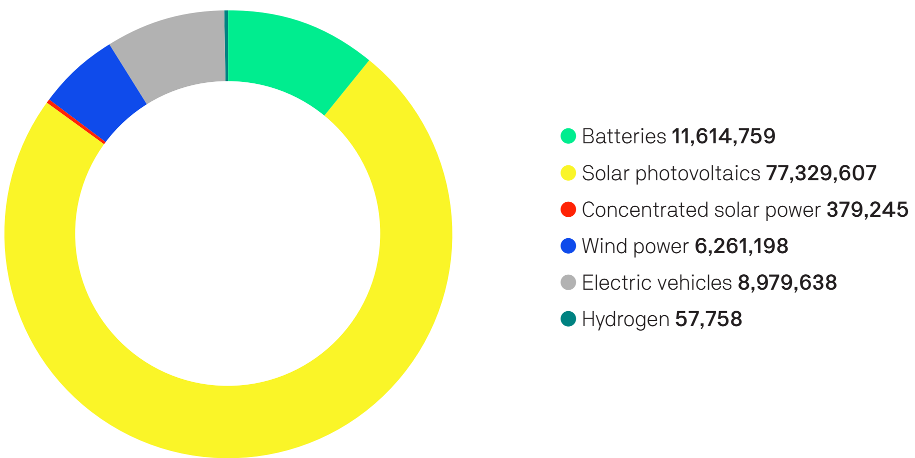


Figure 36 shows the material demands by technology. Solar PV will use approximately 74% of all mineral requirements to implement the OECM AF-1.5°C scenario, but will supply 50% of all electricity by 2050, replacing at least the 150 million tonnes of coal – Africa's annual coal consumption in 2023, accounting for over 50 million tonnes of energy-related CO_2 emissions.

The second most material-intensive energy transition technologies are battery electric vehicles and the stationary batteries used to firm solar and wind power generation. The total amount of materials required is estimated to be around 20 million tonnes. Electric vehicles are key to replacing oil, which is mainly used in the transport sector. In 2023, Africa consumed 4.4 billion barrels of oil per day (1,606 billion barrels per year), which translates to around 600 million tonnes of oil daily.

Figure 36: Cumulative mineral demand (2020–2050) for selected energy transition technologies (in tonnes) and material requirement shares by technology



7.4 Mineral reserves and resources versus requirements for the energy transition

In a second step, the annual mineral demands, which define the global mining capacities, were assessed in annual increments from 2020 to 2050. To calibrate the model, the calculated resources required for the current production volumes of solar, wind, hydrogen, electric vehicle, and battery technologies were compared with the actual annual material demands and the current shares of the energy transition technologies. Only around 12% of globally produced aluminium, for example, is used in the products analysed, but is widely used in the building sector and in other engineering products. In comparison, lithium and graphite are almost exclusively mined for use in solar generation and batteries, respectively.

Table 50 provides an overview of all the analysed minerals, whether the annual mining capacities of Africa must increase, and – if yes – by what factor. In 2050, by far the largest annual mining capacities will be required for silicon and aluminium However, Africa's current mining capacity for bauxite (for aluminium) could supply more than two-thirds of this demand, whereas silicon mining must increase substantially from currently around 50,000 tonnes to almost 3 million tonnes per year.

Table 50: Annual mining capacities – status and requirements for 2030 and 2050

Minerals – Africa			Annual material demand								
			Material demand for energy transition technologies in 2023	Current mining in Africa	Current global mining	Africa's share of global mining volume	Africa's share of global energy transition materials	Increase in annual material demand: 2023–2030	Increase in annual material demand: 2023–2050	Average 2020–2030	Average 2041–2050
			[tonne/a]	[tonne/a]	[tonne/a]	[%]	[%]	[1]	[1]	[tonne/a]	[tonne/a]
Aluminium	Al	[tonne/a]	25,239	1,590,000	72,000,000	2%	2%	8.4	96.1	211,986	2,424,849
Cadmium	Cd	[tonne/a]	1	0	24,000	0%	0%	33.3	183.9	23	127
Chromium	Cr	[tonne/a]	39,805	22,100,000	47,000,000	47%	0%	1.4	6.2	55,776	246,477
Cobalt	Co	[tonne/a]	641	220,000	290,000	76%	0%	1.3	16.9	849	10,833
Copper	Cu	[tonne/a]	41,534	3,980,000	23,000,000	17%	1%	1.8	16.3	73,719	676,896
Graphite	Gr	[tonne/a]	4,393	189,000	1,600,000	12%	2%	1.5	62.4	6,447	274,317
Dysprosium	Dy	[tonne/a]	14	948	1,800	53%	1%	1.4	17.5	20	248
Lithium	Li	[tonne/a]	781	24,700	240,000	10%	3%	1.6	60.2	1,212	47,026
Manganese	Mn	[tonne/a]	1,969	13,180,000	20,000,000	66%	0%	1.4	41.1	2,702	80,858
Neodymium	Nd	[tonne/a]	467	14,052	16,000	88%	3%	1.6	6.8	726	3,156
Nickel	Ni	[tonne/a]	7,440	109,100	3,700,000	3%	7%	1.4	23.1	10,338	171,929
Silicon	Si	[tonne/a]	10,319	50,000	9,700,000	1%	21%	28.8	286.4	297,589	2,955,091
Silver	Ag	[tonne/a]	1,004	1,454	25,000	6%	69%	1.4	7.3	1,375	7,313
Tellurium	Te	[tonne/a]	1	4	980	0%	19%	33.3	183.9	26	143
Vanadium	V	[tonne/a]	88	8,000	100,000	8%	1%	1.3	87.5	111	7,667
Titanium	Ti	[tonne/a]	1,916	3,948,000	9,400,000	42%	0%	1.2	6.0	2,364	11,441

Finally, the cumulative material demands for Africa were compared with currently known global reserves and global resources to identify potential bottlenecks. The data for African reserves and resources are not available for all the minerals analysed, so the demands are compared with global data.

This risk stress test also shows which minerals are most likely to cause supply chain problems or whether sufficient resources are available.

Table 41 shows that the cumulative material demand of all analysed minerals used for energy transition technologies until 2050 does not exceed the currently know resources. However, in comparison with currently known reserves, there are no bottlenecks for Africa. Only silver shows a relatively high share of the globally known reserves, which indicates a possible competitive situation on the global market.

Table 51: Known global mineral reserves and resources versus African requirements until 2050 (African reserves and resources data are incomplete)

Mineral		Current global reserves (statistic 2024) [tonne]	Current global resources (statistic 2024) [tonne]	Total 2020–2050 [tonne]	Africa's cumulative material demand (AF-1.5°C scenario) 2020–2050 relative to global reserves [%]	Africa's cumulative material demand (AF-1.5°C scenario) 2020–2050 relative to global resources [%]
Aluminium	Al	28,000,000,000	55,000,000,000	37,072,130	0%	0%
Cadmium	Cd	500,000	3,300,000	2,311	0%	0%
Chromium	Cr	1,200,000,000	12,000,000,000	4,261,002	0%	0%
Cobalt	Co	11,000,000	25,000,000	225,734	2%	1%
Copper	Cu	980,000,000	3,500,000,000	10,841,265	1%	0%
Gallium	Ga	110,000	1,000,000	135	0%	0%
Graphite	Gr	290,000,000	800,000,000	3,953,834	1%	0%
Indium	In	15,000	356,000	1,031	7%	0%
Dysprosium	Dy	1,100,000	1,980,000	3,510	0%	0%
Lithium	Li	30,000,000	115,000,000	689,107	2%	1%
Manganese	Mn	1,700,000,000	UNKNOWN	1,218,074	0%	UNKNOWN
Neodymium	Nd	12,800,000	23,040,000	60,087	0%	0%
Nickel	Ni	130,000,000	350,000,000	2,775,050	2%	1%
Silicon	Si	UNKNOWN	UNKNOWN	46,205,067	UNKNOWN	UNKNOWN
Silver	Ag	640,000	1,308,000	106,764	17%	8%
Selenium	Se	92,000	171,000	1,077	1%	1%
Tellurium	Te	35,000	48,000	2,609	7%	5%
Vanadium	V	18,000,000	63,000,000	103,296	1%	0%
Titanium	Ti	560,000,000	2,000,000,000	162,985	0%	0%

8 Case studies

Power Shift Africa and the University of Technology Sydney (UTS) have developed comprehensive energy pathways for Tanzania, Rwanda, Kenya, Malawi, Senegal, and Tunisia that are consistent with the goals of the Paris Climate Agreement. The research was undertaken between 2022 and 2024. The following section provides a high-level overview of the methodology that was used for all six country scenarios.

8.1 Overview of the methodology

8.1.1 Development of the electricity demand

To develop a projection of the residential electricity demand for the analysed Africa countries over the coming 30 years, a bottom-up electricity demand analysis was performed. The energy development plans aim to increase the access of all to energy – especially electricity – by 2050, while increasing the electrification and comfort standards to the levels of OECD countries. A 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 appliances, 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.

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, semi-rural households, and urban households. The electricity demand will gradually increase as the electric applications for each of the three household types progress from those 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 form two groups: one with the basic level of electrification and one with 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 and (LPG for cooking is particularly important in decarbonising a household's energy supply. A staged transition towards electrical cooking is assumed.

8.1.2 Energy for cooking

The main energy demand for cooking in households of all the country scenarios analysed was assessed. The use of unsustainable biomass will be gradually phased out and replaced with electric cooking appliances. The total phase-out of traditional bioenergy-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, the use of 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 bioenergy-based cooking in 2050 will be with sustainable charcoal. Electric-cooking can be supplied by renewable energy sources and will therefore be emissions-free.

This cooking scenarios for all the analysed countries are consistent with the Cooking Energy Action Plan (CEAP) developed by *Sustainable Energy For All* (SE4ALL), which aims to achieve 75% access to modern cooking devices (improved cooking stoves for firewood, charcoal, and LPG), whereas the use of tradition biomass for cooking will decline to 25% by 2030.

Technical challenges of e-cooking for electric utilities, energy service companies, and policy requirements

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-fuel-powered vehicles will further increase the electric loads, and will require grid expansion and reinforcement to be implemented by electric grid operators. New policy frameworks, such as specific energy policies, acts, procedures, and/or guidelines, to support the increased utilisation of electric cooking devices will be required for e-cooking implementation. 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 access to those technologies, technology standards, and financing. Finally, the general awareness of the benefits of e-cooking – particularly in rural areas – is still low because access to the necessary information is negligible. This lack of information means that the acceptance of e-cooking devices in the supply chain – specialised kitchenware and hardware shops – is also low. Therefore, awareness programmes for retail staff are required.

8.1.3 Projection of transport energy demands

The structure of a country's transport sector is assessed in terms of the registered vehicle fleet, broken down to motorcycles, three-wheeler vehicles, passenger vehicles, and vans/buses. A breakdown into passenger and freight transport is also part of the analysis. The total amount of passenger and freight kilometres is 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 in all the analysed countries, and early statistics from 2022 and 2023, which were available for some countries, support this trend.

Therefore, it is anticipated that the pre-COVID transport demand of 2019 will be reached by 2023 and 2024, and the transport demand will increase with population growth and GDP. It is assumed that the annual passenger and freight kilometres will increase within the same order of magnitude as GDP growth annually until 2050. 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.

Based on the average technical lifespans for motorcycles and cars, a country-wide overall market share of electric drives for the entire existing car fleet may not exceed 5% 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.

8.1.4 Assumptions for energy scenario development

All six countries analysed must build up and expand their power generation systems 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 2023. 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:** This research assumes that the six African governments 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 rooftop 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 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 a portfolio of options.

8.1.5 Assumptions for the 1.5°C scenarios

All six 1.5°C scenarios are 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 adopted to meet the CO_2 emissions reductions targets in the six 1.5°C scenarios 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:** Dynamic growth in new capacities for renewable heat and power generation is assumed based on current knowledge of the potentials, 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. Coal power plants will be phased out early, followed by gas power plants.
- **Future power supply:** The capacity of large hydropower will remain flat in all countries over the entire scenario period, whereas the quantities of bioenergy will increase within each country'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 bioenergy and wind energy. The figures for solar PV combine rooftop and utility-scale PV plants, including floating and agricultural solar plants.
- **Security of the energy supply:** The six 1.5°C 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 hydropower, and hydro pump storage.
- **Sustainable biomass levels:** A country's projected volume of bioenergy is based on the domestic sustainable bioenergy potential, if this information is available. However, low-tech biomass use, such as in inefficient household wood burners, is largely replaced in all 1.5°C scenarios by state-of-the-art technologies, primarily highly efficient heat pumps and solar collectors.
- **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 and 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). In general, hydrogen and synthetic fuels will NOT be used for road transport, but for shipping, whereas synthetic aviation fuels will be introduced into domestic and international aviation. Furthermore, hydrogen utilisation will be limited to the industry sector only and is not expected to contribute more than 5%–10% of industry's energy supply by 2050.

All 1.5°C scenarios take an ambitious approach to transforming each country's entire energy system to an accelerated new renewable energy supply. However, the 1.5°C scenarios assume a much faster introduction of new technologies, which will lead to the complete decarbonisation of energy for stationary energy (electricity), heating (including process heat for industry), and transportation. In transportation, there will be a strong role for storage technologies, such as batteries, synthetic fuels, and hydrogen.

8.1.6 Assumptions for the REFERENCE scenarios

The REFERENCE scenarios for all six analysed countries were developed based on the OECM 1.5°C scenarios but assume an implementation delay of 15 years. The REFERENCE scenarios are all similar – but not identical – to the 'business-as-usual' (BAU) scenario for the six African countries, which were published in the Nationally Determined Contributions (NDC) submissions of previous years (between 2020 and 2022).

The key differences are:

A. **Heating sector:** The phase-out of coal, oil, and gas is delayed by 15 years in 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.
B. **Transport sector:** Electric mobility will experience significant delays, whereas the transport demand will increase as projected in the 1.5°C scenarios. Vehicles with internal combustion engines (ICEs) will remain dominant until 2040. The market shares for electric vehicles will start to grow significantly from 2040 onwards. Furthermore, biofuels will increase in the road transport sector.
C. **Power supply:** The delayed electrification in the heating and transport sectors will lead to slower growth of the power demand compared with that under the 1.5°C scenarios. It is also assumed that renewable power generation will not fill the gap in the increased electricity demand due to delayed implementation, and fossil-fuel-based power generation will therefore increase.

8.1.7 Projections for the electricity supply: assessment of solar and wind energy potential

The yearly totals of solar irradiation (DNI) levels and average annual wind speeds (in m/s) for all six countries analysed were taken from the literature. In this analysis, we have included only areas with an average annual wind speed of ≥ 5.5 m/s for onshore projects. Each country's solar and wind potentials have 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:** Scenario 1, with the additional restriction that excludes areas greater than or equal to 10 km from existing transmission lines (PT10).

Table 52 shows the assessed solar and wind potentials under the two scenarios and under space-constrained conditions.

Table 52: Solar and wind potentials – key results for six African countries

		Solar potential		Wind potential			
Country	**Units**	**Solar (S1)**	**Solar (S2)**	**Onshore wind (S1)**	**Onshore wind (S2)**	**(Fixed) offshore wind**	**(Floating) offshore wind**
Kenya	[MW]	11,705,731	3,506,163	1,634,539	269,651	19,861	72,835
Rwanda	[MW]	404,420	388,497	1,443	1,425	-	-
Tanzania	[MW]	10,877,881	2,732,253	788,888	231,788	4,157	12,939
Malawi	[MW]	1,715,464	810,313	195,178	82,604	-	-
Senegal	[MW]	3,330,627	1,604,548	583,640	297,237	59,003	106,272
Tunisia	[MW]	3,493,692	750,795	660,826	132,623	156,680	443,991
Sum	**[MW]**	**31,527,816**	**9,792,569**	**3,864,514**	**1,015,329**	**239,701**	**636,037**

8.2 Tanzania summary

The Government of Tanzania recognises the importance of energy in achieving its development goals and aims to improve access to modern and reliable energy services. The energy sector is guided by the energy policy of 2015, which provides guidance for sustainable development and the utilisation of energy resources to ensure optimal benefits to Tanzanians and contributes to the transformation of the national economy. This is consistent with the Tanzania Development Vision 2025 (TDV 2025) of pursuing development through a low-carbon pathway. The Energy Policy of 2015 aims to provide adequate, reliable, and affordable modern energy services to Tanzanians, while contributing to economic growth and environmental protection. The policy covers various aspects of the energy sector, such as petroleum, electricity, renewable energies, energy efficiency, climate resilience, and many more.

The nation recognises the importance of addressing climate change issues. Although the country currently has no stand-alone national climate change policy, aspects of climate change have been integrated into sectoral and national policies. Furthermore, the country has a National Climate Change Strategy 2021 (NCCRS 2021), which provides an overarching framework guiding the nation in addressing aspects of climate change, together with the revised NDC 2021, which highlights the national commitment to climate change mitigation. The NCCRS 2021 and NDC 2021 have both identified the energy sector as one of the key sectors contributing to greenhouse gas (GHG) emissions and also as vulnerable to the impacts of climate change.

According to the World Bank, Tanzania has achieved respectable growth in the past, averaging 6.2% between 2009 and 2019 (World B 2022).[68] However, Tanzania faces significant difficulties in achieving inclusive and sustainable growth. The ongoing global disruptions caused by the COVID-19 pandemic have been compounded by structural constraints on 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.

In accordance with its energy policy and national needs, Tanzania has been working to improve the energy supply, its security, and affordability, and access to it throughout the country. According to the Minister for Energy's 2023/24 budget speech in May 2023, the installed electricity capacity was 1,872.05 MW, contributed by hydropower (30.69%), natural gas (64.04%), fuel oil (4.7%), and biomass (0.56%). In the total energy mix of the country, the use of unsustainable biomass in the form of charcoal and firewood, accounts for nearly 85% of the total energy consumption.

The government has launched initiatives to improve energy access, predominantly in rural areas. This includes extending the electricity grid, promoting off-grid solutions, and increasing the percentage of households with access to electricity. These efforts are critical for reducing energy poverty and supporting economic development.

According to the Tanzania Mainland Energy Access and Use Situation Survey II (2020), for the year 2019/20, 78.4% of the total population in mainland Tanzania had access to electricity, compared with 67.5% in the year 2016/17. The report revealed an 11% increase in electricity access over that in the previous survey conducted in 2016/17.

The energy access rate among the rural population of mainland Tanzania is around 78%, although access to energy services does not necessarily mean that the supply is always available. The primary energy supply is dominated by biomass (over 98% in 2020), used mainly for cooking and heating, whereas electricity is almost entirely supplied by fossil-fuel-based gas (41%) and hydro energy (39%). If the primary energy supply continues according to its development over the past 5 years (by 3% annually), the primary energy demand will double to 1937 PJ/a by 2050.

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

68 World Bank 2022, Country Overview Tanzania, database from 2022.

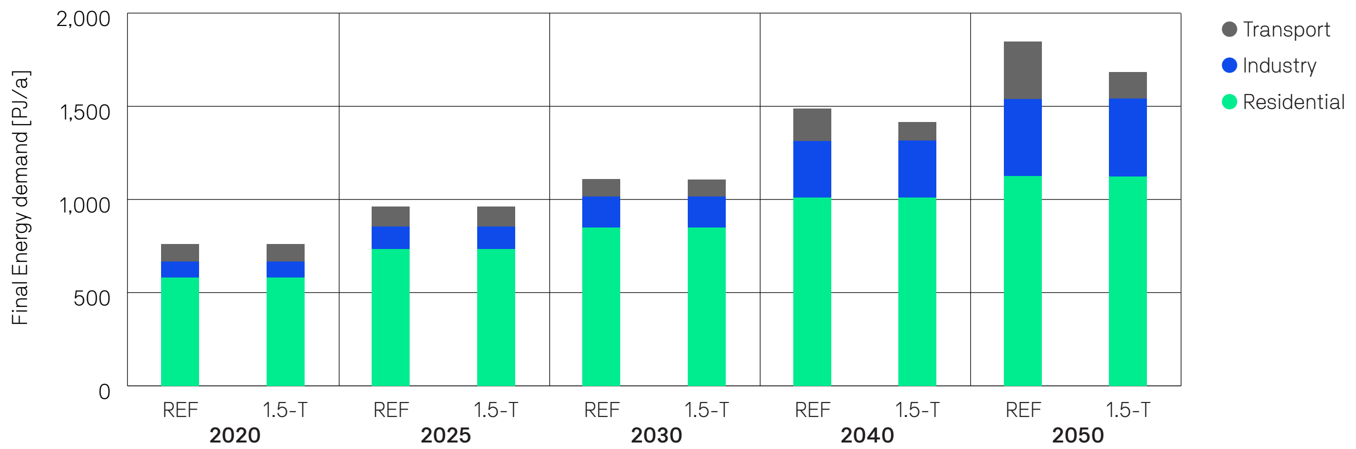
8.2.1 Tanzania – Final energy demand

The projections for population development, GDP growth, and energy intensity were combined to project the future development pathways for Tanzania's final energy demand. As a result of the projected continued annual GDP growth of 5.6%, on average, until 2025 and 6.8% thereafter until 2050, the overall energy demand is expected to grow. The residential sector will remain dominant in Tanzania's energy demand, but the energy demand of the industry sector will increase constantly. By 2050, industry will consume at least four times more energy than in 2020, making this sector the second highest consumer after transport.

The energy demand of the transport sector will increase by 233% by 2050 under the REFERENCE scenario, whereas it will only increase by 54% to 142 PJ/a under the TZ-1.5°C scenario. The main reason for this significant difference in growth projections is the high rate of electrification in the latter pathway.

The large efficiency gains achieved in the TZ-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.

