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Kenya:
Energy Development Plan to decarbonize the Economy

prepared for Power Shift Africa

Report for Public Consultation

by The University Technology Sydney
Institute for Sustainable Futures

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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 wellbeing and social equity. We seek to adopt an inter-disciplinary approach to our work and engage our partner organizations in a collaborative process that emphasizes strategic decision-making.

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

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

DISCLAIMER

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Report for Public Consultation

The energy report ***'Kenya: Energy Development Plan to decarbonize the Economy'*** is the preliminary result of a joint research by ***Power Shift Africa*** and the ***University of Technology Sydney – Institute for Sustainable Futures*** conducted between January and November 2023.

The task was to develop comprehensive energy scenarios for Kenya which challenges the current government and private sector plan and provides new scientific input for future policies.

A focus of this work lies on the development of a 100% Renewable Energy Pathways to provide data for future National Determined Contribution (NDC) report for the UNFCCC.

The 100% Renewable Energy pathways are developed as robust, reliable and cost-effective energy plans and based on GIS based renewable energy potential analysis for solar and wind energy, hourly simulation to determine a high-level analysis of the required storage and grid expansion requirements.

The energy pathways aim to phase-out energy-related CO_2 emissions as fast as possible while implementing fast and ambitious energy access programs.

The energy demand analysis is based on the following assumptions:

1. Economic growth to facilitate high enough to develop towards a middle-income country
2. Increase energy demand for services and industries
3. Increased decarbonized transport sector
4. Access to reliable and affordable energy services for all households to achieve OECD household standards by 2050.

This report provides a detailed technical documentation of the energy scenario development and is part of the global 'One Earth Climate Model research program under leadership of the University of Technology Sydney – Institute for Sustainable Futures. Further details about the One Earth Climate Model are available at www.uts.edu.au/OECM

PSA's mission is to mobilize climate action in Africa, amplify African voices through increased visibility in media and public communications, and leveraging this voice internationally. As part of our work, PSA is helping to build dedicated platforms of African civil society organizations, technical experts and high-level leadership that will engage collectively to ensure a transformative, Africa-led efforts to accelerate and scale-up the harnessing of the continent's huge renewable energy potential. We seek to promote and support Africa to meet its short and long-term targets to achieve the 1.5C target through a just transition to 100% renewable energy.

This report is for PUBLIC CONSULTATION – feedback and comments are welcome.

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Introduction

This report focuses on the development of a 100% Renewable Energy Pathway for Kenya. Here, the 100% Renewable Energy pathways is constructed with the aim to be robust and to proof the technical and financial feasibility. In addition, the 100% Renewable Energy pathways will be a clear demonstration of security of supply for Kenya's industry, transport and residential sectors.

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 Kenya 1.5 °C (K-1.5C) 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 the Kenya's energy supply system into a truly sustainable one. It may serve 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 the country's power grid. The simulations support the assessment of the grid expansion requirements, the power-trade balance, and the investments required to strengthen the backbone of Kenya's electricity infrastructure to ensure its reliability and resilience.

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

1 Research Scope

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 industrialized countries, including all the G20 countries and Switzerland.

All UTS-ISF energy analyses include the following aspects:

- A renewable energy resource analysis based on spatial GIS data under constrained land availability conditions (excluding protected areas, areas with a steep slope, and certain land-cover classes, such as closed forests, wetlands, snow and ice, and permanent water).
- The development of the future energy demands for 2025, 2030, 2035, 2040, 2045, and 2050, based on the latest available statistics—base year for energy demand is 2019 —broken down into the main energy sectors (power, buildings, industry, and transport).
- The sectorial 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 decarbonize 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 to Reference scenario
- These scenarios are combined with renewable energy scenarios with different variable power generation shares (solar photovoltaic [PV], wind, bioenergy, and hydropower).
- Based on the different power demand-and-supply scenarios, a projection of the required load from industry, commercial, and residential demands is compared with the available power generation capacity —to stress-test the security of supply.
- The power generation capacity is simulated at 1-hour resolution for seven provinces with regional long-term average meteorological data for solar and onshore wind.
- Current and future required national grid capacities are simulated, together with the required linkages between different parts of the country's national power grid and import/export transactions with neighbouring countries.