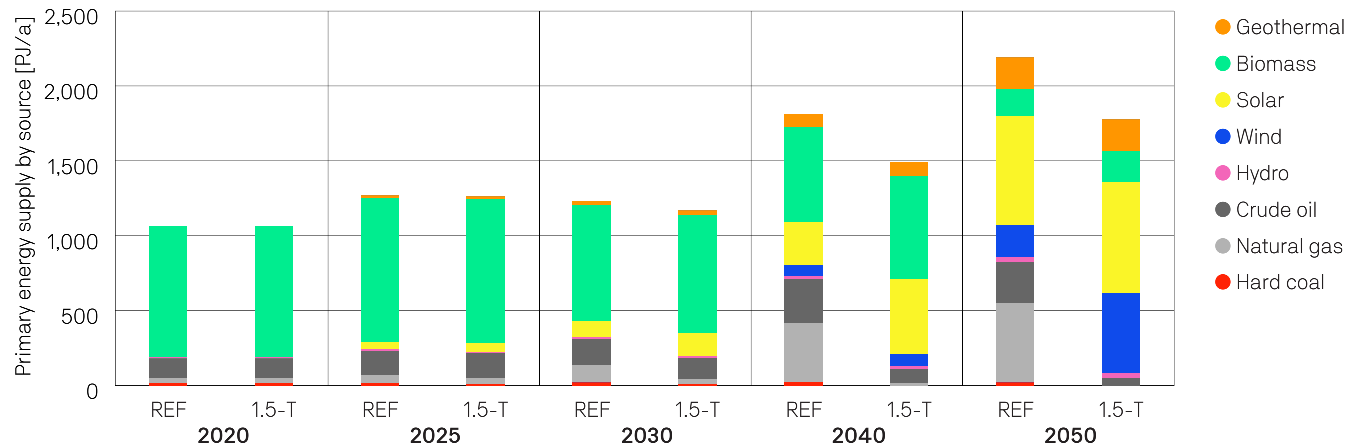
Figure 37: Tanzania – Projection of the total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)



8.2.2 Tanzania – Primary energy consumption

The TZ-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 more than 97% in 2050 under the TZ-1.5°C scenario (including non-energy consumption).

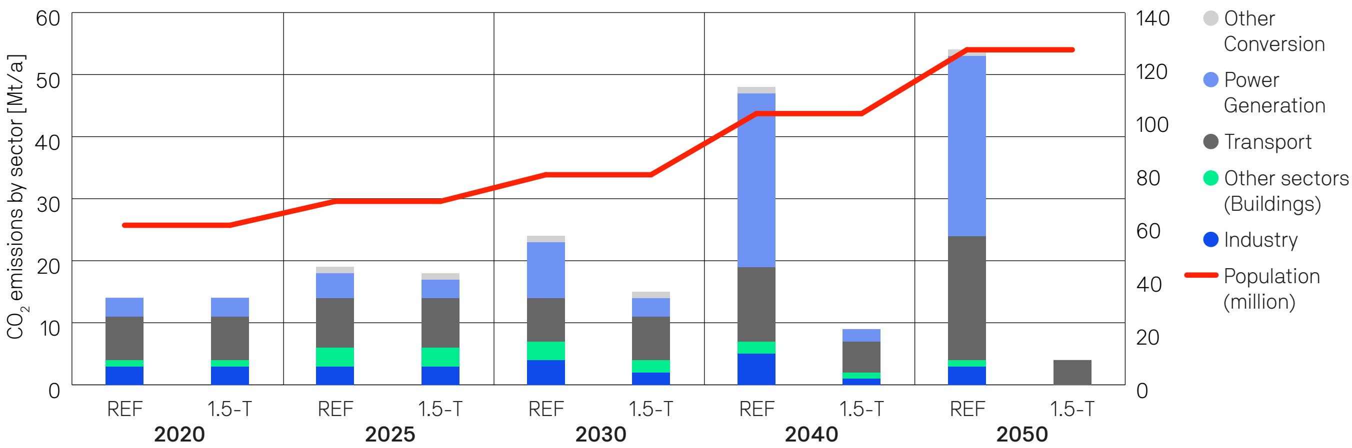
Figure 38: Tanzania – Projection of total primary energy demand by energy carrier (including electricity import balance)



8.2.3 Tanzania – CO_2 emissions trajectories

The TZ-1.5°C scenario will reverse the trend in increasing energy-related CO_2 emissions after 2025, leading to a reduction of about 6% relative to 2020 by 2030 and of about 34% by 2040. The full decarbonisation of Tanzania's energy sector will be achieved in 2050 under the TZ-1.5°C scenario and the cumulative emissions will sum to 283 Mt, compared with 449 Mt under the REFERENCE scenario.

Figure 39: Tanzania – Development of CO_2 emissions by sector



8.2.4 Tanzania – Cost analysis

The electricity supply for the 'traditional' power sector, as well as for the electrified heating and transport have very low costs for the power sector because electricity generation is based on solar and wind power – the remaining fuel costs are for the period 2021–2030. Increased electrification will lead to higher investment costs in power generation and higher overall electricity supply costs for Tanzania. Under the more ambitious electrification strategy of the T-1.5°C scenario, total investment in power generation will be 487 trillion TZS (US$195 billion).

Across the entire scenario period, fuel cost savings under the TZ-1.5°C scenario will be 355 trillion TZS (US$142 billion), more than three times higher than the additional investment in power generation until 2050. Although fuel cost predictions are subject to a great deal of uncertainty, this clear result makes the cost-effectiveness of electrification very clear.

Table 53: Tanzania – Accumulated fuel costs for heat generation under the REFERENCE and TZ-1.5°C scenarios

		2020–2030		2031–2040		2041–2050		2020–2050		2020–2050 average per year	
REFERENCE		Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD
Power	Total	26.9	10.8	87.6	35.0	118.2	47.3	232.7	93.1	7.8	3.1
Heat	Total	369.8	147.9	319.1	127.6	199.9	80.0	888.8	355.5	29.6	11.9
Transport	Total	41.5	16.6	94.3	37.7	149.7	59.9	285.5	114.2	9.5	3.8
Summed costs		**438.1**	**175.3**	**500.9**	**200.4**	**467.9**	**187.1**	**1,407.0**	**562.8**	**46.9**	**18.8**
		2020–2030		2031–2040		2041–2050		2020–2050		2020–2050 average per year	
TZ-1.5°C		Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD
Power	Total	18.7	7.5	20.0	8.0	17.7	7.1	56.4	22.6	1.9	0.8
Heat	Total	372.4	149.0	333.1	133.2	216.7	86.7	922.2	368.9	30.7	12.3
Transport	Total	34.5	13.8	22.6	9.0	16.3	6.5	73.4	29.3	2.4	1.0
Summed costs		**425.6**	**170.2**	**375.6**	**150.3**	**250.8**	**100.3**	**1,052.0**	**420.8**	**35.1**	**14.0**
Difference REFERENCE versus TZ-1.5°C		**12.6**	**5.0**	**125.3**	**50.1**	**217.1**	**86.8**	**354.9**	**142.0**	**11.8**	**4.7**

8.3 Rwanda summary

Rwanda's economy has developed successfully over the past decade with an increase in the per-capita GDP of 70% between 2015 and 2023. This research aims to support Rwanda's energy policy debate, and the further development of the Economic Development and Poverty Reduction Strategy (EDPRS II) published in the same year. According to the Rwanda Energy Policy 2015 document published by the Ministry of Infrastructure of the Republic of Rwanda on the 17th March 2015,[69] the energy policy *'is founded upon three essential government principles:*

i. A resolve for transparent and effective sector governance.

ii. Easing doing business and reducing barriers to private investment.

iii. Enhancing institutional, organisational, and human capacities as well as the legal and regulatory framework.

The Energy Policy and the Energy Sector Strategic Plan (ESSP) are mutually reinforcing. Whereas the policy outlines a long-term vision, provides high-level goals, and recommends clear and co-ordinated approaches for achieving that vision, the ESSP outlines targets and an implementation framework against which to measure progress towards the realisation of the policy. In this way, the policy can guide the actualisation of aligned implementation strategies, while the ESSP outlines the priority strategies and actions that give practical thrust to the policy' (...)

The policy needs to address the following critical sector challenges:

i. Energy security and a sound demand–supply balance.

ii. Dramatic increase in access to modern energy services.

iii. Improvement and streamlining of stakeholder co-ordination to ensure effective partnership and delivery on set targets.

iv. Need for a robust legal and regulatory framework required.

v. Necessity for institutional, organisational, and human capacity development.

vi. Inadequate infrastructure requiring huge investment.

vii. High cost of fuel for electricity generation.

viii. Vulnerability to climate change.

In addition, the development of relevant policies for the energy sector mandates that the key issues that affect the supply and demand of energy in Rwanda be delineated. Broad issues of the energy sector in Rwanda include the following:

i. Inadequate co-ordination and information sharing between or among the various projects, government bodies, the private sector, and civil society organisations.

ii. Lack of investment.

iii. Inadequate energy planning information system (energy supply and demand analysis).

iv. Lower rate of access to modern energy.

v. Inadequate financial resources to plan for and monitor the energy sector and carry out appropriate research and development (R&D).

vi. Lack for appropriate curricula in energy studies at many institutions of higher learning.

vii. Inadequate human resource and institutional capacity.

For each of the energy sub-sectors, there are specific issues to consider, which are given below. The various energy sub-sectors include the following:

- *electricity;*
- *petroleum;*
- *biomass;*
- *energy efficiency and demand-side management.'*

69 Rwanda Energy Policy, Ministry of Infrastructure, Republic of Rwanda, 17th March 2015, https://rura.rw/fileadmin/Documents/Energy/RegulationsGuidelines/Rwanda_Energy_Policy.pdf

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

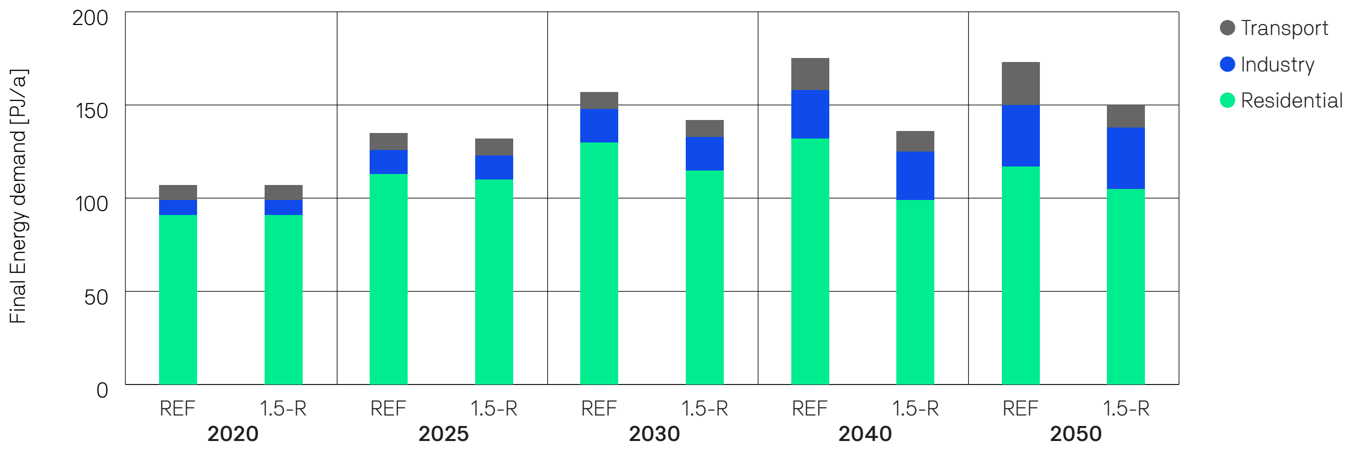
8.3.1 Rwanda's energy sector

According to the Rwanda Energy Group, *'as of end September 2023, the cumulative connectivity rate in Rwanda is 74.40% of Rwandan households, including 54.19% connected to the national grid and 20.21% accessing through off-grid systems (mainly solar). During the elaboration of the EDPRS II, the Government of Rwanda took a clear policy decision to diversify the sources of electricity from traditional dominant grid to include even off-grid connections. Subsequently, households far away from the planned national grid coverage have been encouraged to use alternatively cheaper connections, such as minigrids and solar photovoltaics (PVs) to reduce the cost of access to electricity whilst relieving constraints on historical government subsidies'* (REG 2023). The primary energy supply is dominated by biomass (over 98%), used mainly for cooking and heating, whereas electricity is almost entirely supplied by hydro energy (53%). If the primary energy supply continues according to its development over the past 5 years (by 2% annually), the primary energy demand will increase by almost 60% to 290 PJ/a by 2050.

8.3.2 Rwanda – Final energy demand

The projections of population development, GDP growth, and energy intensity were combined to project the future development pathways for Rwanda's final energy demand. As a result of the projected continued annual GDP growth of 7.8% on average, until 2025 and 4.5% thereafter until 2050, the overall energy demand is expected to grow. The residential sector will remain dominant in Rwanda's energy demand, but the energy demand of the industry sector will increase constantly. By 2050, industry will consume at least four 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 178% by 2050 under the REFERENCE scenario, whereas it will increase by 48% under the R-1.5°C scenario. The main reason for the significant difference in growth projections is the high rate of electrification in the latter pathway. The large efficiency gains achieved in the R-1.5°C scenario are attributable to the high electrification rates, mainly in the cooking and transport sectors, because combustion processes with high losses will be significantly reduced.

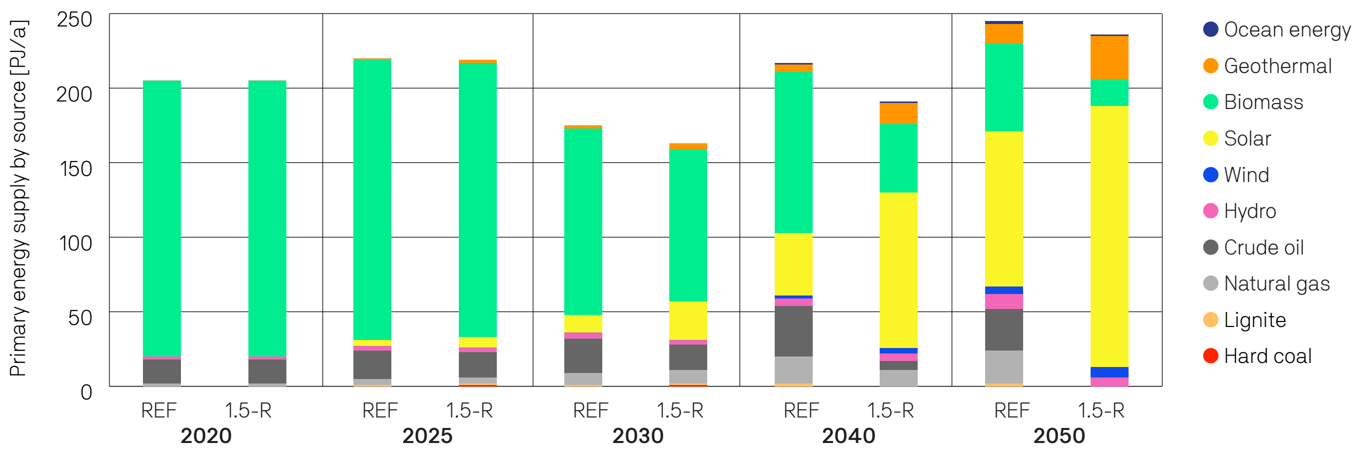
Figure 40: Rwanda – Projection of the total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)



8.3.3 Rwanda – Primary energy consumption

The R-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 more than 92% in 2050 under the R-1.5°C scenario (including non-energy consumption).

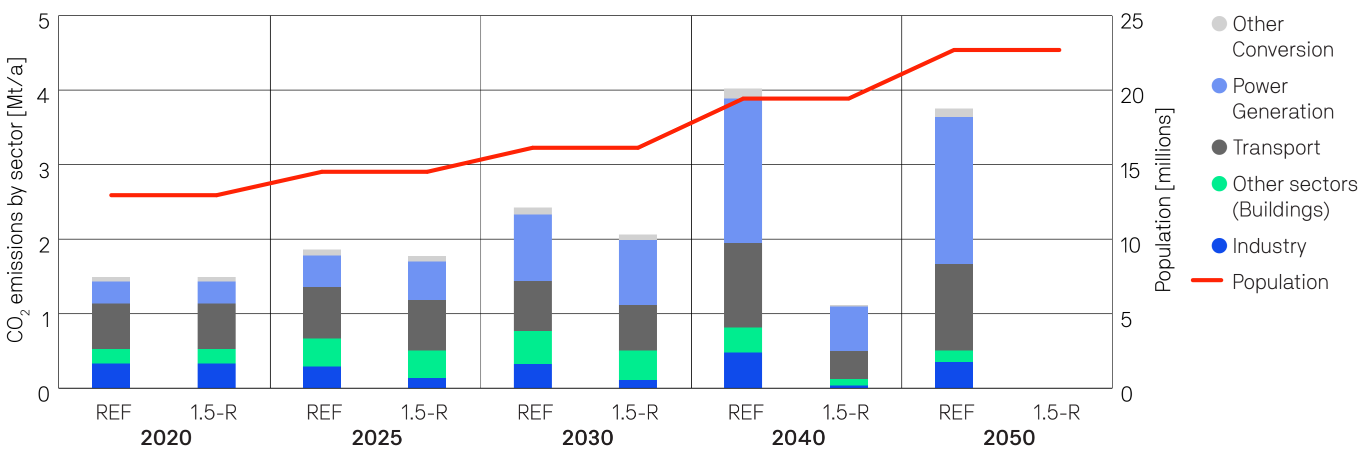
Figure 41: Rwanda – Projection of total primary energy demand by energy carrier (including electricity import balance)



8.3.4 Rwanda – CO_2 emissions trajectories

The R-1.5°C scenario will reverse the trend in increasing energy-related CO_2 emissions after 2025, leading to a reduction of about 40% relative to 2020 by 2030 and of about 23% by 2040 (relative to 2020). The full decarbonisation of Rwanda's energy sector will be achieved by 2050 under the R-1.5°C scenario and the cumulative emissions will sum to 31 Mt.

Figure 42: Rwanda – Development of CO_2 emissions by sector



8.3.5 Rwanda – Investment and fuel cost savings

The power, heat, and transport sectors will all reduce their fuel costs over time because electricity generation will be based on renewables – with significant shares of solar and wind power. However, increased electrification will lead to higher investment costs in power generation and higher overall electricity supply costs under the R-1.5°C scenario. The R-1.5°C scenario requires an investment in power generation of 38 trillion RWF (US$47billion) and 30 trillion RWF (US$24 billion) in heat generation. Therefore, the total investment in power and heat generation capacities will be 68 trillion RWF (US$71 billion). The additional investment in power generation 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 R-1.5°C scenario relative to the REFERENCE scenario will be 4.2 trillion RWF (US$27 billion), which will cover more than half the total investment in generation capacities until 2050 – about 2.5 times the additional investment in the R-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. However, Rwanda has a low energy access rate, so additional investment in the energy infrastructure will be required

Table 54: Rwanda – Accumulated fuel costs for heat generation under the REFERENCE and R-1.5°C scenarios

		2020–2030		2031–2040		2041–2050		2020–2050		2020–2050 average per year	
REFERENCE		**Trillion RWF**	**Billion USD**	**Trillion RWF**	**Billion USD**	**Trillion RWF**	**Billion USD**	**Trillion RWF**	**Billion USD**	**Trillion RWF**	**Billion USD**
Power	Total	0.2	1.6	0.5	3.1	0.5	3.4	1.2	8.1	0.0	0.3
Heat	Total	4.3	27.8	3.3	21.2	2.2	14.0	9.7	62.9	0.3	2.1
Transport	Total	0.2	1.5	0.4	2.8	0.5	3.5	1.2	7.8	0.0	0.3
Summed costs		**4.8**	**30.9**	**4.2**	**27.1**	**3.2**	**20.9**	**12.1**	**78.8**	**0.4**	**2.6**
		2020–2030		**2031–2040**		**2041–2050**		**2020–2050**		**2020–2050 average per year**	
R-1.5°C		**Trillion RWF**	**Billion USD**	**Trillion RWF**	**Billion USD**	**Trillion RWF**	**Billion USD**	**Trillion RWF**	**Billion USD**	**Trillion RWF**	**Billion USD**
Power	Total	0.2	1.2	0.3	2.2	0.3	1.8	0.8	5.2	0.0	0.2
Heat	Total	4.0	26.3	1.8	11.8	0.6	3.8	6.4	41.9	0.2	1.4
Transport	Total	0.2	1.4	0.3	2.2	0.1	1.0	0.7	4.5	0.0	0.2
Summed costs		**4.4**	**28.9**	**2.5**	**16.2**	**1.0**	**6.6**	**7.9**	**51.6**	**0.3**	**1.7**
Difference REFERENCE versus R-1.5°C		**0.3**	**2.0**	**1.7**	**10.8**	**2.2**	**14.3**	**4.2**	**27.2**	**0.1**	**0.9**

8.4 Kenya summary

According to the Climate Action Tracker policy overview, climate mitigation was not prioritised in the 'Big Four Agenda' of former Kenyan President Uhuru Kenyatta, nor in the country's Vision 2030. However, the Kenyan Government had already adopted the Climate Change Act (2016), which provides a framework for the promotion of climate-resilient low-carbon economic development. The Act mandates the government to develop a National Climate Change Action Plan (NCCAP) and to update it every 5 years. The second and most recent NCCAP covers the period 2018–2022. Its main objective is to guide climate action during that time and support the implementation of Kenya's NDC. Under the NCCAP, sector representatives define priority climate-mitigation actions that are designed to ensure that sectors meet their sectoral targets (Government of Kenya 2018).

An amendment to the Climate Change Act was introduced into the National Assembly in August 2023 and mainly contains new definitions for the carbon market, including carbon credits and carbon budgets. Furthermore, the new bill forms the basis of two additional policies introduced in September 2023: Kenya's National Climate Change Action Plan (NCCAP) 2023–2027 and the Long-Term Low Emission Development Strategy (LT-LEDS) 2022–2050. The IEA Kenya Energy Outlook, published already in 2019, provides an overview to Kenya's higher-level economic targets, which may conflict with the later-introduced Climate Change Action Plan.

Table 55: IEA Kenya energy outlook 2019

Policy	Key Target and Measures
Performance targets	National Electrification Strategy: provide universal electricity services to all households and businesses by 2022, with service levels of acceptable quality
	Produce 100,000 barrels of oil per day from 2022 and develop 2,275 MW of geothermal capacity by 2030
Industrial development targets	Increase the contribution of the manufacturing sector share of GDP to 15% by 2022
	Develop domestic iron and steel industries by 2030
	Achieve middle-income status by 2030

According to the World Bank, Kenya has achieved respectable GDP growth in the past, averaging 4.9% between 2009 and 2019. However, Kenya faces significant difficulties in achieving inclusive and sustainable growth. The 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. Kenya's electricity demand is currently 167 kWh per capita, one of the lowest in the world, while the global average consumption is over 3,000 kWh/capita per annum. The primary energy supply is dominated by biomass (around 95% in 2020), used mainly for cooking and heating, whereas electricity is almost entirely supplied by geothermal and hydro (71% combined in 2020). If the primary energy supply continues according to its development over the past 5 years (by 3% annually), the primary energy demand will increase to 1,276 PJ/a by 2050.

The following section provides an overview of the key results of the K-1.5°C energy scenario.

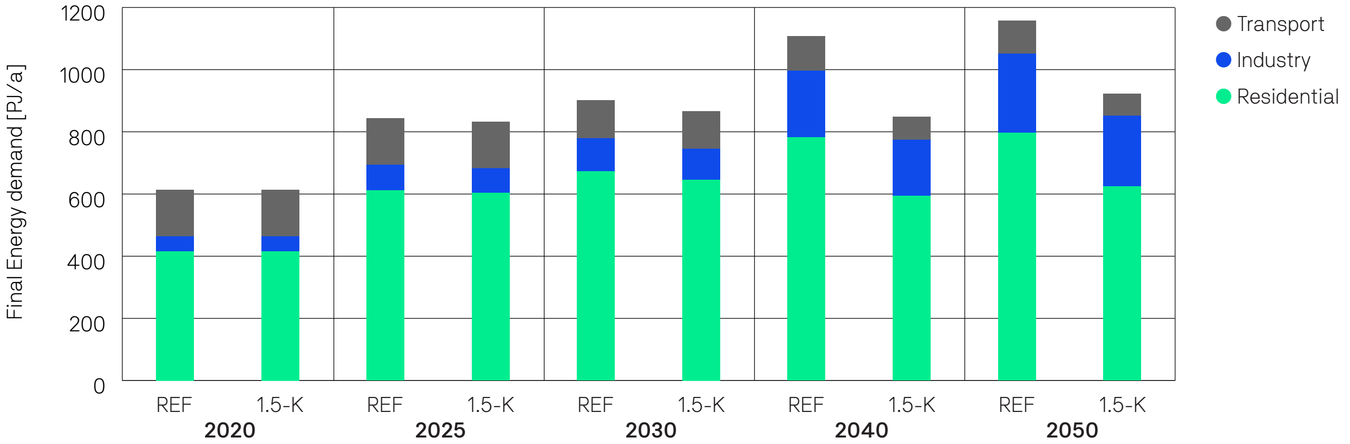
8.4.1 Kenya – Final energy demand

The projections of population development, GDP growth, and energy intensity were combined to project the future development pathways for Kenya's final energy demand. As a result of the projected continued annual GDP growth of 6.5% on average, until 2025 and 4.5% thereafter until 2050, the overall energy demand is expected to grow under the K-1.5°C and REFERENCE scenarios. The residential sector will continue to dominate Kenya's energy demand, but the energy demand of the industry sector will increase constantly. By 2050, industry will consume at least four 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 decrease by 30% by 2050 under the REFERENCE scenario, whereas it will decrease by 53% under the K-1.5°C scenario. The main reason for the significant difference in growth projections is the high rates of electrification in the latter pathway.

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

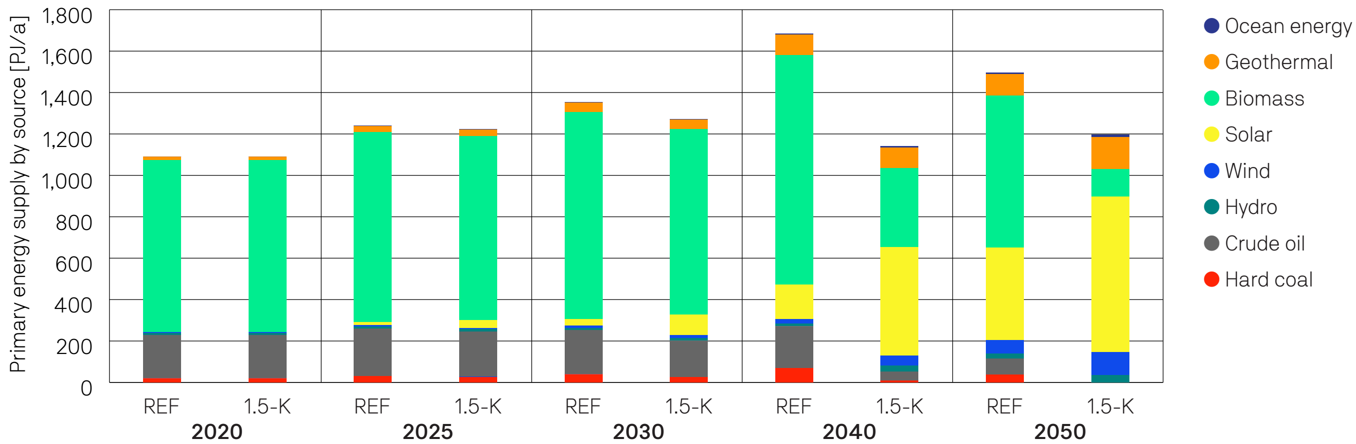
Figure 43: Kenya–Projection of the total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)



8.4.2 Kenya – Primary energy consumption

The K-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 99% in 2050 under the K-1.5°C scenario (including non-energy consumption).

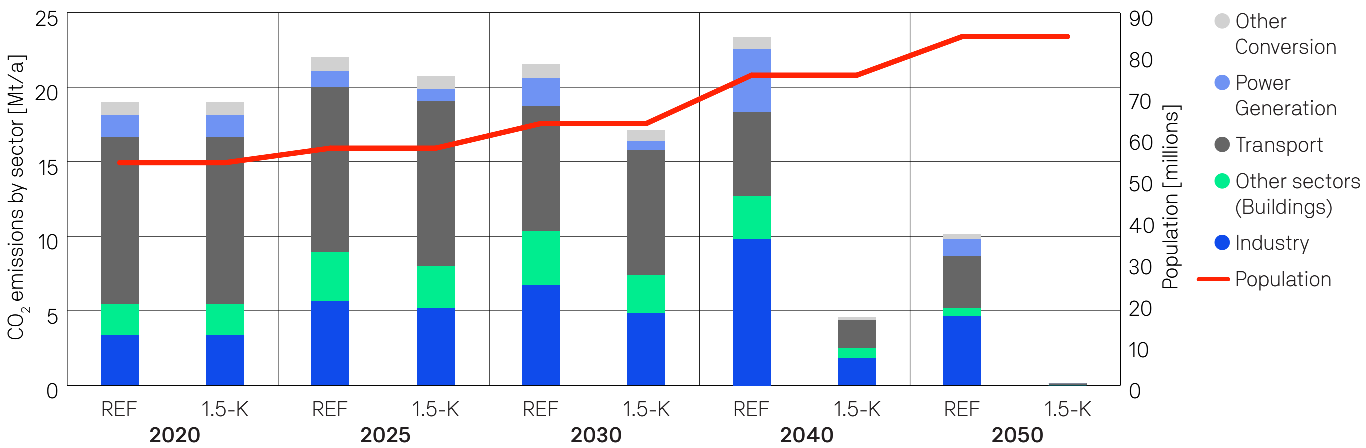
Figure 44: Kenya – Projection of the total primary energy demand by energy carrier (including electricity import balance)



8.4.3 Kenya – CO_2 emissions trajectories

The K-1.5°C scenario will reverse the trend of increasing energy-related CO_2 emissions after 2025, leading to a reduction of about 10% relative to 2020 by 2030 and of about 71% by 2040. The full decarbonisation of Kenya's energy sector will be achieved by 2050 under the K-1.5°C scenario and the cumulative emissions will sum to 358 Mt from 2005 to 2050 compared with 421 Mt CO_2 for the REFERENCE scenario.

Figure 45: Kenya – Development of CO_2 emissions by sector



8.4.4 Kenya – Cost analysis

The fuel costs for the power, heating, and transport sectors will decrease over time because electricity generation will be based renewables – with significant shares of solar and wind power. However, increased electrification will lead to higher investment costs in power generation and higher overall electricity supply costs for Kenya.

Table 56 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 Kenyan shillings and US dollars. The K-1.5°C scenario requires an investment in power generation of 21 trillion KES (US$135 billion) and 25 trillion KES (US$166 billion) in heat generation. Therefore, the total investment in power and heat generation capacities will be 46 trillion KES (US$301 billion).

Additional power generation investments will be compensated by fuel costs savings in the decade in which they are made. Across the entire scenario period, fuel cost savings under the K-1.5°C scenario relative to the REFERENCE scenario will be 91 trillion KES (US$590 billion) – about two times higher than the investment in generation capacities until 2050.

In comparison to the REFERENCE scenario, the fuel cost savings of the K-1.5°C scenario will cover about six times the additional investment required in power generation capacity. Although fuel cost predictions are subject to a great deal of uncertainty, this clear result makes the cost-effectiveness of electrification very clear.

Table 56: Kenya – Accumulated fuel costs for heat generation under the REFERENCE and K-1.5°C scenarios

		2020–2030		2031–2040		2041–2050		2020–2050		2020–2050 average per year	
REFERENCE		Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD
Power	Total	0.8	5.5	1.5	9.8	1.0	6.6	3.4	21.9	0.1	0.7
Heat	Total	24.2	157.3	30.5	198.4	27.2	176.8	81.9	532.6	2.7	17.8
Transport	Total	2.3	15.2	1.8	11.4	1.4	9.0	5.5	35.6	0.2	1.2
Summed costs		**27.4**	**178.0**	**33.8**	**219.7**	**29.6**	**192.3**	**90.8**	**590.1**	**3.0**	**19.7**
		2020–2030		**2031–2040**		**2041–2050**		**2020–2050**		**2020–2050 average per year**	
K-1.5°C		Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD
Power	Total	0.5	3.3	0.7	4.6	0.8	4.9	2.0	12.8	0.1	0.4
Heat	Total	22.9	149.2	16.4	106.6	6.0	38.8	45.3	294.6	1.5	9.8
Transport	Total	2.3	15.1	1.1	7.2	0.6	4.1	4.1	26.4	0.1	0.9
Summed costs		**25.8**	**167.6**	**18.2**	**118.4**	**7.3**	**47.8**	**51.3**	**333.7**	**1.7**	**11.1**
Difference REFERENCE versus K-1.5°C		**1.6**	**10.4**	**15.6**	**101.4**	**22.2**	**144.6**	**39.4**	**256.3**	**1.3**	**8.5**

8.5 Senegal summary

Senegal submitted its first Nationally Determined Contribution (NDC) at the end of 2020 and the country is currently developing its climate policy to reduce its CO_{2e} emissions by 29% by 2030 (conditional on external support) and to achieve a cumulative installed capacity of 235 MW, with 150 MW for solar and wind energy by 2030.[70] However, the former Senegal President Macky Sall has spoken out against developments that would reduce financing for fossil fuel projects.[71] The current President Bassirou Diomaye Diakhar Faye's political agenda includes a simultaneous focus on fossil fuels, with a renegotiation of oil contracts with major energy companies, and an increase in Senegal's renewable energy development. The movement towards renewables is illustrated by Senegal's policies summarised in a 2023 overview by the IEA. In one of those policies, the Just Energy Transition Partnership (JETP), Senegal will receive €2.5 billion over a 3–5-year period to support its energy transition. Within this framework, Senegal has pledged to achieve 40% renewable energy generation by 2030.

Positive steps towards climate action are urgently required, with climate change affecting every aspect of Senegal's daily life, including fishing, agriculture, health, safety in the face of rising sea levels, productivity, and climate adaptation to heat and extreme climate events.[72]

Table 57: IEA Senegal Energy Policy Review 2023

Policy	Key targets and measures
Plan Sénégal mergent	Transformation of Senegal into an emerging market economy, with growth in infrastructure, industrialisation, and the modernisation of agriculture.
Lettre de politique de développement du secteur énergétique (LPDSE 2019-2023)	Securing access to low-cost sustainable energy, modern cooking, and improved regulation.
Lettre de politique de développement du secteur énergétique (LPDSE 2024 -2028)	Under development.
Plan Intégré à Moindre Coût PIMC (10 year Low cost plan)	Replacing hydrofluoroolefins with natural gas.
Just Energy Transition Partnership (JETP)	In a partnership with France, Germany, the EU, the UK and Canada, Senegal will be supported with €2.5 billion in a 3–5-year period to achieve its energy transition ambitions. Senegal has pledged a 40% share in renewable energy generation by 2030 within the JETP.

According to the World Bank, Senegal has achieved respectable GDP growth in the past, averaging 4.6% between 2009 and 2019. However, Senegal faces significant difficulties in achieving inclusive and sustainable growth. The 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. The pandemic has also recently triggered a surge in debt levels, which must be addressed. However, strong economic growth is assumed for the development of the energy scenario.

Senegal's electricity demand is currently 272 kWh per capita, one of the lowest in the world, while the global average consumption exceeds 3,000 kWh/capita per annum. The primary energy supply is dominated by crude oil (around 49% in 2020), which supplies electricity generation, and biomass (around 41%), which is used mainly for cooking and heating. If the primary energy supply continues according to its development over the past 5 years (by 4.2% annually), the primary energy demand will increase to 637 PJ/a by 2050.

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

70 Republique du Senegal, Contribution Déterminée au Niveau National Du Senegal, December 2020, Online: retrieved on 7th of August 2024, https://climatepromise.undp.org/what-we-do/where-we-work/senegal

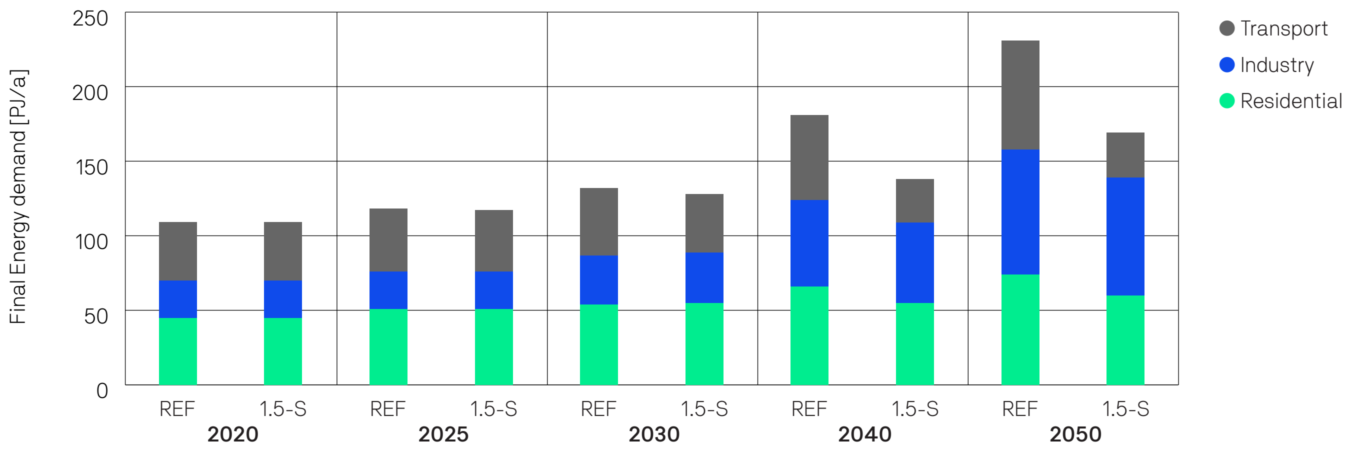
71 https://climateactiontracker.org/documents/1067/2022_08_CAT_Governance_Report_Senegal.pdf

72 https://www.usaid.gov/climate/country-profiles/senegal

8.5.1 Senegal – Final energy demand

The projections of population development, GDP growth, and energy intensity were combined to project the future development pathways for Senegal's final energy demand. As a result of the projected continued annual GDP growth of 7.3%, on average, until 2030 and 6.7% thereafter until 2050, the overall energy demand is expected to grow under the S-1.5°C and REFERENCE scenarios. The residential sector will remain dominant in Senegal's energy demand, but the energy demand of the industry sector will increase slightly. The energy demand of the transport sector will increase by 84% by 2050 under the REFERENCE scenario, whereas it will decrease by 39% under the S-1.5°C scenario. The main reason for the significant difference in growth projections is the high rates of electrification in the latter scenario. The large efficiency gains achieved in the S-1.5°C pathway are attributable to the high electrification rates, mainly in the cooking and transport sectors, because combustion processes with high losses will be significantly reduced.

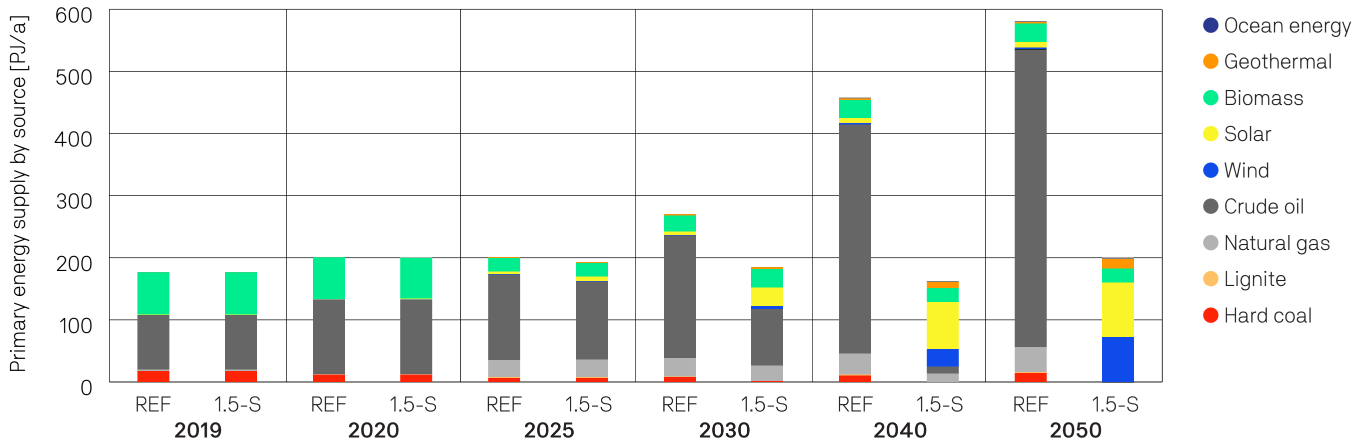
Figure 46: Senegal – Projection of the total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)



8.5.2 Senegal – Primary energy consumption

The S-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 under the S-1.5°C scenario (including non-energy consumption).

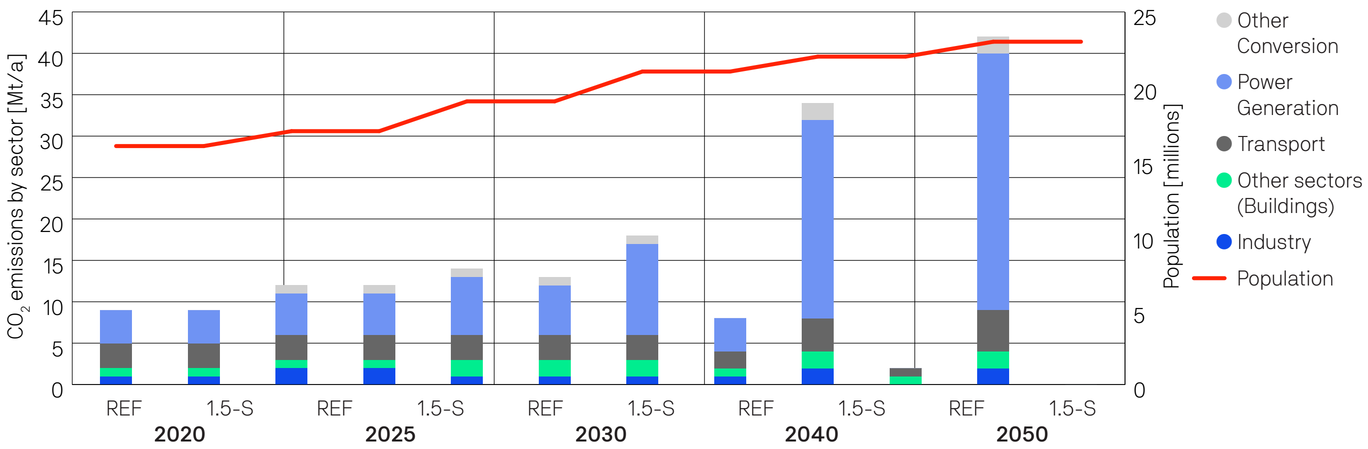
Figure 47: Senegal – Projection of the total primary energy demand by energy carrier (including electricity import balance)



8.5.3 Senegal – CO_2 emissions trajectories

The S-1.5°C scenario will reverse the trend in increasing energy-related CO_2 emissions after 2025, leading to a reduction of about 2% relative to 2020 by 2030 and of about 81% by 2040. The full decarbonisation of Senegal's energy sector will be achieved by 2050 under the S-1.5°C scenario and the cumulative emissions will sum to 275 Mt for 2005–2050 compared with 693 Mt CO_2 for the REFERENCE scenario.

Figure 48: Senegal – Development of CO_2 emissions by sector



8.5.4 Senegal – Cost analysis

The fuel costs for the power, heating, and transport sectors will decrease over time because electricity generation will be based on renewables – with significant shares of solar and wind power. However, increased electrification will lead to higher investment costs in power generation and higher overall electricity supply costs for Senegal. Table 58 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 Central African francs (CFA) and US dollars. The S-1.5°C scenario will require an investment of 16 trillion CFA (US$26 billion) in power generation and 10 trillion CFA (US$16 billion) in heat generation. Therefore, the total investment in power and heat generation capacities will be 25 trillion CFA (US$43 billion). Across the entire scenario period, fuel cost savings under the S-1.5°C scenario relative to the REFERENCE scenario will be 19.2 trillion CFA (US$32.6 billion), which will cover the entire investment in new power generation capacities until 2050 – about 16 times the additional investment required under the REFERENCE pathway. Although fuel cost predictions are subject to a great deal of uncertainty, this clear result makes the cost-effectiveness of electrification very clear.