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

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

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

2 Scenario Assumptions

2.1 KENYA: COUNTRY OVERVIEW

Kenya is situated on the equator in East Africa. It has an Indian Ocean coastline, and the Rift Valley runs through the country. The official languages are Kiswahili and English. Since gaining independence in 1963, Kenya has played a major role in humanitarian, maritime and regional security issues in the Horn of Africa. The capital Nairobi is one of the fastest-growing cities in Africa and serves as a major regional hub for the United Nations, multilateral organisations and diplomatic missions. Kenya is the second largest economy in East Africa, with significant mineral and energy resources. Mombasa Port, located on the south coast, is a gateway to East African trade (DFAT 2023)[2].

The socio-economic assumptions, all data related to the energy demand and supply and GHG emissions, and statistical data that have been used for the development of the energy scenarios are based on publicly available databases.

2.1.1 POLITICAL CONTEXT

According to the Climate Action Tracker policy overview[3] climate mitigation is not prioritised in the 'Big Four Agenda' of former President Uhuru Kenyatta's, 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 update it every five years (Republic of Kenya, 2016b). The second and most recent NCCAP covers the period 2018-2022 and 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 mitigation actions that are designed to ensure that sectors achieve their sectoral targets (Government of Kenya, 2018).

The amendment of the Climate Change Act was introduced into the National Assembly in August 2023[4] and contains mainly new definitions for the carbon market including carbon credits and carbon budgets. Furthermore, the new bill forms the basis for 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[5].

The IEA Kenya Energy Outlook – published already in 2019, provides an overview to Kenya's the higher-level economic targets which may conflict with the later introduced Climate Change Action Plan.

Table 1: IEA Kenya Energy Outlook 2019[6]

Policy	Key Target and Measures
Performance targets	National Electrification Strategy: achieve universal electricity service to all households and businesses by 2022 at acceptable quality of service levels.
	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

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[2] DFAT, Australian Government, Department of Foreign Affairs and Trade (DFAT), country profiles assessed November 2023; https://www.dfat.gov.au/geo/kenya

[3] Climate Action Tracker, online plateform, assessed November 2023, https://climateactiontracker.org/countries/kenya/policies-action/

[4] Kenya Gazette Supplement No.127 (National Assembly Bill No 42, 4.August 2023, http://www.parliament.go.ke/sites/default/files/2023-08/THE%20CLIMATE%20CHANGE%20%28AMENDMENT%29%20BILL%2C%202023.pdf

[5] NDC Partnership Network, online information assessed in November 2023, https://ndcpartnership.org/news/kenya-unveils-comprehensive-legal-framework-accelerate-climate-action

[6] IEA Kenya Energy Outlook 2019, https://iea.blob.core.windows.net/assets/44389eb7-6060-4640-91f8-583994972026/AEO2019_KENYA.pdf

2.1.2 POPULATION DEVELOPMENT

Table 2: Overview—Eight modelling regions of Kenya, Source: Kenya National Bureau of Statistics[7]