Table 58: Senegal – Cumulative fuel costs for heat generation under the REFERENCE and S-1.5°C scenarios

		2020–2030		2031–2040		2041–2050		2020–2050		2020–2050 average per year	
REFERENCE		**Trillion CFA**	**Billion USD**	**Trillion CFA**	**Billion USD**	**Trillion CFA**	**Billion USD**	**Trillion CFA**	**Billion USD**	**Trillion CFA**	**Billion USD**
Power	Total	4.8	8.2	4.8	8.2	7.5	12.7	17.1	29.1	0.6	1.0
Heat	Total	1.5	2.5	1.7	3.0	1.5	2.6	4.7	8.1	0.2	0.3
Transport	Total	1.1	1.8	1.4	2.3	1.6	2.7	4.0	6.8	0.1	0.2
Summed costs		**7.4**	**12.5**	**7.9**	**13.5**	**10.5**	**17.9**	**25.9**	**43.9**	**0.9**	**1.5**
		2020–2030		**2031–2040**		**2041–2050**		**2020–2050**		**2020–2050 average per year**	
S-1.5°C		**Trillion CFA**	**Billion USD**	**Trillion CFA**	**Billion USD**	**Trillion CFA**	**Billion USD**	**Trillion CFA**	**Billion USD**	**Trillion CFA**	**Billion USD**
Power	Total	0.2	0.4	0.2	0.4	0.0	0.0	0.5	0.8	0.0	0.0
Heat	Total	1.6	2.7	1.4	2.4	1.1	1.8	4.0	6.9	0.1	0.2
Transport	Total	1.0	1.7	0.7	1.2	0.4	0.7	2.1	3.6	0.1	0.1
Summed costs		**2.8**	**4.8**	**2.4**	**4.0**	**1.5**	**2.5**	**6.6**	**11.3**	**0.2**	**0.4**
Difference REFERENCE versus S-1.5°C		**4.5**	**7.7**	**5.6**	**9.5**	**9.1**	**15.4**	**19.2**	**32.6**	**0.6**	**1.1**

8.6 Tunisia summary

Since the Jasmine Revolution, Tunisia's government has made progress in the right direction regarding their obligations to submit NDCs and set a net-zero emissions target. This progress includes the submission of its first NDC in 2015, followed by a strengthened revision of the NDC in 2021, with an accompanying long-term strategy and a net-zero emissions target.[73] The updated NDC outlines a commitment to a 45% reduction in carbon intensity (27% unconditional) by 2030 relative to the 2010 level, and a long-term strategy entitled 'Strategy of Carbon Neutral and Resilient Development to Climate Change at the 2050 Horizon' sets a 2050 target for carbon neutrality.[74] These targets can be viewed as a strong pathway towards decarbonisation, but also as a basis for a holistic approach to sustainable development.[75]

The challenge for Tunisia regarding its sustainable development goals and a decarbonisation trajectory consistent with the Paris Agreement is securing a sufficiently high level of political and economic stability across institutions and civil society to allow the NDCs and long-term strategy to be implemented. Despite these challenging conditions, there is cause for hope, particularly given Tunisia's potential to develop its strategy of sustainable development. As stated by Alexandre Arrobbio, the World Bank's Country Manager for Tunisia, "there are significant opportunities for Tunisia to transform and strengthen its economy. With strategic investments, particularly in renewable energy, Tunisia could significantly enhance its economic resilience and sustainability."[76] The press release goes on to state that there are "large economic benefits of deepening this transition through an ambitious decarbonisation agenda ...flagship projects on this agenda is the electricity interconnection between Tunisia and Italy. This project aims to improve the resilience of Tunisia's electricity system and transform it into a net exporter of electricity. This would significantly reduce the country's dependence on costly natural gas imports and improve its balance of payments."[77]

Table 59: IEA summary of recent energy policies in Tunisia[78]

Policy name	Year	Details
Fossil fuels and electricity subsidies	2023	The Tunisian Government earmarked subsidies for fossil fuels and electricity in 2023. The support is distributed to state-owned energy companies, ensuring price regulation.
Tunisian Investment Fund subsidies – Decree 2017-389, Art. 3	2017	Tunisian Investment Fund (FTI) announced subsidies for renewable energy projects. The subsidies aim to promote and attract renewable energy investment in Tunisia, and include a range of policies subdivided by project costs. One offer is equity contribution by the FTI in enterprises with investment volume of less than 15 million dinar, including working capital and investment expansion.
Renewable Energy Law for Electricity Production (No. 74/2013)	2015	This law seeks to encourage investment in renewable energy and consequently increase the contribution of renewable energy electricity to 30% (equivalent to 3,800 MW) of the total electricity production by 2030.
Decree on the Connection and Access of Renewable Electricity to the National Grid	2011	The decree sets the conditions for the connection and access of renewable electricity producers to the national grid. It supersedes the previous conditions set in 2007.
Tax exemptions for the import of renewable energy and energy efficiency equipment and materials	2010	Amendment to the list of materials and products necessary to manufacture energy efficiency or renewable energy equipment, which are exempt from value-added tax or have reduced import duties. The previous list was established in 1995.

73 Climate Watch, Tunisia webpage, accessed September 2024: https://www.climatewatchdata.org/countries/TUN?end_year=2021&start_year=1990

74 ibid.

75 UNDP Climate Promise, Tunisia Webpage, accessed September 2024: https://climatepromise.undp.org/what-we-do/where-we-work/tunisia

76 ibid.

77 ibid.

78 IEA Policy Database, Tunisia Webpage, accessed September 2024: https://www.iea.org/policies?country=Tunisia

Tunisia has experienced dynamic and evolving political and economic circumstances over the last decade. This document does not seek to evaluate the Jasmine Revolution, it's consequences, or the current political climate in Tunisia. The authors refer to the political and economic context of Tunisia where relevant, as it relates to the subject matter of the energy transition and sustainable development ambitions of Tunisia and its people.

It is lamentable that in this time of political friction, Tunisian citizens are also facing a difficult economic outlook, with a decade of attempted democratisation accompanied by slowing economic growth. GDP growth fell from 3.5% between 2000 and 2010 to 1.7% between 2011 and 2019. In addition to this, recent negative economic events have challenged the Tunisian economy. COVID-19, higher food and fuel prices, a fall in European demand for Tunisian products, and rising global interest rates have sharply increased the magnitude of the deterioration in the GDP growth rate. This difficult context has impacted many of Tunisia's fellow African nations, as global disruptions caused by the COVID-19 pandemic have been felt across the continent, and have only compounded the existing structural constraints on Africa, such as slow domestic job creation, high vulnerability to natural disasters, climate change, environmental degradation, and large infrastructure gaps. The pandemic has also recently triggered a surge in debt levels, which must be addressed. Despite these political and economic challenges, there are still positive indicators of the maturity and level of development in Tunisia, with the nation ranking 14th out of 54 African nations in terms of total GDP (US$54 billion). The standing of Tunisia only improves when GDP per capita is considered, because the nation has a much stronger GDP than its sub-Saharan counterparts and countries such as Morocco. Tunisia comes in around 10th place, with a GDP per capita of US$3,895 (higher than either Egypt or Morocco). Given this context, and the potential of Tunisia's economy to strengthen within the context of a sustainable development agenda, strong economic growth is assumed for the development of the energy scenario.

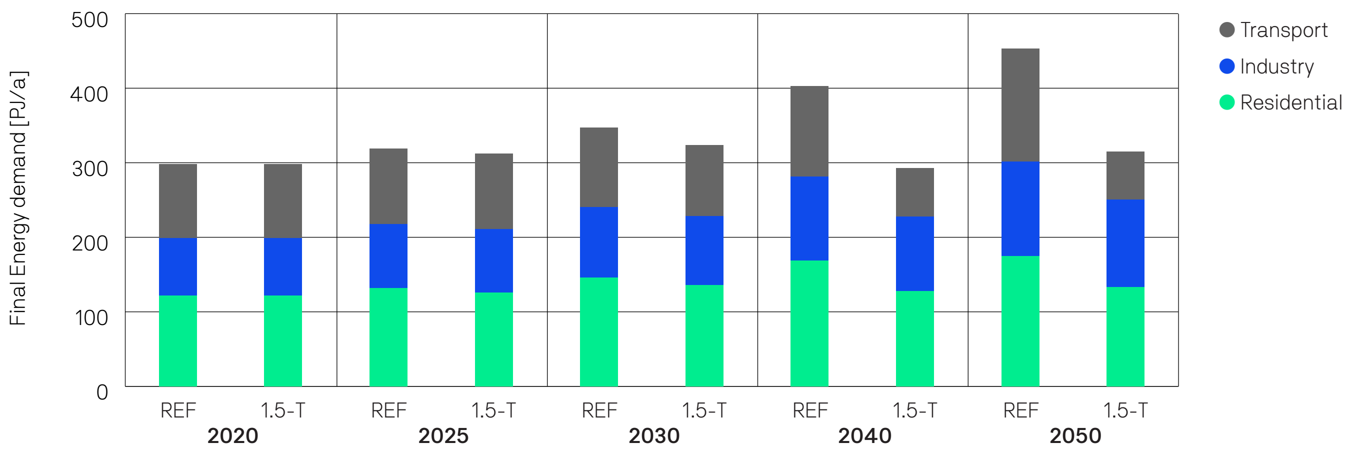
Electricity consumption per capita was 1,111 kWh/person in 2005, and this grew by 25% by 2020 (reaching 1,389 kWh/person). Although this electricity usage is substantially higher than those of Tunisia's sub-Saharan counterparts, it is still significantly lower than the global average consumption of > 3,000 kWh/capita per annum. The primary energy supply is dominated by oil and gas (around 88% combined in 2020), which is used across the economy for a variety of end uses, such as cooking and heating, as well as for electricity generation. Historically, Tunisia's electricity supply has been almost entirely from gas generation, with percentages regularly exceeding 95% between 2005 and 2020. (Of the 16 years in this range, gas generated > 95% of the electricity supply in 11 of them).[79] Tunisia's primary energy consumption was 347 PJ/a in 2005 and increased to 440 PJ/a in 2020 (an average growth rate of 1.19%). If the primary energy supply continues to grow according to the historical average rate, the primary energy demand will increase to 628 PJ/a by 2050. However, our 1.5°C-compatible scenario assumes a net reduction in the primary energy demand to around 395 PJ/a by 2050 – which is only possible through fuel switching, electrification, and increases in appliance efficiency. The following sections provide an overview of the key results for the energy scenario.

79 IEA World Energy Balances

8.6.1 Tunisia – Final energy demand

The projections of population development, GDP growth, and energy intensity were combined to project the future development pathways for Tunisia's final energy demand. As a result of the projected continued annual GDP growth of 2.4% on average, until 2025 and 2.8% thereafter until 2050, the overall energy demand is expected to grow under both the T-1.5°C and REFERENCE scenarios. Even though the residential sector will experience lower growth in demand than the industry sector under both scenarios, the residential and other sectors will still dominate Tunisia's energy demand. The energy demand of the industry sector will increase constantly under both scenarios, and will increase by around 50% by 2050, making this sector the second highest consumer after transport under both scenarios. The energy demand of the transport sector will increase by 60% by 2050 under the REFERENCE scenario, whereas it will only be 68% of the 2020 value under the T-1.5°C scenario. The main reason for the significant difference in growth projections is the high rate of electrification in the latter pathway. The large efficiency gains achieved in the T-1.5°C pathway are attributable to the high electrification rates, mainly in the cooking and transport sectors, because combustion processes with high losses will be significantly reduced.

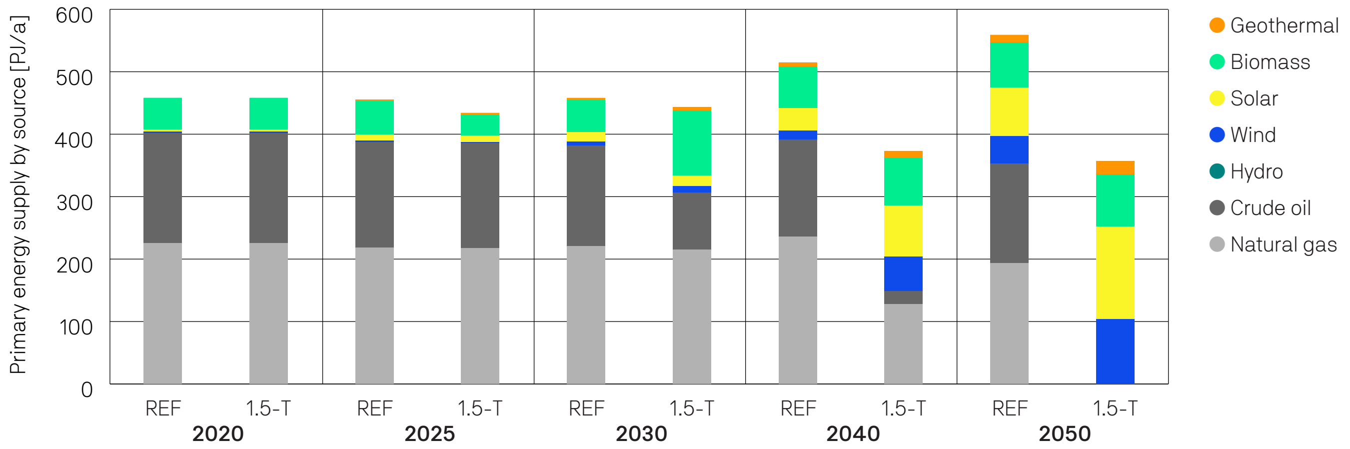
Figure 49: Tunisia – Projection of the total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)



8.6.2 Tunisia – Primary energy consumption

The T-1.5°C scenario will result in primary energy consumption of around 395 PJ in 2050. The T-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. Therefore, when non-energy consumption is excluded, the T-1.5°C scenario aims for a renewable primary energy share of 100% in 2050 (92% including non-energy consumption).

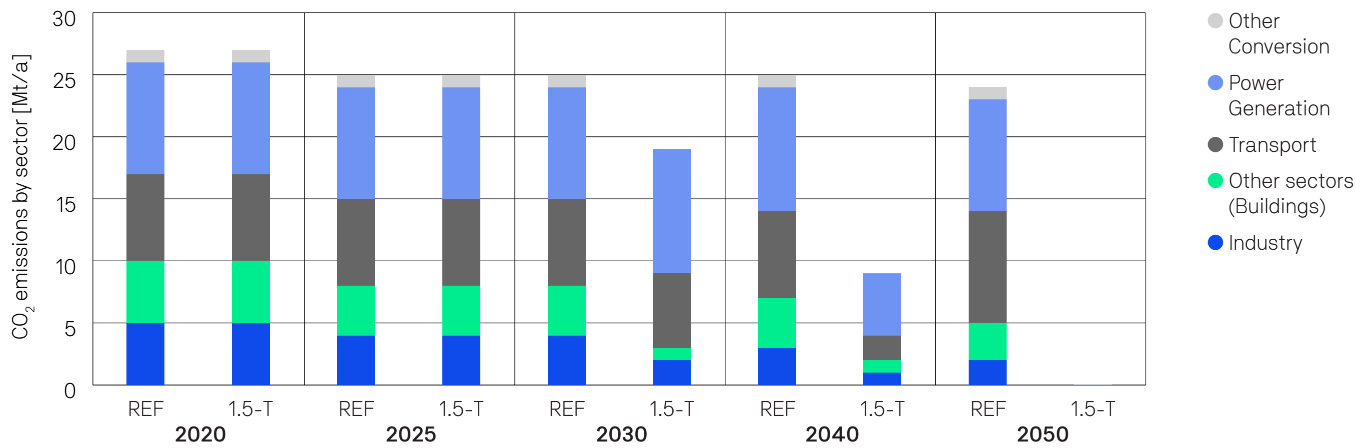
Figure 50: Tunisia – Projection of total primary energy demand by energy carrier (including electricity import balance)



8.6.3 Tunisia – CO_2 emissions trajectories

The T-1.5°C scenario will reverse the trend in increasing energy-related CO_2 emissions from 2025, leading to a reduction of 27% by 2030 relative to 2020 – which is the same of order of magnitude specified by the unconditional emission reduction target of 27% relative to 2010 emissions levels. The T-1.5°C scenario will achieve a 22% reduction in emissions relative to the 2010 baseline used. The ambition of the Tunisia 1.5°C scenario increases substantially, and by 2040, emissions will be reduced by 66% relative to the 2020 level (64% relative to 2010). The full decarbonisation of Tunisia's energy sector will be achieved in 2050 under the T-1.5°C scenario.

Figure 51: Tunisia – Development of CO_2 emissions by sector



8.6.4 Tunisia – Cost analysis

The fuel costs for the power, heating, and transport sectors will all decrease over time because electricity generation will be based on renewables – with significant shares of solar and wind power.

However, increased electrification will lead to higher investment costs in power generation and higher overall electricity supply costs for Tunisia. The T-1.5°C scenario will require an investment of 110 billion Tunisian dinar (US$36 billion) in power generation and 129 billion trillion TND (US$42 billion) in heat generation. Therefore, the total investment in power and heat generation capacities will be 239 billion trillion TND (US$78 billion).

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 T-1.5°C scenario relative to the REFERENCE scenario will be 170 billion TND (US$56 billion) – about four times higher than the additional investment in power generation capacities until 2050. Although fuel cost predictions are subject to a great deal of uncertainty, this clear result makes the cost-effectiveness of electrification very clear.

Table 60: Tunisia – Accumulated fuel costs for heat generation under the REFERENCE and T-1.5°C scenarios

		2020–2030		2031–2040		2041–2050		2020–2050		2020–2050 average per year	
REFERENCE		**Billion TND**	**Billion USD**	**Billion TND**	**Billion USD**	**Billion TND**	**Billion USD**	**Billion TND**	**Billion USD**	**Billion TND**	**Billion USD**
Power	Total	56.9	18.8	56.9	18.8	53.1	17.5	166.8	55.1	5.6	1.8
Heat	Total	55.9	18.5	56.8	18.8	47.6	15.7	160.4	52.9	5.3	1.8
Transport	Total	90.4	29.8	99.2	32.7	90.0	29.7	279.5	92.2	9.3	3.1
Summed costs		**203.2**	**67.0**	**212.9**	**70.3**	**190.7**	**62.9**	**606.7**	**200.2**	**20.2**	**6.7**
		2020–2030		**2031–2040**		**2041–2050**		**2020–2050**		**2020–2050 average per year**	
T-1.5°C		**Billion TND**	**Billion USD**	**Billion TND**	**Billion USD**	**Billion TND**	**Billion USD**	**Billion TND**	**Billion USD**	**Billion TND**	**Billion USD**
Power	Total	50.3	16.6	50.3	16.6	24.4	8.1	125.0	41.2	4.2	1.4
Heat	Total	54.4	17.9	46.5	15.4	28.3	9.4	129.3	42.7	4.3	1.4
Transport	Total	89.2	29.4	69.3	22.9	23.4	7.7	181.8	60.0	6.1	2.0
Summed costs		**193.8**	**64.0**	**166.1**	**54.8**	**76.1**	**25.1**	**436.1**	**143.9**	**14.5**	**4.8**
Difference REFERENCE versus T-1.5°C		**9.3**	**3.1**	**46.8**	**15.4**	**114.5**	**37.8**	**170.6**	**56.3**	**5.7**	**1.9**

8.7 Malawi summary

Malawi submitted an updated Nation Determined Contribution (NDC) report to the UNFCCC in July 2021.[80] The new NDC sets a target to reduce GHG emissions by 2030 relative to the business-as-usual (BAU) scenario.

The NDC provides a detailed assessment of identified GHG-mitigation options for Malawi, which estimates a total emissions reduction potential of around 17.7 million tonnes of carbon dioxide equivalent (tCO_{2e}) in 2040 against the BAU scenario emissions in the same year of 34.6 million tCO_{2e}, a reduction of 51%.

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

- **Unconditional contribution:** A reduction of 6% relative to BAU in the year 2040, which is 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 contribution:** An additional reduction of 45% relative to BAU in the year 2040, which is equivalent to an estimated mitigation level of 15.6 million tCO_{2e} in that year. This represents an additional targeted contribution, **contingent upon 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 GDP growth in the past, averaging 5% between 2004 and 2019 (World Band 2024).[81] 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. The pandemic has also 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, while the global average consumption is over 3,000 kWh/capita per annum (World Bank 2019)[82].

Biomass for cooking dominates Malawi's energy demand. Industry and transport – usually large energy consumers – have minor shares in the country's 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.

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

80 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

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

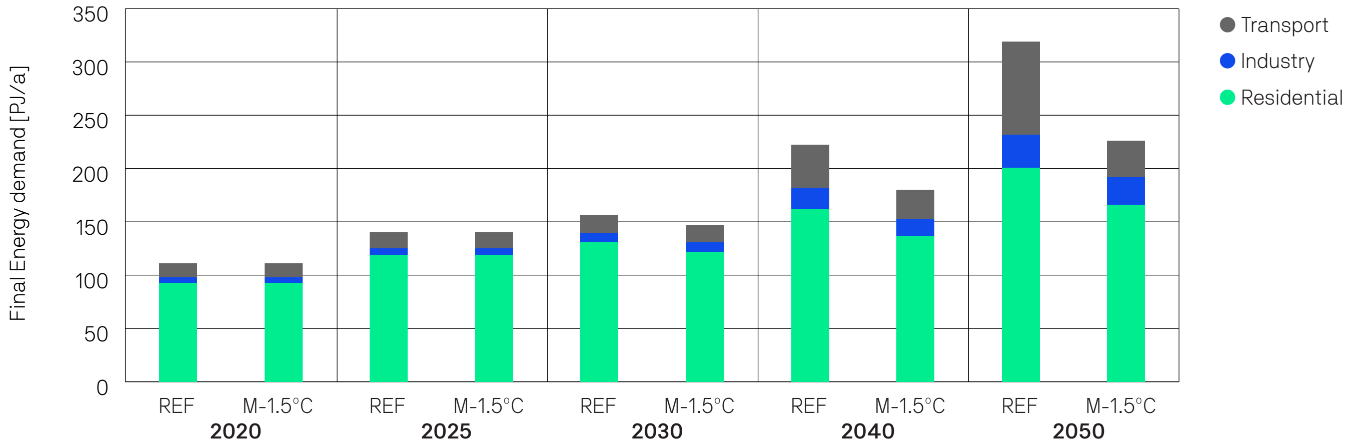
82 World Bank Database 2019, https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?end=2019&name_desc=true&start=1960&view=chart

8.7.1 Malawi – Final energy demand

The projections for population development, GDP growth, and energy intensity were combined to project the future development pathways for Malawi's final energy demand. 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 grow under both scenarios. The residential sector will remain dominant in Malawi's energy demand, but the energy demand of the industry sector will increase constantly. 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 latter pathway. The large efficiency gains achieved under the M-1.5°C scenario are attributable to the high electrification rates, mainly in the cooking and transport sectors, because combustion processes with high losses will be significantly reduced.