Scenario Region	Provinces	Counties	Population [2019]	Area [km²]	Population Density
1	South Coast	Kilifi	1,453,790	126,46	116
		Kwale	866,820	8,479	105
		Lamu	143,920	6,883	23
		Mombasa	1,208,330	243	5,495
		Taita/Taveta	340,671	17,406	20
		Tana River	315,943	37,924	8
	South Coast		**4,329,474**	**83,582**	**52**
2	North Coast	Garissa	841,353	45,596	19
		Mandera	867,457	27,961	33
		Wajir	781,263	55,639	14
	North Coast		**2,490,073**	**129,196**	**19**
3	Northern	Isiolo	268,002	25,495	11
		Marsabit	459,785	76,794	6
	Northern		**727,787**	**102,289**	**7**
4	Eastern Central	Embu	608,599	2,838	216
		Kitui	1,136,190	30,469	37
		Machakos	1,421,930	6,045	236
		Makueni	987,653	8,468	121
		Meru	1,545,710	7,394	220
		Tharaka-Nithi	393,177	2,251	153
	Eastern Central		**6,093,259**	**57,466**	**106**
5	Central	Kiambu	2,417,740	2,600	952
		Kirinyaga	610,411	1,496	413
		Murang'a	1,056,640	2,543	419
		Nairobi City	4,397,070	762	6,247
		Nyandarua	638,289	3,299	194
		Nyeri	759,164	3,372	228
	Central		**9,879,314**	**702**	**14,071**
6	North Western	Baringo	666,763	10,925	61
		Samburu	310,327	21,327	15
		Turkana	926,976	70,772	14
		West Pokot	621,241	9,243	68
	North Western		**2,525,307**	**112,267**	**22**
7	Western Central	Bomet	875,689	2,375	349
		Elgeyo/Marakwet	454,480	3,074	150
		Kajiado	1,117,840	21,893	51
		Kericho	901,777	2,607	370
		Laikipia	518,560	9,750	55
		Nakuru	2,162,200	7,577	288
		Nandi	885,711	2,886	311
		Narok	1,157,870	17,939	65
		Trans Nzoia	990,341	2,501	397
		Uasin Gishu	1,163,190	3,362	342
	Western Central		**10,227,658**	**73,965**	**138**
8	Lake Zone	Bungoma	1,670,570	3,044	552
		Busia	893,681	1,831	526
		Homa Bay	1,131,950	4,748	359
		Kakamega	1,867,580	3,036	619
		Kisii	1,266,860	1,343	957
		Kisumu	1,155,570	2,682	554
		Migori	1,116,440	3,113	427
		Nyamira	605,576	886	675
		Siaya	993,183	3,585	393
		Vihiga	590,013	568	1,047
	Lake Zones		**11,291,423**	**24,835**	**455**

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[7] Kenya National Bureau of Statistics (KNBS) (2019)
Population and Housing Census Volume II: Distribution of Population by Administrative Units

Source) Kenya's National Bureau of Statistics (KNBS) (2019)

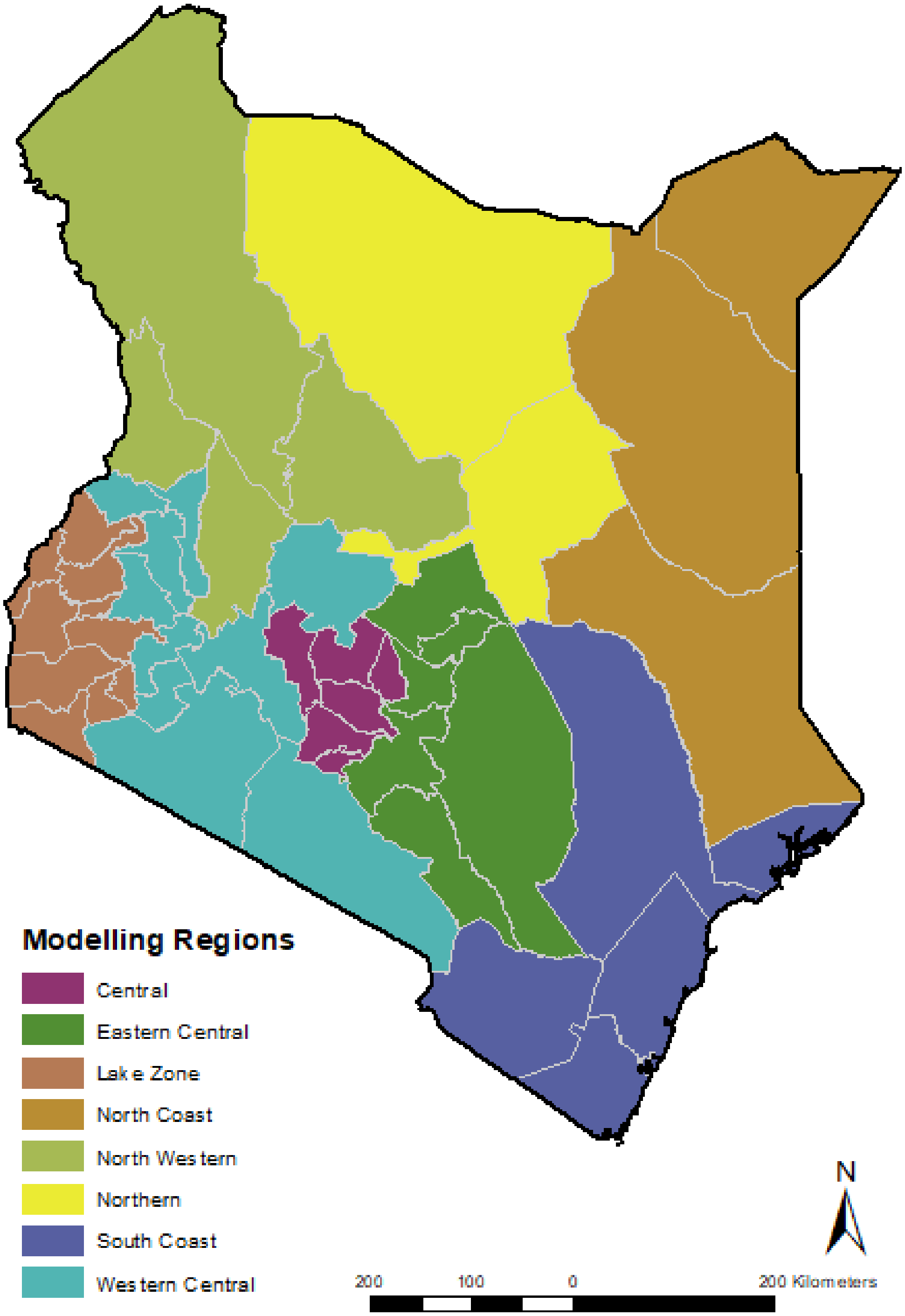

Figure 1: Kenya—Modelling Regions;

Source: generated ISF from World Administrative Divisions[8]

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

2.1.3 ECONOMIC CONTEXT

According to the World Bank, Kenya has achieved respectable GDP growth in the past, averaging 4.9% between 2009 and 2019. (World B 2022)[9] However, Kenya faces significant vulnerabilities in achieving inclusive and sustainable growth. The ongoing global disruptions caused by the COVID-19 pandemic have been compounded by structural constraints for Africa, such as slow domestic job creation, high vulnerability to natural disasters, climate change, environmental degradation, and large infrastructure gaps. Furthermore, the pandemic has recently triggered a surge in debt levels, which must be addressed. However, strong economic growth is assumed for the development of the energy scenario.

Population and economic development projections until 2050

The population and gross domestic product (GDP) shown in Table 2 are based on projections of the Kenya's Government, which have been used for the NDC and the long-term energy plan.

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

Kenya	Units	2019	2025	2030	2035	2040	2045	2050
Population	[individuals]	52,573,967	53,950,895	53,929,825	53,823,203	53,645,633	53,371,463	52,981,129
Annual Population Growth	[%/a]	2.30%	0.07%	-0.01%	-0.04%	-0.07%	-0.10%	-0.15%
GDP	[US$ billion]	84.13	115.10	154.04	206.14	260.58	307.33	346.77
Annual Economic Growth (data for 2030, 2040 and 2050 from LTLEDS)	[%/a]	-0.32%	6.00%	6.00%	6.00%	4.00%	3.00%	2.00%
GDP/Person (calculated)	[US$/capita]	1598	2132	2856	3827	4865	5771	6550

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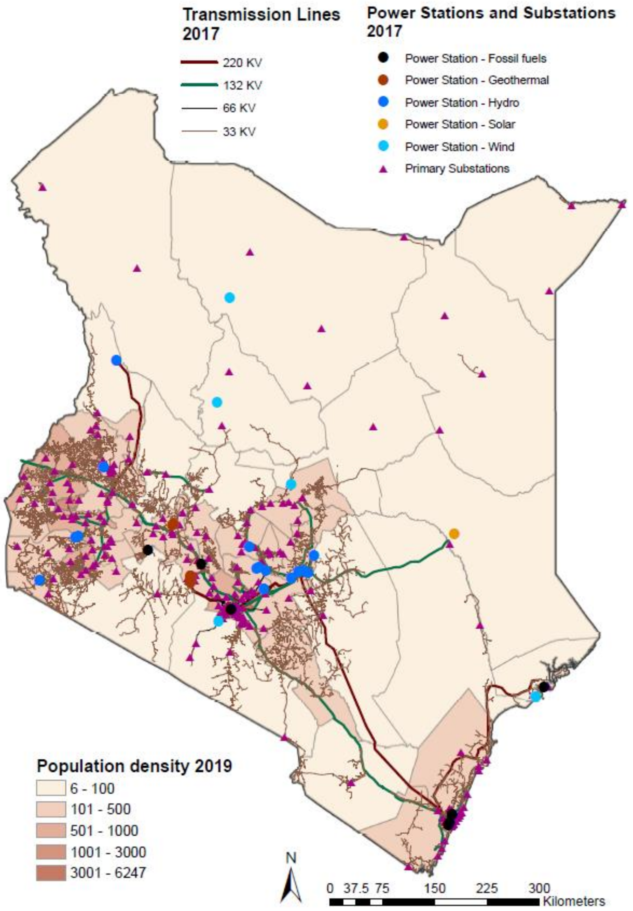
[9] World Bank 2022, Country Overview Kenya, database from 2022.