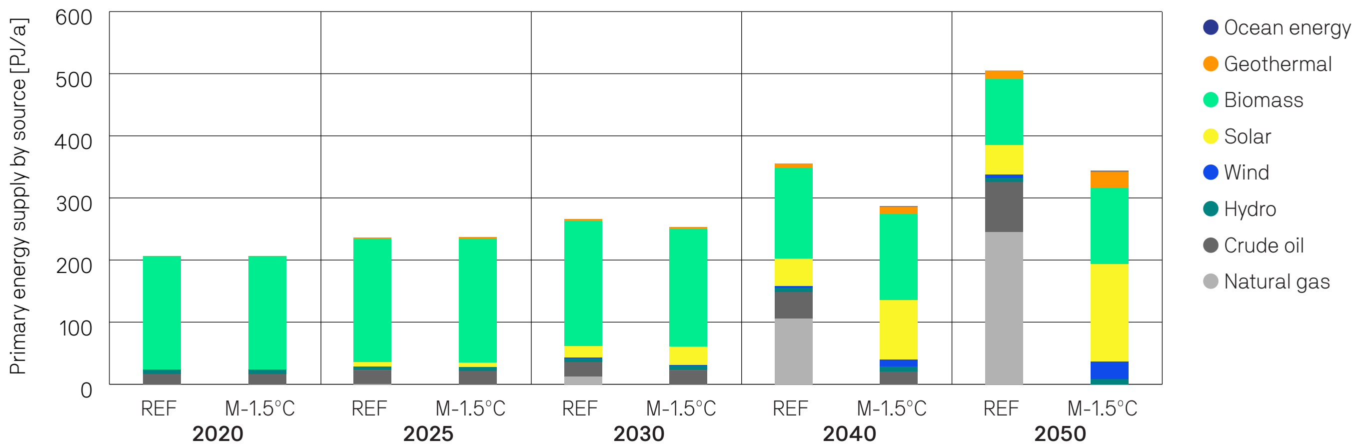
Figure 52: Malawi – Projection of the total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)



8.7.2 Malawi – 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 under the M-1.5°C scenario (including non-energy consumption).

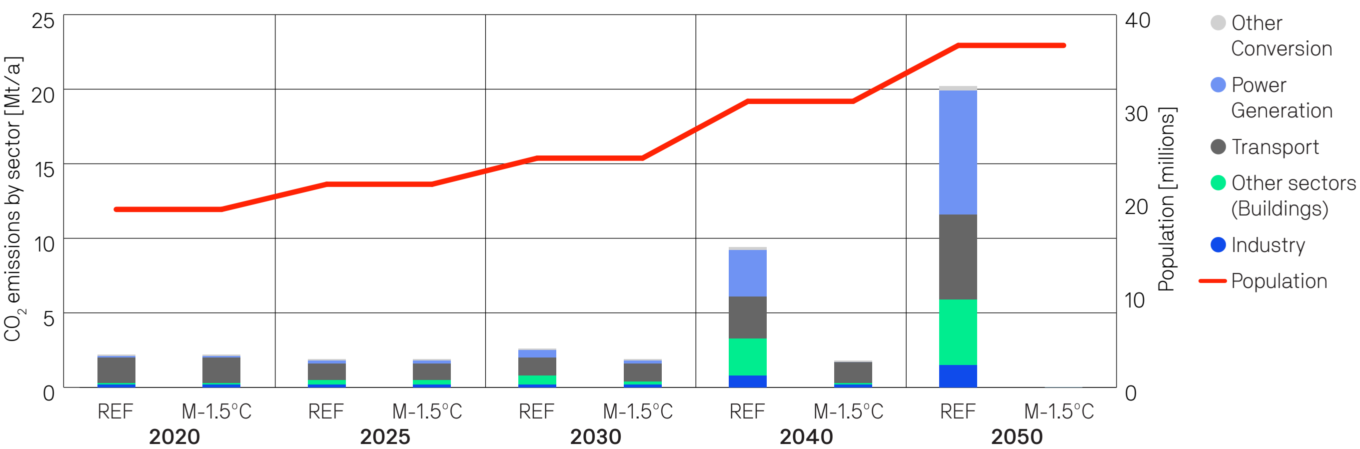
Figure 53: Malawi – Projection of total primary energy demand by energy carrier (including electricity import balance)



8.7.3 Malawi – CO_2 emissions trajectories

The M-1.5°C scenario will reverse the trend in 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. The full decarbonisation of Malawi's energy sector will be achieved in 2050 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 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 for the REFERENCE scenario.

Figure 54: Malawi – Development of CO_2 emissions by sector



8.7.4 Malawi – Cost analysis

The power, heat, and transport sectors will all reduce their fuel costs over time because electricity generation will be based on renewables – with significant shares of solar power, 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 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 be MWK 86 trillion (US$74 billion).

Table 61 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 MWK 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 scenario – 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 for the entire investment required under the M-1.5°C scenario.

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

Table 61: Malawi – Accumulated fuel costs under the REFERENCE and M-1.5°C scenarios

		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**

8.8 Summary – case studies

The key results of all the analysed countries show that the transition towards a middle-income country is possible with a parallel phase-out of fossil fuels and a full supply of renewable energy. Solar PV and onshore wind energy are the most economic renewable power generation technologies. They are fast to build and modular, and can therefore follow a rapidly increasing electricity demand. The replacement of fuels – especially for cooking and in the transport sector – with electricity is both economic and efficient. Electricity will be the most important energy carrier after 2030. The solar and wind potentials – even under space-constrained conditions – is larger by an order of magnitude than the electricity demand projected for 2050 for all the countries analysed.

Table 62: Annual solar photovoltaic market volume required to implement the case studies

Annual market PV [MW/a]	2020–2025	2026–2030	2031–2035	2036–2040	2041–2050
Kenya	445	1,381	3,324	5,530	4,376
Rwanda	360	905	1,137	1,109	1,486
Tanzania	1,044	3,629	7,356	6,956	7,281
Malawi	242	659	1,117	1,350	2,368
Senegal	97	652	715	260	205
Tunisia	146	168	595	1,386	1,995
Sum	**2,334**	**7,394**	**14,243**	**16,591**	**17,301**

The annual solar PV market required in all six countries combined must increase from around 2.5 GW per year in 2025 to 7.5 GW per year in 2030. By 2050, the annual solar PV market must increase to over 17 GW per year (Table 62). The annual wind power market must grow from currently around 0.5 GW to 2.3 GW in 2030 and by 14.5 GW annually to 2050 (Table 63).

Table 63: Annual wind market volume required to implement the case studies

Annual wind market [MW/a]	2020–2025	2026–2030	2031–2035	2036–2040	2041–2050
Kenya	168	377	673	659	1,655
Rwanda	41	95	152	174	234
Tanzania	121	315	583	1,215	9,291
Malawi	0	81	293	463	1,144
Senegal	1	119	249	320	1,109
Tunisia	47	296	421	576	1,001
Sum	**379**	**1,283**	**2,371**	**3,407**	**14,435**

With the increased electrification and the replacement of fossil-fuel-based power generation with renewable electricity, fuel costs will decrease significantly under the 1.5°C scenarios compared with the REFERENCE scenarios. Fuel cost savings across all sectors will be significantly larger than the investment required in power generation (Table 63). In Senegal, for example, fuel cost savings will be over 7 times larger annually than the required additional investment in new power generation under the S-1.5°C pathway. The difference between the fuel cost savings and the additional power generation investment is lowest for Rwanda, with a ratio factor of 2. Therefore, even with the high uncertainty of fuel costs, the likelihood that investments will be financed by fuel costs savings is high.

Table 64: Fuel cost savings versus the investment required in power generation in six African countries

	[Billion USD]								
	Fuel cost savings (all sectors) 1.5°C versus REFERENCE		Investments in the power sector 1.5°C		Investments in the power sector REFERENCE		Additional investment 1.5°C versus REFERENCE		Factor fuel cost savings versus additional power generation investments (1.5°C vs REFERENCE)
	2021–2050	2020–2050 average per year	2021–2050	2020–2050 average per year	2021–2050	2020–2050 average per year	2021–2050	2020–2050 average per year	
Kenya	256	8.5	135.0	4.5	93.0	3.1	42.0	1.4	6.1
Rwanda	27	0.9	47.0	1.6	34.0	1.1	13.0	0.4	2.1
Tanzania	142	4.7	195.0	6.5	156.0	5.2	39.0	1.3	3.6
Malawi	50	1.7	33.5	1.1	14.4	0.5	19.1	0.6	2.6
Senegal	33	1.1	9.2	0.3	5.0	0.2	4.2	0.1	7.8
Tunisia	57	1.9	36.0	1.2	22.0	0.7	14.0	0.5	4.1
Sum	**335**	**11.2**	**367.7**	**12.2**	**265.4**	**8.9**	**102.3**	**3.3**	**3.3**

9 Recommendations

In this section, we focus on the outcomes and conclusions of qualitative research rather than on the quantitative results documented in previous chapters. The most important technical measures are highlighted for each sector, followed by policy recommendations. This section reflects extensive discussions and workshops with stakeholders from various industries, and includes the recommendations of the One Earth Climate Model (OECM) research series that has been published between 2019 and 2024.[83,84,85,86,87,88,89]

9.1 Key changes across energy sectors

To comply with the Paris Climate Agreement and limit the global mean temperature rise to +1.5°C, rapid decarbonisation of the energy sector with currently available technologies is necessary and possible. However, to achieve the transition to a fully renewable energy supply, all available efficiency potentials must be combined to reduce the total demand. To reach net zero emissions by 2050, the complete phase-out of fossil fuels for all combustion processes is essential.

In the **Industry** sector, the transition from fossil-fuel-based process heat to renewable energy or electrical systems is the single most important measure. The further reduction of non-energy-related process emissions – mainly from cement and steel manufacture – by altering or optimising manufacturing processes is also essential. The remaining process emissions might be compensated by natural carbon sinks, so the Industry sector must actively support the Service sector in terms of soil regeneration and reforestation measures.

In the **Service** sector, especially agriculture and forestry, reducing GHG emissions must clearly involve reducing the GHG emissions arising from land-use changes. Increasing yield efficiency to avoid the further expansion of agricultural land at the expense of forests and other important ecosystems is key. However, feeding the growing world population without increasing the area committed to agriculture will require more than just an increase in technical efficiency. Moreover, there seems to be no alternative to reducing the consumption of meat and dairy products.

The **Forestry** sector is the single most important sector for the implementation of nature-based carbon sinks. Deforestation must cease immediately. Reforestation with native trees and plants that are typical of specific regions and climate zones must replace the forest areas that have been lost since 1990.

To reduce the demand of the **Transport** sector, a shift from resource-intensive air and road transport to more-efficient and electrified means of transport is required, together with an overall reduction in transport activity, especially in high-income countries. Phasing-out the production of combustion engines for passenger cars by 2030 and introducing synthetic fuels for long-distance freight transport are essential elements for the future transportation sector. Even with this ambitious goal, the full decarbonisation of the road transport sector will not be achieved before 2050, because cars are used, on average, for 15–20 years. There is also significant potential for efficiency gains in shipping and aviation. However, due to the foreseeable further growth in traffic volume and the lack of alternatives, the large-scale use of synthetic fuels from renewable electricity will also be necessary for these modes of transport. Because not all regions will be able to produce these with domestic resources at reasonable costs, a global trade of these new energy sources must be established. Africa – as a particularly resource-rich continent – must ensure that resources for domestic use and the domestic market will REMAIN within the region and that the entire value chain will benefit African economies.

83 It Is Still Possible to Achieve the Paris Climate Agreement: Regional, Sectoral, and Land-Use Pathways.

84 One Earth Climate Model – Integrated Energy Assessment Model to Develop Industry-Specific 1.5°C Pathways with High Technical Resolution for the Finance Sector.

85 1.5°C Pathways for the Global Industry Classification (GICS) sectors chemicals, aluminium, and steel.

86 Global sector-specific Scope 1, 2, and 3 analyses for setting net-zero targets: agriculture, forestry, and processing harvested products.

87 Achieving the Paris Climate Agreement Goals – Part 2: Science-based Target Setting for the Finance industry – Net-Zero Sectoral 1.5°C Pathways for Real Economy Sectors.

88 The 'Global Stocktake' and the remaining carbon budgets for G20 countries to limit global temperature rise to +1.5°C.

89 Net-zero 1.5°C sectorial pathways for G20 countries: energy and emissions data to inform science-based decarbonization targets.

The decarbonisation of the **Buildings** sector will requires a significant reduction in the energy demand for climatisation – heating and cooling – per square metre. The utilisation of the technical efficiency potential will require high renovation rates and changed building codes for new constructions. The widespread use of heat pumps and heat grids is an important element on the supply side. However, in some areas, the supply of renewable gases can substitute for today's natural gas consumption with a long-term perspective, especially where there is an industrial gas demand. The conversion of today's gas networks and the local/regional availability of resources to produce green gases will play a decisive role here.

Significant electrification across all sectors before 2030 – especially for heating, process heat, and to replace combustion engines in the **Transport** sector – is the decisive and most urgent step. Increased electrification will require sector coupling, demand-side management, and multiple forms of storage (for heat and power), including hydrogen and synthetic fuels. Accelerating the implementation of renewable heat technologies is equally important because half the global energy supply must derive from thermal processes by 2050.

The transition of the energy sector will only be possible with significant policy changes and reforms in the energy market.

The complete restructuring of the **Energy** and **Utilities** sectors will be required. The primary **Energy** sector – the oil, gas, and coal industries – must wind down all fossil-fuel extraction and mining projects and move towards utility-scale renewable energy projects, such as offshore wind and the production of hydrogen and synthetic fuels.

Power utilities will play a key role in providing the rapidly increasing electricity demand, generated from renewable power. The nexus of the global energy transition will be the power grid. Replacing oil and gas with electricity means that power grids must transport most energy, instead of oil and gas pipelines.

Therefore, the expansion of power grid capacities is one of the most important and also most overlooked measures required. Moreover, converting existing gas pipelines and using them for the long-range transport of hydrogen and synthetic methane will significantly reduce the infrastructural demands on the power system and increase efficiency.

According to the 1.5°C scenario, transmission and distribution grids must transport at least three times more electricity by 2050 than in 2020. The upgrading and expansion of power grids must start immediately because infrastructure projects, such as new power lines, can take 10 years or more to implement. The conversion of existing gas pipelines will be possible first where industrial users need large quantities of hydrogen for decarbonised processes.

Limiting the global mean temperature rise to +1.5°C cannot be achieved by the decarbonisation of the energy sector alone. As stated earlier, it will also require significant changes in land use, including the rapid phase-out of deforestation and significant reforestation. These measures are not alternative options to the decarbonisation of the energy sector but must be implemented in parallel. If governments fail to act and mitigation is delayed, we face the serious risk of exceeding the carbon budget. In the OECM 1.5°C scenario, the land-use sequestration pathways complement very ambitious energy-mitigation pathways and should therefore be regarded as necessary to reduce the CO_2 concentrations that have arisen from the overly high emissions in the past, and not as compensatory measures that can be extended indefinitely into the future.

9.2 Industry sector

Policies to achieve the implementation of new highly efficient technologies and to replace fossil-fuel use in industry must be defined country-wide or even on the level of continental African and will require stringent and regulated implementation. Economic incentives, national initiatives, and voluntary agreements with branches of industry will probably not, by themselves, achieve rapid technological change. Concrete standards and requirements must be defined in great detail, covering as far as possible all technologies and their areas of application. The systematic implementation of already-identified best-available technologies should begin immediately.

Mandatory energy management systems must be introduced to identify efficiency potentials and to monitor efficiency gains. The sustainability features of process chains and material flows must also be considered when designing political measures. Particular attention must be paid to the material efficiency of both production processes and their products, because this can open up major energy efficiency potentials and reduce other environmental effects. Public procurement policies and guidelines will help to establish new markets and to introduce new, more-efficient products and opportunities.

The effectiveness of policy interventions must be assessed by independent experts, and the further development of efficiency programmes and measures will require ongoing co-ordination by independent executive agencies. The public provision of low-interest loans, investment risk management, and tax exemptions for energy-efficient technologies and processes will significantly support technological changes and stimulate the huge investments required. Knowledge transfer between sectors and countries can be achieved through networks initiated and co-ordinated by governments.

International funding for research and development activities with regard to technological innovation, low-carbon solutions, and the integration of their processes will be vital in pushing the technological limits further. Innovative approaches to the realisation of material cycles and recycling options, the recovery of industrial waste heat, and low-carbon raw materials and process routes in industry must also be identified and implemented.

9.2.1 Steel industry

There are two key policy recommendations for the steel industry:

1. The decarbonisation of the thermal and electrical energy supplies must be supported until 2030.
2. The expansion of new production processes to decarbonise steel manufacture must be supported, including for:
   - Electric arc furnace processes.
   - Hydrogen-based steel production.

Although policies to support the transition towards a renewable energy supply are identical to those described for the **Energy** and **Utilities** sectors, support for mainstreaming steel production processes to reduce process emissions must be developed specifically for the regional steel industry.

Research and development grants are required, as well as product certification schemes, to financially encourage changes towards new production lines. Steel-processing industries, such as the automotive and construction sectors, require binding purchase quotas for CO_2-neutral steel. CO_2-intensive steel should gradually be made more expensive with a special ‘steel tax’, to further promote the production of ‘green steel’.

9.2.2 Cement industry

Just as in the steel industry, the decarbonisation of energy production for the cement industry has the highest priority in achieving short-term emissions reductions. Reducing process emissions requires increased efficiency along all steps of the production line. However, to date, no processes are available for the production of emissions-free cement. Therefore, nature-based carbon sinks must be established to compensate for the residual process emissions.

The Global Cement and Concrete Association (GCCA 2020) published a 2050 road map that sets a 'long-term vision for the industry' that covers the following topics:

- emissions reductions in cement and concrete production;
- savings delivered by concrete during its lifetime;
- reduced demand by promoting design and different materials (e.g., wood);
- material and construction efficiencies and improved standards;
- re-use of whole-concrete structures; and
- designs for the disassembly and re-use of elements.

9.2.3 Chemical industry

The production of the main feedstocks for the chemical industry, such as ammonia, methanol, ethylene, and propylene, is almost entirely based on oil and gas, but also on some biomass and coal. The refinery and production processes are very energy intensive. The production facilities are significantly different in each country and depend upon the company's product range. Therefore, universal policy recommendations are not possible.

However, the decarbonisation of the chemical industry must focus on the following key areas:

- developing alternatives to fossil-based feedstock for the production of high-value chemicals, such as ethylene, propylene, benzene, toluene, and xylene;
- expansion of renewable-energy-based ammonia production; and
- transition from coal- and gas-fuelled process heat generation to predominantly electrical systems.

The electrification of process heat will significantly increase the electric load on the production side. Therefore, in the transition from fossil- to electricity-based process heat generation, upgrading the power grids must also be considered and planning must involve the local power-grid operator.

9.2.4 Land-use and non-energy GHGs in the service sector

The key recommendations for the **Service** sector focus on non-energy GHG emissions and especially the emissions associated with changes in land use (agriculture, forestry, and other land use). Although, the transition to a renewable energy supply is a prerequisite for the decarbonisation of the **Service** sector, deforestation and other forms of land conversion must decrease much more rapidly. Reductions in methane and nitrogen must also be achieved in the agriculture sector. Without nature-based solutions, the 1.5°C limit will not be possible, even with a rapid decline in fossil-fuel emissions.

Four main natural sequestration pathways are utilised in the OECM, divided into temperate and tropical zones: reforestation, natural forest restoration, sustainable forest management, and cropland afforestation (trees in croplands):

1. **Wild lands** are vital to the world's carbon cycle, sequestering up to one-quarter of anthropogenic carbon emissions and storing approximately 450 gigatonnes of solid carbon globally (Erb et al. 2018). Preserving these lands and forests intact is key to maintaining our global carbon sinks, making the 1.5°C limit possible.
2. **Ending deforestation:** Today, land-use changes account for more than 10% of global CO_2 emissions (approximately 4 $GtCO_2$ per year), resulting largely from the clearing of forests for agriculture or other forms of development. Rapidly phasing-out the practice of deforestation will greatly increase the chance of achieving the 1.5°C limit.
3. **Large-scale reforestation:** The most important sequestration measure identified is large-scale reforestation, particularly in the sub-tropics and tropics. Under the 1.5°C model, 300 megahectares (Mha) of land area will be reforested in the tropics and an additional 50 Mha will be reforested in temperate regions.
4. **Natural restoration:** The second most important pathway for carbon removal relies upon natural forest restoration or 'rewilding', increasing the carbon density within approximately 600 Mha of existing forests. Reduced logging and better forestry practices in managed forests will also contribute significantly to reducing total carbon removal.

Planting trees on croplands

Tree cropping – a strategy in which trees are planted within croplands – can significantly increase carbon storage on agricultural lands. The four sequestration pathways occur in all countries and regions, although we have excluded reforestation in the boreal forest zone because of the albedo effect.

All four sequestration pathways commenced in 2020, but have different phase-in and phase-out rates, which also differ between the boreal/temperate and tropical/sub-tropical biomes.

1. **Forest restoration:** Boreal/temperate – full potential by 2035, saturation by 2065 (decline to zero around 2100). Tropical/sub-tropical – full potential by 2030, saturation by 2045 (decline to zero around 2100).
2. **Reforestation:** Boreal/temperate – full potential by 2045, saturation by 2075 (decline to zero around 2150). Tropical/sub-tropical – full potential by 2040, saturation by 2065 (decline to zero around 2120).
3. **Sustainable use of forests:** Boreal/temperate – full potential by 2040, saturation by 2070 (decline to zero around 2150). Tropical/sub-tropical – full potential by 2035, saturation by 2055 (decline to zero around 2100).
4. **Agroforestry:** Boreal/temperate – full potential by 2040, saturation by 2060 (decline to zero around 2080). Tropical/sub-tropical – full potential by 2030, saturation by 2050 (decline to zero around 2080).