2.2 ELECTRICITY INFRASTRUCTURE AND ENERGY ACCESS

For this analysis, Kenya's power sector is divided into 8 regions. The regional distribution of the population and the availability of the energy infrastructure correlate with the socio-economic situation in all regions. The following map provides an overview of the locations of power lines and power plants, a regional breakdown of energy pathways, and a power sector analysis (Chapter 6).



Source) Power stations and substations—World Bank Group (2017)[10], (2019)[11] and (2020)[12], the population density is based on Kenya's National Bureau of Statistics (KNBS) (2019)

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

Source) Power stations and substations—World Bank Group (2017), (2019) and (2020), the population density is based on Kenya's National Bureau of Statistics (KNBS) (2019)

Figure 2 shows the population density of Kenya. The highest population concentrations are shown in dark red and the lowest in white. The map clearly shows the high population densities in the metropolitan areas of Nairobi, Nakuru, Kisumu and Eldoret in the southern east of Kenya. The existing constructed electricity infrastructure (power lines, power plants, and sub-stations), with their different types of grids, are shown as lines, and the differently coloured dots mark grid-connected power plants—each colour represents a specific technology, identified in the legend. The lines represent power transmission lines with different voltage levels. The figure visualizes the distribution of the grid, power plants, and population density, but does not

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[10] Kenya – Power Stations (2017), Kenya Power and Lighting Company (KPLC) / World Bank Group, https://energydata.info/dataset/kenya-kenya-electricity-network

[11] Kenya - Kenya Electricity Network (2020), Kenya Power and Lighting Company (KPLC) / World Bank Group; https://energydata.info/dataset/kenya-kenya-electricity-network

[12] Kenya - Primary Substations (2020), World Bank Group, https://energydata.info/dataset/kenya-primary-substations

claim to be complete. The energy access rate of the local population in Kenya is around 76.8%[13], although access to energy services does not necessarily mean that the supply is available at all times.

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[13] World bank Kenya, https://data.worldbank.org/country/kenya?view=chart

2.3 ENERGY DEMAND—DEVELOPMENT SINCE 2005

It is necessary to analyse the development of the past energy demand in order to project that of the future. Therefore, the statistical data for Kenya's energy demand between 2005 and 2019 have been analysed (IEA 2022)[14].

Figure 3 shows Kenya's final energy demand development between 2005 and 2020. 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 47% since 2005 to around 613 petajoules per annum (PJ/a). The main energy demand is required in the residential sector (category of Other Sectors), whereas only 8% of the energy is for industry use and 24% for the transport sector.