9.2.5 Transport sector

There are actionable measures in three key areas to decarbonise **Transport** in line with the 1.5°C target: avoiding or reducing the need to travel, shifting to more-efficient transport modes, and improving efficiency through vehicular technology. The implementation of these measure must take place until 2030 to reduce emissions sufficiently rapidly.

1. **Phase-out of internal combustion engines (ICEs) by 2040 across Africa:** To achieve the decarbonisation of transport, it is essential to transition to electric mobility powered by renewable energy. To facilitate the shift to electric mobility, the phase-out of new vehicles (passenger cars, vans, 2–3 wheelers, city buses, etc.) with ICEs by 2040 in Africa (2030 in OECD countries) is vital. By setting targets, governments can send strong signals to markets and customers to adopt the new technology. Efficiency standards for all vehicle types, with an annual efficiency improvement target of 1%, should also be mandated.
2. **Increasing walking and cycling to optimal levels, exemplified by international leaders in sustainable mobility:** The large-scale expansion of quality infrastructure for bicycles and walking is required to maintain and extend access to these activities around the globe, while curbing the increase in passenger transport. Compact regional und urban planning principles will support the greater uptake of active mobility. Under the 1.5°C scenario, up to 50% of trips will be made on foot or by cycling, as exemplified by international leaders in sustainable mobility, such as Amsterdam and Copenhagen.
3. **Doubling the public transport capacity by 2030:** Public transport will continue to play a key role as the backbone of urban and inter-urban mobility. To leverage its potential, the capacity of public transport must be doubled, with attention given to service quality and convenience to ensure its acceptance. The integration of shared mobility and 'last mile' transport services will support intramodality between public transport and individual mobility.
4. **Almost full electrification of rail by 2035:** Freight transported by trucks must be shifted to rail transport systems. The share of electric trains must increase, and all diesel locomotives must be phased-out by 2050 across all regions. Therefore, the full electrification of rail transport (via overhead- or battery-powered electric trains) must be achieved.
5. **Introduction of hydrogen and synthetic fuels** before 2030 as a complementary solution for modes of transport and technologies that cannot be electrified, such as shipping and aviation, and to some extent long-distance freight transport by road.

9.2.6 Buildings sector

Strong and ambitious policies are required to realise the immense potential of the **Buildings** sector. The findings of our study are translated into the following policy recommendations:

1. The energy demand of the **Buildings** sector can be harnessed by implementing the advanced retrofitting of existing and historical buildings in developed nations. To promote advanced retrofitting, ambitious building codes and standards must be introduced and effectively enforced. To effectively reinforce these advanced retrofitting strategies, positive incentives, such as subsidies or tax deductions, can be given to both developers and owners. If retrofitting is not performed at an advanced level, then the increased floor area means that the global energy demand will also increase. Furthermore, with the substantial carbon lock-in, the energy demand cannot be reduced substantially in subsequent years. This study shows that strict policies for energy efficiency measures for buildings and their urgent implementation are even more important than an increased retrofitting rate in achieving low-energy building stock.
2. Most of the future thermal energy demand will come from developing nations across Africa. In developing regions, new building stock will play a dominant role in reducing the energy demand, so the construction of new energy-efficient buildings should follow a stringent building code that requires a high level of energy performance in all new construction. Building certification and labelling, technology transfer, training of building specialists, and financial incentives should also be considered to achieve adequate high-efficiency construction.
3. Together with stringent energy-efficient building codes and performance standards, behavioural and lifestyle changes will help to limit floor space growth, especially in urban areas. This will increase the efficiency of energy systems in buildings. Therefore, more education about low-carbon lifestyles must be provided.
4. Even with ambitious policy assumptions, the building sector will still consume substantial thermal energy, which may hinder the transition towards climate neutrality. Therefore, reducing the building energy demand must be accompanied by the promotion of building-integrated solar electric production. The findings of the Nearly Net Zero scenario show that in developed regions, it will be possible to achieve net-zero status by 2060. Therefore, positive incentives should be given for on-site building-integrated solar energy production.

9.2.7 Energy and utilities sectors

The **Energy** and **Utilities** sectors may constitute separate categories for the financial sector, but for the energy sector, they are two sides of the same coin. The 1.5°C pathway will lead to a 100% renewable electricity supply, with a significant share of variable power generation. The framework of the traditional electricity market has been developed for central suppliers operating dispatchable and limited dispatchable ('base-load') thermal power plants. However, the electricity markets of the future will be dominated by variable generation, with no marginal or fuel costs. The power system will also require the build-up and economic operation of a combination of dispatch generation, storage, and other system services, the operation of which will be conditioned by renewable electricity feed-ins. For both those reasons, a significantly different market framework is urgently required, in which the technologies can be operated economically and refinanced. Renewable electricity must be guaranteed priority access to the grid. Access to the exchange capacity available at any given moment should be fully transparent and the transmission of renewable electricity must always have preference. Furthermore, the design of distribution and transmission networks, particularly for interconnections and transformer stations, should be guided by the objective of facilitating the integration of renewables and achieving a 100% renewable electricity system.

To establish fair and equal market conditions, the ownership of electrical grids should be completely disengaged from the ownership of power-generation and -supply companies. To encourage new businesses, relevant grid data must be made available by the operators of transmission and distribution systems. This will require establishing communication standards and data protection guidelines for smart grids. Legislation to support and expand demand-side management is required to create new markets for the integration services for renewable electricity. Public funding for research and development is required to further develop and implement technologies that allow variable power integration, such as the smart-grid technology, virtual power stations, low-cost storage solutions, and responsive demand-side management. Finally, a policy framework that supports the electrification and sector coupling of the Heating and Transport sectors is urgently required to ensure a successful and cost-efficient transition process.

9.2.8 Policy recommendations

The OECM is an integrated energy assessment tool for the development of science-based targets for all major industries in a granularity. It includes the key performance indicators (KPIs) required to make informed investment decisions that will credibly align with the global net-zero emissions in the short, medium, and long terms. The key finding of our work on the OECM 1.5°C cross-sectoral pathway is that it is still possible to remain with the 1.5°C limit if governments, industries, and the financial sector act immediately. The technology required to decarbonise the energy supply with renewable energy is available, market ready, and in most cases, already cost competitive. The energy efficiency measures required to reduce the energy demand have also been understood for years and can be introduced without delay. Finally, the finance industry – for instance, the Net-Zero Asset Owners Alliance – is committed to implementing carbon targets for its investment portfolios. However, policies are required to ensure that all measures are implemented in the rather short time frame required.

Implementing short-term targets for 2025 and 2035

To implement the documented short-term targets for 2025 and 2035, the following actions are required.

Government Policies:

1. Immediate cessation of public and private investment in new oil, coal, and gas projects.
2. Implementation of carbon pricing with a reliable minimum CO_2 price, consistent with the underlying OECM emissions caps.
3. All African countries must phase-out coal by 2040.
4. The automobile industry must phase-out internal combustion engines for passenger cars by 2040 across Africa (and by 2030 across the OECD).
5. Legally binding efficiency standards must be instituted for all electrical applications, vehicles, and buildings.
6. Renewable energy targets must be based on IPCC-carbon-budget-based 1.5°C scenarios or detailed country-specific master plans.
7. Mandatory transparent forward-looking and historic disclosure of the most relevant KPIs: energy intensity, share of renewable energy supply, energy demand, carbon emissions, and carbon intensities per production unit.
8. A phase-out of all fossil-fuel subsidies by 2030.
9. The pursuit of a nationally and internationally to globally integrated and co-ordinated policy to create investment security and incentives for the necessary transformation processes.
10. A comprehensive scientific analysis of feasible national pathways and the formulation of corresponding NDCs for 2025/2030 and beyond.
11. Establishment of global governance of the transformation of energy systems, including monitoring the necessary political, social, economic, environmental, and legal requirements.

Actions needed by industry and financial institutions

Industry:

1. Setting and implementation of a climate strategy consistent with 1.5°C no- or low-overshoot sector models.
2. Immediate cessation of investments in new oil, coal, and gas projects.
3. Utilities must rapidly up-scale renewable electricity to provide logistical support for reducing Scope 2 emissions for all industries and services. This is a huge market opportunity for utilities.
4. Development of efficient technologies to implement electric mobility.
5. Mandatory transparent forward-looking and historic disclosure of the most relevant KPIs, such as carbon emissions, energy demand, and carbon intensities per production unit.

Financial Institutions:

1. Setting and implementation of decarbonisation targets for investment, lending, and underwriting portfolios that are consistent with 1.5°C no- or low-overshoot sector models.
2. Cessation of investment in new oil, coal, and gas projects.
3. Ensured coal phase-out in African countries by 2040.
4. Scaled climate solution investments, especially in emerging economies.
5. Disclosure of:
    - climate mitigation strategies;
    - short- and mid-term target setting;
    - target achievements;
    - progress of climate solution investments; and
    - engagement outcomes.

10 Appendices

Appendix A – GDP and GDP growth rates

To calculate the total GDP for the African continent, the summative approach was used, adding up the GDP values of all 54 African countries, using figures measured in constant (2015) US dollars.

To determine the annual GDP growth rate across the African continent, each country's GDP growth prate was weighted according to its share of the continent's overall GDP. This weighting was calculated using each country's contribution ratio, which is the proportion of a country's GDP relative to the total GDP of the continent.

The calculation process was as follows. First, each country's contribution (%) to the continent's total GDP was determined. For example, the contribution ratio for country i ($\textit{contribution ratio}_i$) was calculated as the ratio of that country's GDP to the total GDP of Africa, as shown in Equation (1). Next, the weighted GDP growth rate for each country was calculated by multiplying the contribution ratio by the country's GDP growth rate, as in Equation (2). Finally, the weighted average GDP growth rate ($\textit{GDP growth Rate}_{Africa}$) for the African continent was obtained by summing the weighted GDP growth rates of all 54 countries, as demonstrated in Equation (3).

Eq. (1) $$\textit{contribution ratio}_i = \frac{GDP_i}{GDP_{continent}}$$

Eq. (2) $$\textit{weighted GDP growth rate}_i = \textit{contribution ratio}_i \ X \ \textit{GDP growth rate}_i$$

Eq. (3) $$\textit{GDP growth rate}_{Africa} = \sum_{1}^{54} \textit{weighted GDP growth rate}_i$$

Here, GDP_i is the GDP of country ***i***

$GDP_{continent}$ is the total GDP of the ***continent***

$\textit{GDP growth rate}_i$ is the % GDP growth for country ***i***

NOTE: The calculations given above are based on percentage GDP growth values. The same approach is applied to sectors such as "value added in *Manufacturing*," substituting "percentage of value added in *Manufacturing*" for "percentage of GDP".

Appendix B – Comparison of GDP and growth rates of LDCs and non-LDCs

The GDP growth and GDP values for the African continent were compared against those of the least-developed countries (LDCs) and non-LDCs within Africa. Figure A1 and Figure A2 show that the continent's percentage GDP growth, computed as a weighted average across all 54 countries,[90] generally aligns with that of the non-LDCs. This trend is also evident in the GDP value profile (constant 2015 USD),[91] which shows that Africa's economic performance over time closely follows that of the continent's more-developed regions, with slight variations.

Although these comparisons provide valuable insights, the aggregated approach may overlook the unique growth dynamics of LDCs, potentially obscuring important disparities. A similar approach was used to calculate the GDP values across specific sectors, including agriculture, forestry, manufacturing, and industry, to ensure the consistency of the methodology across the analysis.

Figure A1. GDP annual growth (%) for the African continent vs those in LDCs and non-LDCs

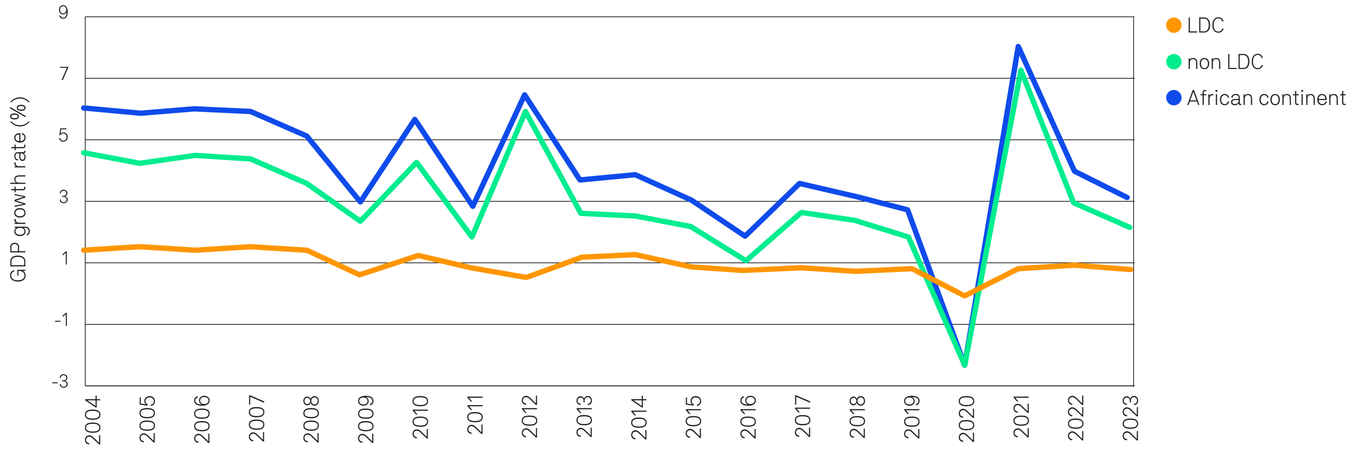
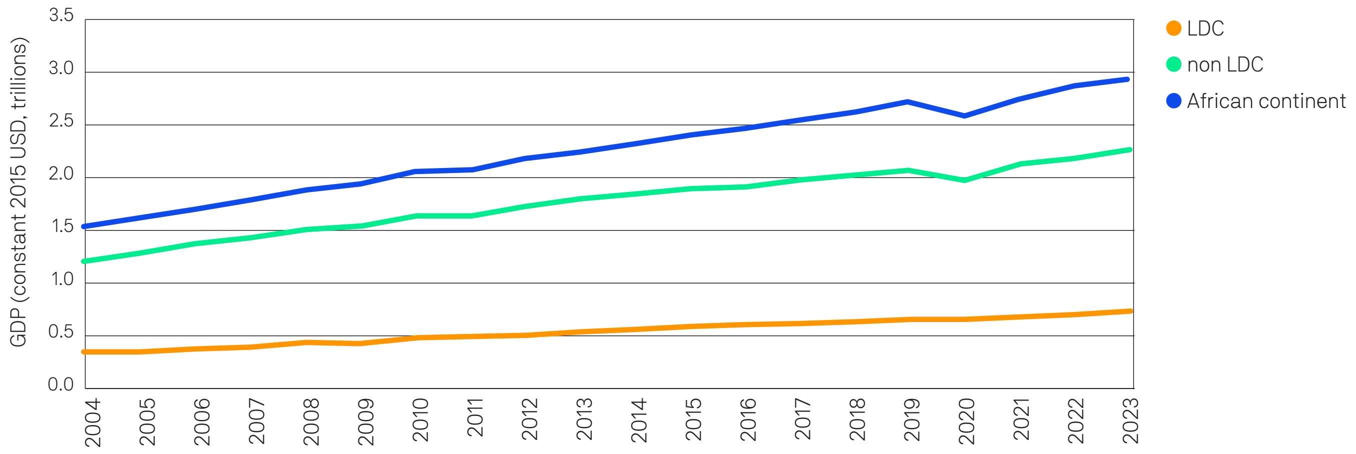


Figure A2. GDP (constant 2015 USD) of the African continent vs those of LDCs and non-LDCs



90 World Bank data, 2024, GDP growth (annual %), available at: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG

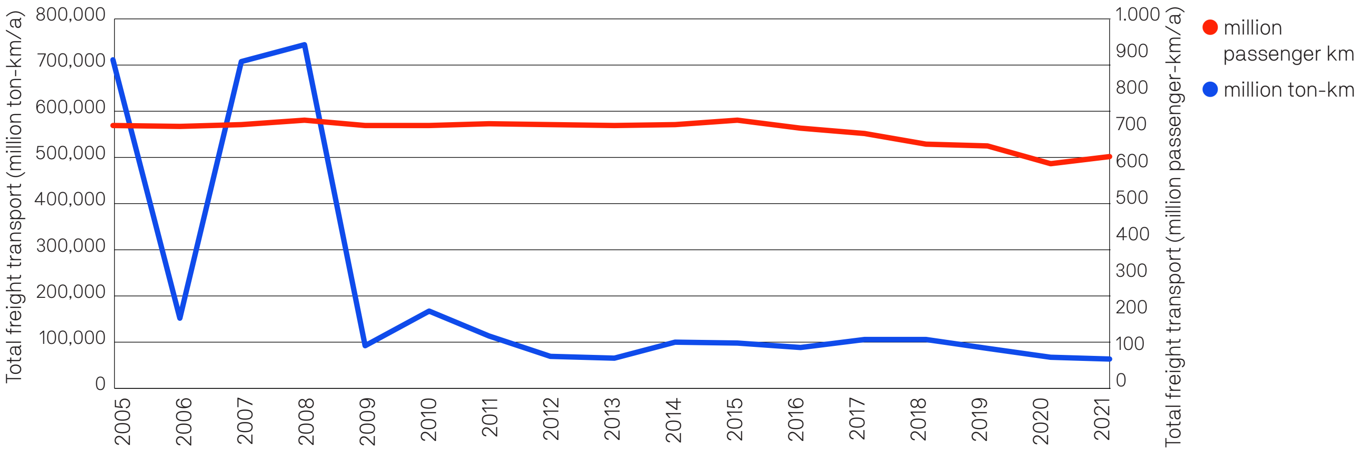
91 World Bank data, 2024, GDP (constant 2015 US$), available at: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD

Appendix C – Inland passenger and freight transport data analysis

Data for 'total inland freight transport' specific to the African continent are limited, and only 'total inland rail transport' data are available (World Bank, 2024).[92] Databases for road, pipeline, and waterway transport are also unavailable. According to the United Nations Economic and Social Council (2009),[93] road transport dominates African motorised freight, accounting for 80% of goods traffic and 90% of passenger traffic on the continent. Therefore, we assume that road transport accounts for 80% of inland freight. Inland waterway freight, although utilised in regions such as Eastern Africa, remains negligible overall, with countries like Egypt – despite its extensive Nile waterway network – reporting that less than 1% of goods are transported via waterways. Rail is assumed to make up the remaining 19% of freight transport when pipeline transport is excluded.

For inland passenger transport, the assumption is consistent with the 2009 United Nations Economic and Social Council report, which stated that 90% of passenger transport occurs via road, with rail comprising most of the remaining 10%, and waterways accounting for a negligible fraction. Rail passenger transport data for the African continent (World Bank 2024)[94] supports the analysis. Using these assumptions, passenger-kilometres (for passenger transport) and tonne-kilometres (for freight transport) were estimated and are visualised in Figure A3.

Figure A3. Total freight and passenger transport – Africa



92 World Bank, 2024, Railways, goods transported (million tonne-km), available at: https://data.worldbank.org/indicator/IS.RRS.GOOD.MT.K6

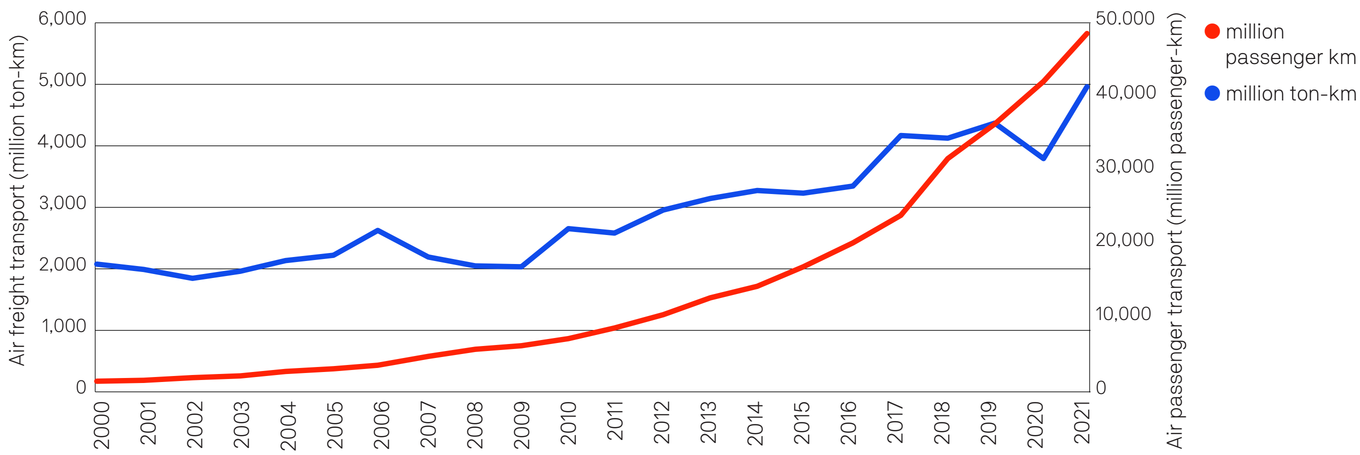
93 United Nations Economic and Social Council, 2009, Africa review report on transport, https://sustainabledevelopment.un.org/content/documents/AfricanReviewReport-on-TransportSummary.pdf

94 World Bank, 2024, Railways, passengers carried (million passenger-km), available at: https://data.worldbank.org/indicator/IS.RRS.PASG.KM

Appendix D – Aviation transport

The air freight metric, defined in metric tonne-kilometres travelled (World Bank 2024),[95] was compiled from data across 54 African countries to determine the overall value for the continent. For domestic aviation, the calculation of passenger-kilometres includes only flights within individual African countries. Intra-continental flights within Africa, occurring between different African countries, were excluded from the analysis. The statistical report from the International Civil Aviation Organization (ICAO, 2021),[96] based on historical data from 2017–2021, was used. A compound annual growth rate (CAGR) of 15.29% was applied to project the values for subsequent years. The results, expressed as domestic passenger-kilometres in millions and freight in million tonne-kilometres, are presented in Figure A4.