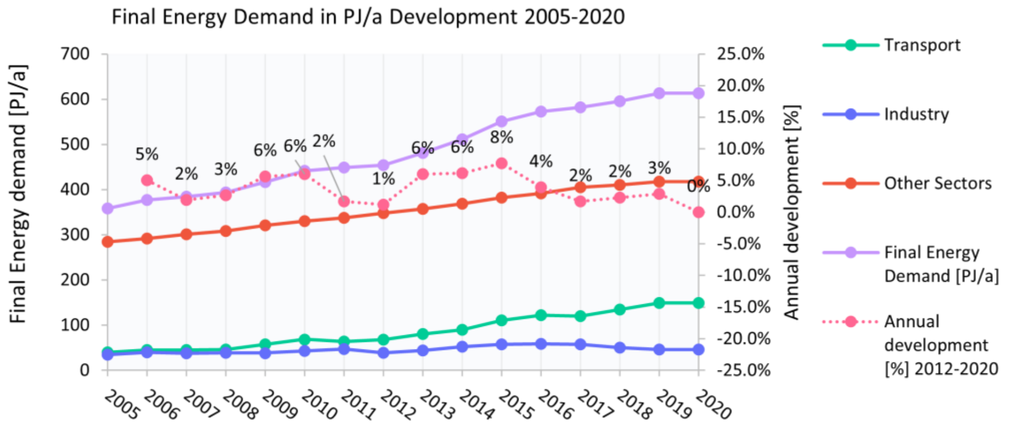

Figure 3: Final energy demand development in Kenya from 2005 to 2019

The electricity demand has increased significantly faster than the final energy demand. By 2019, the annual electricity demand was close to 9 billion kilowatt-hours (9 TWh/a), up from 5 TWh/a in 2005 (Figure 4), growing by a factor 2. 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 rise significantly.

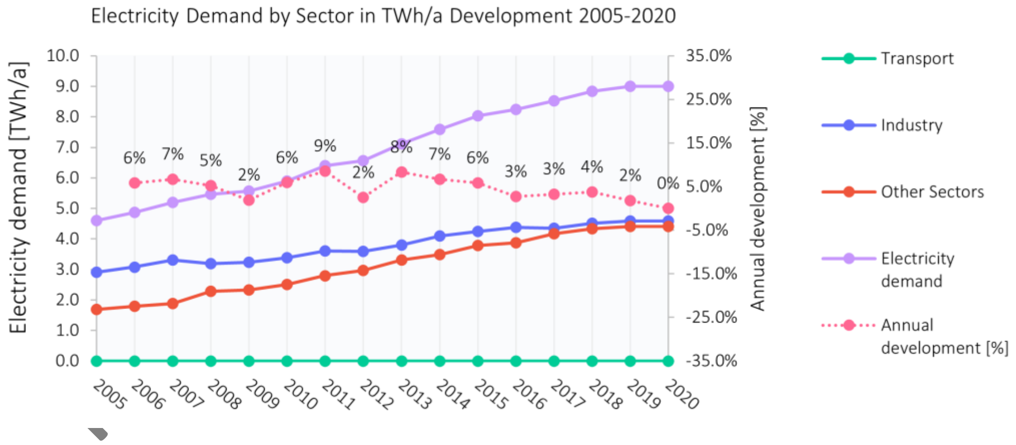

Figure 4: Electricity demand development in Kenya from 2005 to 2020

However, Kenya's electricity demand is currently 167 kWh per capita, one of the lower ones in the world (IBN 2011)[15], with the global average consumption over 3,000 kWh/capita per annum (World Bank 2019)[16].

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[14] IEA 2022, Advanced World Energy Balances, Kenya

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

2.3.1 ENERGY SUPPLY

The primary energy supply is dominated by biomass (around 95% in 2020), used mainly for cooking and heating, as shown in Table 4, whereas electricity is almost entirely supplied by geothermal and hydro (71 % 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.

Table 4: Kenya's primary energy supply between 2005 and 2019 (IEA World Energy Balances 2021)

Primary Supply -	Units	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Annual development		-	4%	3%	3%	5%	5%	2%	1%	2%	4%	6%	5%	3%	1%	2%	0%
Primary energy	[PJ/a]	548	571	585	601	632	661	676	685	709	756	799	840	863	876	897	897
Net Export (–) /Import (+)	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	-1	-1
Fossil fuels	[PJ/a]	92	103	102	105	125	138	138	129	147	169	192	217	230	222	226	226
Coal	[PJ/a]	4	5	5	5	4	7	10	9	13	20	21	20	19	18	15	15
Lignite	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oil	[PJ/a]	88	98	98	101	121	131	128	121	134	150	172	196	211	204	211	211
Gas	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nuclear	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conventional Renewables	[PJ/a]	454	466	481	493	504	521	536	552	562	583	604	619	629	650	666	666
Hydro	[PJ/a]	11	11	13	12	8	12	11	14	16	12	12	14	10	14	12	12
Wind	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	6
Solar	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	[PJ/a]	439	452	464	477	492	505	519	533	540	560	574	589	602	616	630	630
Geothermal	[PJ/a]	4	4	4	4	5	4	5	5	6	11	16	16	17	18	19	19
Ocean energy	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conventional Renewables Share:	[%]	99%	99%	99%	99%	99%	99%	99%	99%	99%	98%	97%	97%	97%	97%	96%	96%
New Renewables Share	[%]	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	3%	3%	3%	3%	4%	4%

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

Definition of renewable energy

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body assessing climate change. In its Special Report on Renewable Energy Sources and Climate Change Mitigation,[17] 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 utilize 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 utilization 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 utilization.'