Figure A4. Total air-freight and domestic air-passenger transport – Africa



95 World Bank, 2024, Railways, passengers carried (Million passenger-km), Available at: https://data.worldbank.org/indicator/IS.RRS.PASG.KM

96 ICAO, 2007, Air transport reporting, Available at: https://www.icao.int/annual-report-2017/Documents/Annual.Report.2017_Air%20Transport%20Statistics.pdf

11 Data Annex

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

	Statistical Data		Estimation	AF 1.5°C scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Power plants	857	830	886	1,218	1,789	2,649	3,992	5,668
– Hard coal (and non-renewable waste)	260	245	258	257	298	252	187	0
– Lignite	0	0	0	0	0	0	0	0
– Gas	353	347	367	364	423	377	187	0
of which from H_2	0	0	0	0	0	0	0	0
– Oil	51	40	42	24	2	0	0	0
– Diesel	0	0	0	0	0	0	0	0
– Nuclear	13	10	10	12	15	18	23	0
– Biomass (and renewable waste)	2	2	2	8	21	43	82	141
– Hydro	141	146	154	203	221	288	428	597
– Wind	19	19	27	107	266	549	1,057	1,853
of which wind offshore	0	0	3	10	31	69	139	252
– PV	11	15	14	209	488	1,040	1,884	2,876
– Geothermal	5	5	5	24	34	50	75	104
– Solar thermal power plants	3	0	3	4	6	0	12	17
– Ocean energy	0	0	3	6	17	31	56	78
Combined heat and power plants	1	1	1	1	1	1	1	1
– Hard coal (and non-renewable waste)	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0
– Gas	1	1	1	1	0	0	0	0
of which from H_2	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0
– Biomass (and renewable waste)	1	1	1	1	1	1	1	1
– Geothermal	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0
CHP by producer								
– Main activity producers	0	0	0	0	0	0	0	0
– Autoproducers	1	1	1	1	1	1	1	1
Total generation	858	831	887	1,219	1,790	2,650	3,993	5,669
– Fossil	664	633	669	645	723	629	374	0
– Hard coal (and non-renewable waste)	260	245	258	257	298	252	187	0
– Lignite	0	0	0	0	0	0	0	0
– Gas	353	348	368	365	423	378	187	0
– Oil	51	40	42	24	2	0	0	0
– Diesel	0	0	0	0	0	0	0	0
– Nuclear	13	10	10	12	15	18	23	0
– Hydrogen	0	0	0	0	0	0	0	0
of which renewable H_2	0	0	0	0	0	0	0	0
– Renewables (w/o renewable hydrogen)	181	188	208	561	1,052	2,003	3,595	5,669
– Hydro	141	146	154	203	221	288	428	597
– Wind	19	19	27	107	266	549	1,057	1,853
– PV	11	15	14	209	488	1,040	1,884	2,876
– Biomass (and renewable waste)	2	2	2	9	21	43	83	141
– Geothermal	5	5	5	24	34	50	75	104
– Solar thermal power plants	3	0	3	4	6	0	12	17
– Ocean energy	0	0	3	6	17	31	56	78
Distribution losses	122	120	43	63	91	132	196	317
Own consumption electricity	54	51	62	84	117	166	246	328
Electricity for hydrogen production	0	0	9	30	67	133	250	448
Electricity for synfuel production	0	0	0	0	3	16	34	64
Final energy consumption (electricity)	682	661	775	1,044	1,514	2,208	3,273	4,522
Variable RES (PV, wind, ocean)	29	35	43	322	770	1,621	2,997	4,808
Share of variable RES	3%	4%	5%	26%	43%	61%	75%	85%
RES share (domestic generation)	21%	23%	23%	46%	59%	76%	90%	100%

Africa: Transport – final energy [PJ/a] – 1.5°C

	Statistical Data		Estimation	AF 1.5˚C scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Road	4,904	4,577	4,394	4,265	4,369	5,172	4,663	6,575
– Fossil fuels	4,881	4,549	4,195	3,835	3,245	3,001	294	0
– Biofuels	3	2	160	249	355	525	769	1,137
– Synfuels	0	0	0	0	0	0	0	0
– Natural gas	20	17	20	9	11	4	7	0
– Hydrogen	0	0	0	0	0	0	0	0
– Electricity	0	9	21	173	759	1,641	3,593	5,438
Rail	65	82	81	90	114	141	203	310
– Fossil fuels	44	69	60	63	50	16	1	0
– Biofuels	0	0	2	3	7	11	9	0
– Synfuels	0	0	0	0	0	0	0	0
– Electricity	21	13	19	24	56	114	193	310
Navigation	51	42	43	51	78	122	192	303
– Fossil fuels	51	42	42	39	53	18	6	0
– Biofuels	0	0	1	8	16	61	96	152
– Synfuels	0	0	0	1	4	24	60	100
Aviation	73	56	57	66	102	158	250	394
– Fossil fuels	73	56	57	56	63	63	50	0
– Biofuels	0	0	1	10	31	63	137	264
– Synfuels	0	0	0	0	8	32	62	130
Total (incl. pipelines)	5,123	4,758	4,576	4,472	4,664	5,593	5,307	7,583
– Fossil fuels	5,071	4,733	4,373	4,002	3,422	3,103	358	0
– Biofuels (incl. Biogas)	3	2	163	269	408	661	1,011	1,553
– Synfuels	0	0	0	1	12	56	122	230
– Natural gas	20	17	20	9	11	4	7	0
– Hydrogen	0	0	0	3	6	18	31	52
– Electricity	21	23	39	197	816	1,755	3,786	5,748
Rotal RES	7	7	172	364	906	2,062	4,572	7,583
RES share	0%	0%	4%	8%	19%	37%	86%	100%

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

	Statistical Data		Estimation	AF 1.5°C scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
District heating plants	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0
– Biomass	0	0	0	0	0	0	0	0
– Solar collectors	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0
Heat from CHP 1)	2	2	2	2	2	1	1	1
– Fossil fuels	1	1	1	1	1	0	0	0
– Biomass	1	1	1	1	1	1	1	1
– Geothermal	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0
Direct heating	12,785	14,370	14,204	15,671	16,726	18,051	19,695	21,602
– Fossil fuels	3,098	3,353	3,151	2,660	1,891	1,521	544	0
– Biomass	9,107	10,381	9,816	10,399	10,096	8,899	9,100	7,650
– Solar collectors	7	8	92	488	1,289	1,828	2,474	3,465
– Geothermal	0	0	303	483	715	1,119	1,448	1,861
Heat pumps 2)	0	0	158	672	1,451	2,974	3,843	5,450
– Electric direct heating	572	628	659	718	773	832	905	998
– Hydrogen	0	0	0	8	18	52	99	242
Total heat supply 3)	12,787	14,372	14,206	15,672	16,728	18,052	19,696	21,603
– Fossil fuels	3,099	3,354	3,152	2,661	1,892	1,521	544	0
– Biomass	9,108	10,382	9,817	10,399	10,097	8,900	9,101	7,651
– Solar collectors	7	8	92	488	1,289	1,828	2,474	3,465
– Geothermal	0	0	303	483	715	1,119	1,448	1,861
– Heat pumps 2)	0	0	158	672	1,451	2,974	3,843	5,450
– Electric direct heating (incl. process heat)	572	628	685	960	1,267	1,658	2,187	2,934
– Hydrogen	0	0	0	8	18	52	99	242
RES share (including RES electricity)	72%	73%	73%	77%	82%	85%	94%	100%
Electricity consumption heat pumps (TWh/a)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Africa: Installed capacity [GW] – 1.5°C

	Statistical Data		Estimation	AF 1.5°C scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Total generation	271	265	274	493	838	1,443	2,370	3,519
– Fossil	196	184	194	186	205	180	102	0
– Hard coal (and non-renewable waste)	55	49	52	51	60	50	37	0
– Lignite	0	0	0	0	0	0	0	0
– Gas (w/o H_2)	121	119	126	125	145	129	64	0
– Oil and Diesel	20	16	17	10	1	0	0	0
– Diesel	0	0	0	0	0	0	0	0
– Nuclear	2	2	2	2	2	3	4	0
– Hydrogen (fuel cells, gas power plants, gas CHP)	0	0	0	0	0	0	0	0
– Renewables	73	80	77	306	630	1,260	2,265	3,519
– Hydro	51	53	51	65	70	89	131	182
– Wind	9	10	10	40	96	192	357	625
of which wind offshore	0	0	1	3	8	17	35	63
– PV	10	16	13	190	443	946	1,712	2,615
– Biomass (and renewable waste)	0.5	0.520	0.505	2.012	4.835	9.894	18.9	32.3
– Geothermal	1	1	1	3	5	7	10	14
– Solar thermal power plants	1	0	1	2	3	0	6	8
– Ocean energy	0	0	1	3	9	17	30	42
Variable RES (PV, Wind, Ocean)	19	26	24	234	549	1,154	2,100	3,282
Share of variable RES	7%	10%	9%	47%	65%	80%	89%	93%
RES share (domestic generation)	27%	30%	28%	62%	75%	87%	96%	100%

Africa: Final energy demand [PJ/a] – 1.5°C

	Statistical Data		Estimation	AF 1.5°C scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy use)	22,611	22,621	22,824	24,004	25,571	27,762	29,968	35,264
Total energy use 1)	21,767	21,810	22,016	23,159	24,680	26,762	28,868	33,936
Transport	5,123	4,758	4,576	4,472	4,664	5,593	5,307	7,583
– Oil products	5,071	4,733	4,373	4,002	3,422	3,103	358	0
– Natural gas	20	17	20	9	11	4	7	0
– Biofuels	3	2	163	269	408	661	1,011	1,553
– Synfuels	0	0	0	1	12	56	122	230
– Electricity	21	23	39	197	816	1,755	3,786	5,748
– RES electricity	5	5	9	44	183	394	850	1,291
– Hydrogen	0	0	0	3	6	18	31	52
RES share Transport	0%	0%	4%	8%	19%	37%	86%	100%
Industry	3,647	3,573	3,938	4,595	5,352	6,160	7,530	9,171
– Electricity	925	882	1,043	1,580	2,289	3,381	4,582	6,288
– RES electricity	195	200	245	728	1,346	2,555	4,126	6,288
– Public district heat	0	0	0	0	0	0	0	0
– RES district heat	0	0	0	0	0	0	0	0
– Hard coal and lignite	621	605	712	672	653	534	0	0
– Oil products	639	564	144	135	80	47	0	0
– Gas	797	753	853	797	786	779	390	0
– Solar	0	0	66	144	194	258	345	469
– Biomass	665	769	1,082	1,182	1,184	880	1,758	1,567
– Geothermal	0	0	39	70	131	178	256	363
– Hydrogen	0	0	0	15	35	103	197	484
– RES share Industry	24%	27%	36%	47%	54%	65%	89%	100%
Other sectors	12,997	13,479	13,503	14,091	14,665	15,009	16,032	17,183
– Electricity	1,486	1,476	1,706	1,982	2,347	2,811	3,417	4,244
– RES electricity	313	334	400	913	1,380	2,125	3,077	4,244
– Public district heat	0	0	0	0	0	0	0	0
– RES district heat	0	0	0	0	0	0	0	0
– Hard coal and lignite	177	170	175	169	0	0	0	0
– Oil products	929	889	916	510	238	53	4	0
– Gas	555	592	599	631	332	269	196	0
– Solar	7	8	26	345	1,095	1,570	2,128	2,996
– Biomass	9,844	10,344	9,816	10,040	10,068	9,364	9,094	8,445
– Geothermal	0	0	263	413	584	942	1,192	1,498
– Hydrogen	0	0	0	0	0	0	0	0
RES share other sectors	78%	79%	78%	83%	90%	93%	97%	100%
Total RES	11,031	11,662	12,110	14,167	16,626	19,103	24,189	29,479
RES share	51%	53%	55%	61%	67%	71%	84%	87%
Non energy use	844	811	808	845	891	1,000	1,100	1,328
– Oil	330	304	312	314	340	367	416	594
– Gas	470	439	438	461	487	549	606	734
– Coal	44	68	58	71	63	84	78	0

Africa: Energy-releated CO_2 emissions [million tons/a] – 1.5°C

	Statistical Data		Estimation	AF 1.5°C scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	495	626	533	362	366	303	184	0
– Hard coal (and non-renewable waste)	289	243	241	184	204	165	117	0
– Lignite	0	0	0	0	0	0	0	0
– Gas	163	165	168	141	159	138	66	0
– Oil and Diesel	43	218	123	37	3	0	0	0
Combined heat and power plants	0	0	0	0	0	0	0	0
– Hard coal (and non-renewable waste)	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0
CO_2 emissions power and CHP plants	495	626	533	362	366	303	184	0
– Hard coal (and non-renewable waste)	289	243	241	184	204	165	117	0
– Lignite	0	0	0	0	0	0	0	0
– Gas	163	165	168	142	159	138	67	0
– Oil and Diesel	43	218	123	37	3	0	0	0
CO_2 intensity (g/kWh)	0	0	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0	0	0
– CO_2 intensity fossil electr. generation	746	989	797	561	507	481	492	0
– CO_2 intensity total electr. generation	577	753	601	297	205	114	46	0
CO_2 emissions by sector	1,193	1,294	1,122	915	814	677	244	0
– Industry 1)	182	180	126	118	112	97	22	0
– Other sectors 1)	135	133	136	134	80	44	11	0
– Transport	382	355	328	300	257	233	27	0
– Power generation 2)	495	626	533	362	366	303	184	0
– Other conversion 3) part of industry and transport	31	39	30	23	18	15	2	0
Population (Mill.)	1,328	1,361	1,530	1,711	1,899	2,093	2,290	2,485
CO_2 emissions per capita (t/capita)	0.9	1.0	0.7	0.5	0.4	0.3	0.1	0.0

Africa: Primary energy demand [PJ/a] – 1.5°C

	Statistical Data		Estimation	AF 1.5°C scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy-use)	32,023	35,052	32,759	30,876	30,778	31,565	33,134	37,664
– Fossil (excluding on-energy use)	15,953	17,208	15,450	12,758	11,405	9,538	3,467	0
– Hard coal	4,032	3,547	3,593	2,905	2,951	2,400	1,326	0
– Lignite	4	4	52	45	26	15	0	0
– Natural gas	4,592	4,455	4,619	4,331	4,323	3,731	1,787	0
– Crude oil	7,324	9,202	7,187	5,477	4,105	3,392	354	0
– Nuclear	145	107	114	131	161	200	253	0
– Renewables	15,082	16,926	16,387	17,142	18,321	20,826	28,313	36,336
– Hydro	508	526	555	730	794	1,036	1,541	2,150
– Wind	67	70	74	314	796	1,661	3,212	5,609
– Solar	76	63	164	1,250	3,030	5,409	9,095	13,474
– Biomass	14,412	16,249	15,263	14,257	12,800	11,305	12,545	12,585
– Geothermal	19	18	322	569	839	1,301	1,718	2,237
– Ocean energy	0	0	9	21	62	113	202	282
Total RES	15,082	16,925	16,386	17,138	18,314	20,814	28,292	36,303
RES share	49%	50%	51%	57%	62%	69%	89%	100%

Africa: Electricity generation [TWh/a] – Pledges

	Statistical Data		Estimation	AF Pledges scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Power plants	857	830	873	1,181	1,582	2,114	2,848	3,830
– Hard coal (and non-renewable waste)	260	245	255	152	93	49	29	18
– Lignite	0	0	0	0	0	0	0	0
– Gas	353	347	361	396	344	319	295	263
of which from H_2	0	0	0	0	0	0	0	0
– Oil	51	40	42	23	2	0	0	0
– Diesel	0	0	0	0	0	0	0	0
– Nuclear	13	10	10	26	52	58	80	103
– Biomass (and renewable waste)	2	2	2	8	18	34	58	95
– Hydro	141	146	152	197	194	229	304	405
– Wind	19	19	26	120	223	333	487	596
of which wind offshore	0	0	3	10	30	56	104	167
– PV	11	15	14	226	606	1,026	1,494	2,216
– Geothermal	5	5	5	23	30	40	53	71
– Solar thermal power plants	3	0	3	4	5	0	9	12
– Ocean energy	0	0	3	6	15	25	40	53
Combined heat and power plants	1	1	1	1	1	1	1	1
– Hard coal (and non-renewable waste)	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0
– Gas	1	1	1	1	0	0	0	0
of which from H_2	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0
– Biomass (and renewable waste)	1	1	1	1	1	1	1	1
– Geothermal	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0
CHP by producer								
– Main activity producers	0	0	0	0	0	0	0	0
– Autoproducers	1	1	1	1	1	1	1	1
Total generation	858	831	874	1,182	1,583	2,115	2,849	3,831
– Fossil	664	633	659	572	440	368	325	280
– Hard coal (and non-renewable waste)	260	245	255	152	93	49	29	18
– Lignite	0	0	0	0	0	0	0	0
– Gas	353	348	362	397	345	319	296	263
– Oil	51	40	42	23	2	0	0	0
– Diesel	0	0	0	0	0	0	0	0
– Nuclear	13	10	10	26	52	58	80	103
– Hydrogen	0	0	0	0	0	0	0	0
of which renewable H_2	0	0	0	0	0	0	0	0
– Renewables (w/o renewable hydrogen)	181	188	205	584	1,092	1,688	2,444	3,448
– Hydro	141	146	152	197	194	229	304	405
– Wind	19	19	26	120	223	333	487	596
– PV	11	15	14	226	606	1,026	1,494	2,216
– Biomass (and renewable waste)	2	2	2	9	19	35	59	96
– Geothermal	5	5	5	23	30	40	53	71
– Solar thermal power plants	3	0	3	4	5	0	9	12
– Ocean energy	0	0	3	6	15	25	40	53
Distribution losses	122	120	42	61	80	106	140	217
Own consumption electricity	54	51	61	81	103	133	175	225
Electricity for hydrogen production	0	0	9	30	67	110	195	292
Electricity for synfuel production	0	0	0	0	1	2	4	7
Final energy consumption (electricity)	682	661	763	1,012	1,334	1,768	2,340	3,097
Variable RES (PV, wind, ocean)	29	35	43	352	844	1,384	2,020	2,865
Share of variable RES	3%	4%	5%	30%	53%	65%	71%	75%
RES share (domestic generation)	21%	23%	23%	49%	69%	80%	86%	90%

Africa: Transport – final energy [PJ/a] – Pledges

	Statistical Data		Estimation	AF Pledges scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Road	4,904	4,577	5,020	5,563	6,418	7,393	8,553	9,964
– Fossil fuels	4,881	4,549	4,988	5,478	6,270	7,150	8,177	9,457
– Biofuels	3	2	2	17	24	57	67	79
– Synfuels	0	0	0	0	0	0	0	0
– Natural gas	20	17	13	11	12	4	5	0
– Hydrogen	0	0	0	0	0	0	0	0
– Electricity	0	9	16	57	111	182	305	428
Rail	65	82	81	90	114	141	203	310
– Fossil fuels	44	69	60	63	50	16	1	0
– Biofuels	0	0	2	3	7	11	9	0
– Synfuels	0	0	0	0	0	0	0	0
– Electricity	21	13	19	24	56	114	193	310
Navigation	51	42	43	51	78	122	192	303
– Fossil fuels	51	42	42	45	68	96	150	233
– Biofuels	0	0	1	2	2	4	6	9
– Synfuels	0	0	0	2	2	4	6	9
Aviation	73	56	57	66	102	158	250	394
– Fossil fuels	73	56	57	65	99	152	237	371
– Biofuels	0	0	1	1	2	3	5	8
– Synfuels	0	0	0	0	1	3	7	16
Total (incl. pipelines)	5,123	4,758	5,201	5,769	6,712	7,815	9,198	10,972
– Fossil fuels	5,071	4,733	5,160	5,662	6,499	7,419	8,569	10,061
– Biofuels (incl. Biogas)	3	2	5	22	36	75	87	96
– Synfuels	0	0	0	2	3	7	13	25
– Natural gas	20	17	13	11	12	4	5	0
– Hydrogen	0	0	0	3	6	18	31	52
– Electricity	21	23	35	81	168	296	498	738
Total RES	7	7	14	66	161	336	558	837

Africa: Heat supply and air conditioning [PJ/a] – Pledges

	Statistical Data		Estimation	AF Pledges scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
District heating plants	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0
– Biomass	0	0	0	0	0	0	0	0
– Solar collectors	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0
Heat from CHP 1)	2	2	2	2	2	1	1	1
– Fossil fuels	1	1	1	1	1	0	0	0
– Biomass	1	1	1	1	1	1	1	1
– Geothermal	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0
Direct heating	12,785	14,370	14,810	15,946	17,416	19,050	20,894	23,386
– Fossil fuels	3,098	3,353	3,151	3,867	4,270	4,177	4,328	4,773
– Biomass	9,107	10,381	10,656	10,087	10,046	10,515	10,557	10,033
– Solar collectors	7	8	92	420	672	909	1,219	1,982
– Geothermal	0	0	171	207	277	334	427	550
– Heat pumps 2)	0	0	71	397	796	1,272	1,855	2,598
– Electric direct heating	572	628	659	718	773	832	905	998
– Hydrogen	0	0	0	8	18	21	25	30
Total heat supply 3)	12,787	14,372	14,812	15,948	17,418	19,051	20,895	23,387
– Fossil fuels	3,099	3,354	3,152	3,868	4,271	4,177	4,328	4,773
– Biomass	9,108	10,382	10,657	10,088	10,047	10,516	10,558	10,034
– Solar collectors	7	8	92	420	672	909	1,219	1,982
– Geothermal	0	0	171	207	277	334	427	550
– Heat pumps 2)	0	0	71	397	796	1,272	1,855	2,598
– Electric direct heating (incl. process heat)	572	628	669	960	1,337	1,823	2,483	3,418
– Hydrogen	0	0	0	8	18	21	25	30
RES share (including RES electricity)	72%	73%	75%	71%	72%	75%	76%	77%
Electricity consumption heat pumps (TWh/a)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Africa: Installed capacity [GW] – Pledges	Statistical Data		Estimation	AF Pledges scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Total generation	271	265	270	503	856	1,274	1,776	2,505
– Fossil	196	184	192	176	137	119	107	94
– Hard coal (and non-renewable waste)	55	49	51	31	19	10	6	4
– Lignite	0	0	0	0	0	0	0	0
– Gas (w/o H_2)	121	119	124	136	118	109	101	90
– Oil and Diesel	20	16	17	9	1	0	0	0
– Diesel	0	0	0	0	0	0	0	0
– Nuclear	2	2	2	4	8	9	12	16
– Hydrogen (fuel cells, gas power plants, gas CHP)	0	0	0	0	0	0	0	0
– Renewables	73	80	76	324	711	1,146	1,657	2,396
– Hydro	51	53	50	63	61	71	93	124
– Wind	9	10	10	45	80	114	160	192
of which wind offshore	0	0	1	3	8	14	26	42
– PV	10	16	13	205	550	933	1,358	2,014
– Biomass (and renewable waste)	0.5	0.520	0.500	1.954	4.271	7.914	13.4	21.9
– Geothermal	1	1	1	3	4	5	7	10
– Solar thermal power plants	1	0	1	2	2	0	4	5
– Ocean energy	0	0	1	3	8	14	22	29
Variable RES (PV, wind, ocean)	19	26	24	254	639	1,061	1,540	2,235
Share of variable RES	7%	10%	9%	50%	75%	83%	87%	89%
RES share (domestic generation)	27%	30%	28%	64%	83%	90%	93%	96%

Africa: Final energy demand [PJ/a] – Pledges

	Statistical Data		Estimation	AF Pledges scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy use)	22,611	22,621	24,258	25,934	29,194	33,057	38,234	45,769
Total Energy use 1)	21,767	21,810	23,403	25,025	28,175	31,892	36,236	42,661
Transport	5,123	4,758	5,201	5,769	6,712	7,815	9,198	10,972
– Oil products	5,071	4,733	5,160	5,662	6,499	7,419	8,569	10,061
– Natural gas	20	17	13	11	12	4	5	0
– Biofuels	3	2	5	22	36	75	87	96
– Synfuels	0	0	0	2	3	7	13	25
– Electricity	21	23	35	81	168	296	498	738
– RES electricity	5	5	8	18	38	67	112	166
– Hydrogen	0	0	0	3	6	18	31	52
– RES share Transport	0%	0%	0%	1%	2%	4%	6%	8%
Industry	3,647	3,573	3,962	4,550	5,411	6,539	7,951	9,760
– Electricity	925	882	1,006	1,580	2,289	3,257	4,508	6,167
– RES electricity	195	200	236	780	1,579	2,601	3,868	5,550
– Public district heat	0	0	0	0	0	0	0	0
– RES district heat	0	0	0	0	0	0	0	0
– Hard coal and lignite	621	605	712	870	1,093	645	380	235
– Oil products	639	564	144	144	85	51	0	0
– Gas	797	753	853	1,113	1,266	1,446	1,687	2,023
– Solar	0	0	66	76	88	124	197	484
– Biomass	665	769	1,143	683	423	798	873	428
– Geothermal	0	0	39	70	131	178	256	363
– Hydrogen	0	0	0	15	35	41	49	61
– RES share Industry	24%	27%	37%	36%	42%	57%	66%	71%
Other sectors	12,997	13,479	14,240	14,706	16,052	17,538	19,087	21,930
– Electricity	1,486	1,476	1,706	1,982	2,347	2,811	3,417	4,244
– RES electricity	313	334	400	978	1,619	2,245	2,932	3,820
– Public district heat	0	0	0	0	0	0	0	0
– RES district heat	0	0	0	0	0	0	0	0
– Hard coal and lignite	177	170	175	188	205	226	252	284
– Oil products	929	889	916	1,044	1,159	1,306	1,487	1,707
– Gas	555	592	599	864	904	959	1,027	1,113
– Solar	7	8	26	345	584	785	1,022	1,498
– Biomass	9,844	10,344	10,685	10,145	10,707	11,294	11,713	12,898
– Geothermal	0	0	132	138	146	157	170	187
– Hydrogen	0	0	0	0	0	0	0	0
– RES share other sectors	78%	79%	79%	79%	81%	83%	83%	84%
Total RES	11,031	11,662	12,741	13,274	15,395	18,388	21,323	25,627
RES share	51%	53%	54%	53%	55%	58%	59%	60%
Non energy use	844	811	855	909	1,019	1,165	1,998	3,108
– Oil	330	304	330	337	389	428	755	1,129
– Gas	470	439	464	495	557	640	1,101	1,718
– Coal	44	68	61	76	73	98	142	260

Africa: Energy-releated CO_2 emissions [million tons/a] – Pledges

	Statistical Data		Estimation	AF Pledges scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	495	626	525	299	196	149	123	114
– Hard coal (and non-renewable waste)	289	243	237	109	64	32	18	13
– Lignite	0	0	0	0	0	0	0	0
– Gas	163	165	166	154	130	116	105	102
– Oil and Diesel	43	218	121	36	3	0	0	0
Combined heat and power plants	0	0	0	0	0	0	0	0
– Hard coal (and non-renewable waste)	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0
CO_2 emissions power and CHP plants	495	626	525	299	197	149	123	114
– Hard coal (and non-renewable waste)	289	243	238	109	64	32	18	13
– Lignite	0	0	0	0	0	0	0	0
– Gas	163	165	166	154	130	117	105	102
– Oil and Diesel	43	218	121	36	3	0	0	0
CO_2 intensity (g/kWh)	0	0	0	0	0	0	0	0
Without credit for CHP heat	0	0	0	0	0	0	0	0
– CO_2 intensity fossil electr. generation	746	989	797	522	447	404	380	408
– CO_2 intensity total electr. generation	577	753	601	253	124	70	43	30
CO_2 emissions by sector	1,231	1,329	1,174	1,070	1,069	1,054	1,089	1,221
– Industry 1)	182	180	126	155	180	145	130	135
– Other sectors 1)	135	133	137	191	206	203	192	217
– Transport	420	391	387	425	488	557	643	755
– Power generation 2)	495	626	525	299	196	149	123	114
– Other conversion 3) – part of industry and transport	31	39	34	32	34	37	42	49
Population (Mill.)	1,328	1,361	1,530	1,565	1,601	1,637	1,674	1,711
CO_2 emissions per capita (t/capita)	0.9	1.0	0.8	0.7	0.7	0.6	0.7	0.7

Africa: Primary energy demand [PJ/a] – Pledges

	Statistical Data		Estimation	AF Pledges scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy-use)	32,023	35,052	34,128	32,592	33,625	36,163	41,226	49,482
– Fossil (excluding on-energy use)	15,953	17,208	16,145	15,162	15,152	15,075	15,592	17,498
– Hard coal	4,032	3,547	3,553	2,291	2,052	1,264	876	697
– Lignite	4	4	52	45	26	15	0	0
– Natural gas	4,592	4,455	4,577	5,148	4,927	4,791	4,665	5,033
– Crude oil	7,324	9,202	7,964	7,678	8,147	9,005	10,051	11,768
– Nuclear	145	107	112	289	562	632	869	1,119
– Renewables	15,082	16,926	17,016	16,233	16,892	19,290	22,767	27,757
– Hydro	508	526	547	708	699	825	1,093	1,457
– Wind	67	70	73	361	644	938	1,290	1,452
– Solar	76	63	163	1,240	2,829	4,470	6,461	9,737
– Biomass	14,412	16,249	16,034	13,613	12,280	12,488	13,162	14,115
– Geothermal	19	18	190	290	386	479	618	805
– Ocean energy	0	0	9	21	55	90	143	191
Total RES	15,082	16,925	17,015	16,229	16,885	19,280	22,752	27,736
RES share	49%	50%	51%	52%	53%	56%	59%	61%

Africa: Electricity generation [TWh/a] – REFERENCE

	Statistical Data		Estimation	AF REFERENCE scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Power plants	857	830	873	1,086	1,364	1,733	2,243	2,897
– Hard coal (and non-renewable waste)	260	245	255	173	127	95	72	55
– Lignite	0	0	0	0	0	0	0	0
– Gas	353	347	361	465	496	541	593	679
of which from H_2	0	0	0	0	0	0	0	0
– Oil	51	40	42	21	2	0	0	0
– Diesel	0	0	0	0	0	0	0	0
– Nuclear	13	10	10	24	44	47	61	68
– Biomass (and renewable waste)	2	2	2	7	15	28	45	70
– Hydro	141	146	152	180	166	186	234	298
– Wind	19	19	26	73	129	170	262	336
of which wind offshore	0	0	3	10	29	52	95	149
– PV	11	15	14	113	341	614	896	1,291
– Geothermal	5	5	5	21	26	32	41	52
– Solar thermal power plants	3	0	3	4	4	0	7	9
– Ocean energy	0	0	3	5	13	20	31	39
Combined heat and power plants	1	1	1	1	1	1	1	1
– Hard coal (and non-renewable waste)	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0
– Gas	1	1	1	1	0	0	0	0
of which from H_2	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0
– Biomass (and renewable waste)	1	1	1	1	1	1	1	1
– Geothermal	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0
CHP by producer								
– Main activity producers	0	0	0	0	0	0	0	0
– Autoproducers	1	1	1	1	1	1	1	1
Total generation	858	831	874	1,087	1,365	1,734	2,244	2,898
– Fossil	664	633	659	659	625	636	666	734
– Hard coal (and non-renewable waste)	260	245	255	173	127	95	72	55
– Lignite	0	0	0	0	0	0	0	0
– Gas	353	348	362	465	497	541	593	679
– Oil	51	40	42	21	2	0	0	0
– Diesel	0	0	0	0	0	0	0	0
– Nuclear	13	10	10	24	44	47	61	68
– Hydrogen	0	0	0	0	0	0	0	0
– of which renewable H_2	0	0	0	0	0	0	0	0
– Renewables (w/o renewable hydrogen)	181	188	205	404	696	1,051	1,517	2,096
– Hydro	141	146	152	180	166	186	234	298
– Wind	19	19	26	73	129	170	262	336
– PV	11	15	14	113	341	614	896	1,291
– Biomass (and renewable waste)	2	2	2	8	16	28	46	71
– Geothermal	5	5	5	21	26	32	41	52
– Solar thermal power plants	3	0	3	4	4	0	7	9
– Ocean energy	0	0	3	5	13	20	31	39
Distribution losses	122	120	42	56	69	86	108	159
Own consumption electricity	54	51	61	74	89	107	135	165
Electricity for hydrogen production	0	0	9	30	67	110	195	292
Electricity for synfuel production	0	0	0	0	1	2	4	7
Final energy consumption (electricity)	682	661	763	929	1,142	1,432	1,805	2,278
Variable RES (PV, wind, ocean)	29	35	43	191	483	805	1,189	1,666
Share of variable RES	3%	4%	5%	18%	35%	46%	53%	58%
RES share (domestic generation)	21%	23%	23%	37%	51%	61%	68%	72%

Africa: Transport – final energy [PJ/a] – REFERENCE								
	Statistical Data		Estimation	AF REFERENCE scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Road	4,904	4,577	5,020	5,563	6,418	7,393	8,553	9,964
– Fossil fuels	4,881	4,549	4,988	5,478	6,270	7,150	8,177	9,457
– Biofuels	3	2	2	17	24	57	67	79
– Synfuels	0	0	0	0	0	0	0	0
– Natural gas	20	17	13	11	12	4	5	0
– Hydrogen	0	0	0	0	0	0	0	0
– Electricity	0	9	16	57	111	182	305	428
Rail	65	82	81	90	114	141	203	310
– Fossil fuels	44	69	60	63	50	16	1	0
– Biofuels	0	0	2	3	7	11	9	0
– Synfuels	0	0	0	0	0	0	0	0
– Electricity	21	13	19	24	56	114	193	310
Navigation	51	42	43	51	78	122	192	303
– Fossil fuels	51	42	42	45	68	96	150	233
– Biofuels	0	0	1	2	2	4	6	9
– Synfuels	0	0	0	2	2	4	6	9
Aviation	73	56	57	66	102	158	250	394
– Fossil fuels	73	56	57	65	99	152	237	371
– Biofuels	0	0	1	1	2	3	5	8
– Synfuels	0	0	0	0	1	3	7	16
Total (incl. pipelines)	5,123	4,758	5,201	5,769	6,712	7,815	9,198	10,972
– Fossil fuels	5,071	4,733	5,160	5,662	6,499	7,419	8,569	10,061
– Biofuels (incl. Biogas)	3	2	5	22	36	75	87	96
– Synfuels	0	0	0	2	3	7	13	25
– Natural gas	20	17	13	11	12	4	5	0
– Hydrogen	0	0	0	3	6	18	31	52
– Electricity	21	23	35	81	168	296	498	738
Total RES	7	7	14	57	131	279	467	706
RES share	0%	0%	0%	1%	2%	4%	5%	6%

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

	Statistical Data		Estimation	AF REFERENCE scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
District heating plants	0	0	0	0	0	0	0	0
– Fossil fuels	0	0	0	0	0	0	0	0
– Biomass	0	0	0	0	0	0	0	0
– Solar collectors	0	0	0	0	0	0	0	0
– Geothermal	0	0	0	0	0	0	0	0
Heat from CHP 1)	2	2	2	2	2	1	1	1
– Fossil fuels	1	1	1	1	1	0	0	0
– Biomass	1	1	1	1	1	1	1	1
– Geothermal	0	0	0	0	0	0	0	0
– Hydrogen	0	0	0	0	0	0	0	0
Direct heating	12,785	14,370	14,810	16,084	17,711	19,513	21,279	23,276
– Fossil fuels	3,098	3,353	3,151	4,016	4,746	5,851	7,229	9,001
– Biomass	9,107	10,381	10,656	10,513	10,922	11,161	10,720	9,350
– Solar collectors	7	8	92	420	672	888	1,145	1,649
– Geothermal	0	0	171	207	277	334	427	550
– Heat pumps 2)	0	0	71	159	247	351	730	1,564
– Electric direct heating	572	628	659	718	773	832	905	998
– Hydrogen	0	0	0	8	18	21	25	30
Total heat supply 3)	12,787	14,372	14,812	16,086	17,712	19,514	21,280	23,277
– Fossil fuels	3,099	3,354	3,152	4,017	4,747	5,851	7,229	9,001
– Biomass	9,108	10,382	10,657	10,514	10,923	11,162	10,721	9,351
– Solar collectors	7	8	92	420	672	888	1,145	1,649
– Geothermal	0	0	171	207	277	334	427	550
– Heat pumps 2)	0	0	71	159	247	351	730	1,564
– Electric direct heating (incl. process heat)	572	628	669	760	829	906	1,004	1,131
– Hydrogen	0	0	0	8	18	21	25	30
RES share (including RES electricity)	72%	73%	75%	71%	70%	67%	63%	58%
Electricity consumption heat pumps (TWh/a)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Africa: Installed capacity [GW] – REFERENCE

	Statistical Data		Estimation	AF REFERENCE scenario projection				
	2019	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Total generation	271	265	270	403	627	905	1,232	1,670
– Fossil	196	184	192	202	196	204	218	244
– Hard coal (and non-renewable waste)	55	49	51	35	25	19	14	11
– Lignite	0	0	0	0	0	0	0	0
– Gas (w/o H_2)	121	119	124	159	170	185	203	233
– Oil and Diesel	20	16	17	8	1	0	0	0
– Diesel	0	0	0	0	0	0	0	0
– Nuclear	2	2	2	4	7	7	9	10
– Hydrogen (fuel cells, gas power plants, gas CHP)	0	0	0	0	0	0	0	0
– Renewables	73	80	76	197	424	694	1,004	1,416
– Hydro	51	53	50	58	53	58	72	91
– Wind	9	10	10	27	45	56	82	103
of which wind offshore	0	0	1	3	7	13	24	37
– PV	10	16	13	103	310	559	815	1,173
– Biomass (and renewable waste)	0.5	0.520	0.500	1.803	3.676	6.441	10.4	16.2
– Geothermal	1	1	1	3	4	4	6	7
– Solar thermal power plants	1	0	1	2	2	0	3	4
– Ocean energy	0	0	1	3	7	11	17	21
Variable RES (PV, wind, ocean)	19	26	24	133	362	625	914	1,298
Share of variable RES	7%	10%	9%	33%	58%	69%	74%	78%
RES share (domestic generation)	27%	30%	28%	49%	68%	77%	82%	85%

Africa: Final energy demand [PJ/a] – REFERENCE

	Statistical Data		Estimation	AF REFERENCE scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy use)	22,611	22,621	24,258	26,279	30,024	34,412	39,588	46,098
Total energy use 1)	21,767	21,810	23,403	25,377	29,018	33,272	37,671	43,213
Transport	5,123	4,758	5,201	5,769	6,712	7,815	9,198	10,972
– Oil products	5,071	4,733	5,160	5,662	6,499	7,419	8,569	10,061
– Natural gas	20	17	13	11	12	4	5	0
– Biofuels	3	2	5	22	36	75	87	96
– Synfuels	0	0	0	2	3	7	13	25
– Electricity	21	23	35	81	168	296	498	738
– RES electricity	5	5	8	18	38	67	112	166
– Hydrogen	0	0	0	3	6	18	31	52
– RES share Transport	0%	0%	0%	1%	2%	4%	5%	6%
Industry	3,647	3,573	3,962	4,602	5,437	6,481	7,803	9,519
– Electricity	925	882	1,006	1,280	1,597	2,048	2,584	3,220
– RES electricity	195	200	236	476	814	1,241	1,747	2,329
– Public district heat	0	0	0	0	0	0	0	0
– RES district heat	0	0	0	0	0	0	0	0
– Hard coal and lignite	621	605	712	787	890	1,025	1,207	1,477
– Oil products	639	564	144	144	85	51	0	0
– Gas	797	753	853	1,249	1,595	2,138	2,927	4,118
– Solar	0	0	66	76	88	103	123	151
– Biomass	665	769	1,143	981	1,015	897	656	130
– Geothermal	0	0	39	70	131	178	256	363
– Hydrogen	0	0	0	15	35	41	49	61
– RES share Industry	24%	27%	37%	35%	38%	38%	36%	32%
Other Sectors	12,997	13,479	14,240	15,005	16,869	18,977	20,671	22,722
– Electricity	1,486	1,476	1,706	1,982	2,347	2,811	3,417	4,244
– RES electricity	313	334	400	737	1,196	1,704	2,310	3,069
– Public district heat	0	0	0	0	0	0	0	0
– RES district heat	0	0	0	0	0	0	0	0
– Hard coal and lignite	177	170	175	188	205	226	252	284
– Oil products	929	889	916	1,044	1,159	1,306	1,487	1,707
– Gas	555	592	599	970	1,294	1,751	2,200	2,482
– Solar	7	8	26	345	584	785	1,022	1,498
– Biomass	9,844	10,344	10,685	10,339	11,134	11,939	12,123	12,321
– Geothermal	0	0	132	138	146	157	170	187
– Hydrogen	0	0	0	0	0	0	0	0
– RES share other sectors	78%	79%	79%	77%	77%	77%	76%	75%
Total RES	11,031	11,662	12,741	13,220	15,226	17,212	18,699	20,447
RES share	51%	53%	54%	52%	52%	52%	50%	47%
Non energy use	844	811	855	902	1,006	1,140	1,917	2,885
– Oil	330	304	330	335	384	419	724	1,048
– Gas	470	439	464	492	550	626	1,056	1,595
– Coal	44	68	61	76	72	95	137	242

Africa: Energy-releated CO_2 emissions [million tons/a] – REFERENCE

	Statistical Data		Estimation	AF REFERENCE scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	495	626	525	337	276	260	256	303
– Hard coal (and non-renewable waste)	289	243	237	123	87	63	45	39
– Lignite	0	0	0	0	0	0	0	0
– Gas	163	165	166	180	187	197	211	263
– Oil and Diesel	43	218	121	33	3	0	0	0
Combined heat and power plants	0	0	0	0	0	0	0	0
– Hard coal (and non-renewable waste)	0	0	0	0	0	0	0	0
– Lignite	0	0	0	0	0	0	0	0
– Gas	0	0	0	0	0	0	0	0
– Oil	0	0	0	0	0	0	0	0
CO_2 emissions power and CHP plants	495	626	525	337	276	260	256	303
– Hard coal (and non-renewable waste)	289	243	238	123	87	63	45	39
– Lignite	0	0	0	0	0	0	0	0
– Gas	163	165	166	180	187	198	211	263
– Oil and Diesel	43	218	121	33	3	0	0	0
CO_2 intensity (g/kWh)	0	0	0	0	0	0	0	0
Without credit for CHP heat	0	0	0	0	0	0	0	0
– CO_2 intensity fossil electr. generation	746	989	797	511	442	409	385	412
– CO_2 intensity total electr. generation	577	753	601	310	203	150	114	104
CO_2 emissions by sector	1,231	1,329	1,174	1,114	1,172	1,285	1,433	1,719
– Industry 1)	182	180	126	155	179	219	276	368
– Other sectors 1)	135	133	137	198	229	249	258	293
– Transport	420	391	387	425	488	557	643	755
– Power generation 2)	495	626	525	337	276	260	256	303
– Other conversion 3) - part of industry and transport	31	39	34	32	34	38	42	49
Population (Mill.)	1,328	1,361	1,530	1,565	1,601	1,637	1,674	1,711
CO_2 emissions per capita (t/capita)	0.9	1.0	0.8	0.7	0.7	0.8	0.9	1.0

Africa: Primary energy demand [PJ/a] – REFERENCE

	Statistical Data		Estimation	AF REFERENCE scenario projection				
	2019	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy-use)	32,023	35,052	34,128	33,174	34,939	38,148	43,181	50,729
– Fossil (excluding on-energy use)	15,953	17,208	16,145	15,935	16,992	18,811	21,123	25,541
– Hard coal	4,032	3,547	3,553	2,367	2,100	2,002	2,044	2,298
– Lignite	4	4	52	45	26	15	0	0
– Natural gas	4,592	4,455	4,577	5,880	6,714	7,777	9,028	11,475
– Crude oil	7,324	9,202	7,964	7,643	8,152	9,017	10,051	11,768
– Nuclear	145	107	112	265	481	512	671	739
– Renewables	15,082	16,926	17,016	16,071	16,459	17,685	19,470	21,564
– Hydro	508	526	547	649	598	669	844	1,073
– Wind	67	70	73	190	303	351	479	516
– Solar	76	63	163	832	1,870	2,966	4,214	6,039
– Biomass	14,412	16,249	16,034	14,097	13,271	13,175	13,248	13,058
– Geothermal	19	18	190	284	370	451	574	738
– Ocean energy	0	0	9	19	47	73	111	141
Total RES	15,082	16,925	17,015	16,069	16,455	17,678	19,461	21,552
RES share	49%	50%	51%	50%	49%	48%	48%	46%

Notes

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