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

2.4 DEVELOPMENT OF THE RESIDENTIAL ENERGY DEMAND

To develop a projection for the residential electricity demand in Kenya over the coming 30 years to achieve the Kenya 1.5 °C (K-1.5C) scenario, a bottom-up electricity demand analysis was performed. The K-1.5C 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 organized 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 Kenya's households were analysed from the second half of 2021 onwards under the leadership of the Power Shift Africa. The future development of the household demand has been discussed in a multiple-stakeholder dialogue with representatives from Kenya's academia, civil society, and government.
Error! Reference source not found. shows the breakdown of Kenya's households by size (UN-ES 2019)[18]. The current average electricity demands of Kenya's households are significantly lower than those of OECD countries.

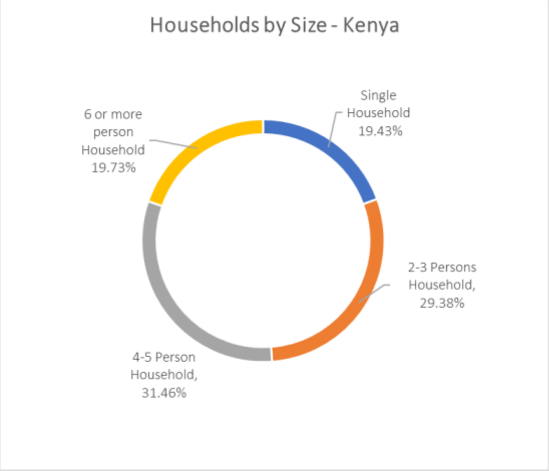

Figure 5: Household by size - Kenya

Table 5 shows the electricity demand and the electrical appliances used by households in Kenya 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 households with very basic needs, such as light and mobile phone charging, to a household standard equivalent to that of industrialized countries. The different levels of electrification and the utilization 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 and one for the more-advanced stage of electrification. 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 industrialized countries. Adjustments will be made to the levels of comfort in households in city and rural areas to prevent residents—

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[18] 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

especially young people—from leaving their home regions and moving to big cities. The phase-out of unsustainable biomass, liquefied pressurized gas (LPG) and paraffin for cooking is particularly important in decarbonizing Kenya's household energy supply. A staged transition towards electrical cooking is assumed (see Section 2.1.8.2).

Table 5: Household types used in all scenarios and their assumed annual electricity demands.

Kenya—Annual household electricity demands			
Household Type	Group		Annual electricity demand
			[kWh/a]
Rural	Phase 1	- Very-low-income rural household - Low-income rural household	337
	Phase 2	- Lower-middle-income rural household	1021
	Phase 3	- Upper-middle-income rural household	2210
Semi-Urban	Basic	- Low-to-middle-income semi-urban household	501
	Advanced	- Middle-income semi-urban household	1763
Urban - Apartment	Basic	- Low-to-middle-income urban household (apartment)	836
	Advanced	- Middle-income urban household (apartment)	2422
Urban House	Basic	- Middle-income urban household (house)	2405
	Advanced	- Middle-to-high-income urban household (house)	2477

The typical household electricity demands are compared with:

i) Regional countries in South Asia: India, Sri Lanka, Pakistan, and Bhutan;
ii) 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 6 shows an example of the electricity demands of different household types in the OECD country of Switzerland. The example of Switzerland was chosen because of its well-documented electricity demands and its good representation of the energy-efficient and highly electrified households among the OECD countries. In predicting the future development of Kenya's electricity demand, we assume that the level of electrification and household appliances used will be similar to those in industrialized countries. Although the electricity demand of households in industrialized countries—excluding electric mobility—can be reduced through technical efficiency measures and more-efficient appliances by improving technical standards, the current demand provides an orientation for the future demands in developing countries.

Table 6: Standard household demand in an industrialized country (Switzerland)

Standard Household—OECD	Apartment			Separate House			
Category	2 People	Additional person	4 People	2 People	Any additional person/s	4 People	Calculated Urban Family 2
	[kWh/a]	[kWh/a]	[kWh/a]	[kWh/a]	[kWh/a]	[kWh/a]	[kWh/a]
Cooking/baking including special equipment, e.g., coffee maker	300	80	460	300	80	460	0
Dishwasher	250	25	300	250	25	300	
Refrigerator with or without freezer compartment	275	40	355	325	60	445	340
Separate freezer	275	25	325	350	25	400	
Lighting	350	90	530	450	125	700	198
Consumer electronics (TV, video, hi-fi, various players, etc.)	250	60	370	275	80	435	110
Home office (PC, printer, modem, comfort phone, etc.)	200	60	320	200	80	360	
Div. Nursing and small appliances including humidifier	250	45	340	325	60	445	272
Washing machine	225	65	355	250	78	405	127
Laundry dryer (about 2/3 of the laundry, with a tumbler)	250	85	420	275	88	450	
General (building services)	400		400+	900	150	1200	
Total	**3025**	**575**	**4175**	**3900**	**850**	**5600**	**1047**
Climatization							1,013
Total, including climatization	3025	575	4175	3900	850	5600	2060
Source: Der typische Haushalt-Stromverbrauch Energieverbrauch von Haushalten in Ein- und Mehrfamilienhäusern/Schweiz, https://www.werkezuerichsee.ch/dl.php/de/0dn3t-3gjac9/Typischer_Haushaltstromverbrauch-SEV0719.pdf							

The development of the country-wide shares of the electricity demand in Kenya according to the various household types is presented in Table 7. 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, while 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 Kenya's households to close the gap between households in OECD countries and countries in the global south, to achieve greater equity.

Table 7: Household types—development of household shares of the electricity demand country-wide in Kenya

Household type	Country-wide electricity shares [%] (rounded)			
	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 Energy Progress Report* published in June 2021 (EPR 2021)[19], over 77% of Kenya's households have access to electricity. However, households might not have access to reliable and uninterrupted electricity Here, rapidly expanding cities are problematic because the infrastructure for transport and energy supply and the requirements of residential apartment buildings cannot match the demand, often leading to social tensions. Mini-grids for remote areas have proven a successful technology option for bringing energy services to remote communities, helping villages develop local economies, and providing alternative opportunities for young people to establish careers outside the metropolitan areas.

2.4.2 HOUSEHOLD FUEL DEMAND—COOKING

The main energy demand for Kenya's households is for cooking. Firewood is the main energy source for rural households, whereas cylinders of LPG are the main source of energy for cooking in semi-urban and urban households. In addition, Kenya's households use paraffin.

Error! Reference source not found. shows the variety of cooking fuels used for cooking. Firewood and LPG dominate greatly, whereas in 2021 only 23.9% of the population has access to clean fuels and technologies for cooking, such as an electric cooking appliance (Figure 6) - 51.3% of the urban population has the access to clean fuels and technologies for cooking, while only 8.3% of the rural population has the access (The World Bank, 2023).[20] Table 8 provides an overview of the most important cooking technologies and their key technical and economic parameters (WFC 2019).[21] 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)[22]. With slow cookers and pressure cookers enabling household cooking costs of

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[19] (EPR 2021), IEA, IRENA, UNSD, World Bank, WHO. 2021. Tracking SDG 7: The Energy Progress Report. World Bank, Washington DC; World Bank. License: Creative Commons Attribution—Non-Commercial 3.0 IGO (CC BYNC 3.0 IGO). https://www.irena.org/publications/2021/Jun/Tracking-SDG-7-2021

[20] https://databank.worldbank.org/source/world-development-indicators/Series/EG.CFT.ACCS.ZS

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

[22] 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

between USUS$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).

Based on the current cooking energy usage, a transition scenario from fuel-based cooking to electric cooking (e-cooking) has been developed for the K-1.5C scenario (**Error! Reference source not found.**). 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.

Table 8: Basic data on technologies and energy use

Appliance	Cost range [EUR]	Median Cost [EUR]	Median Cost [KES]	Watts (range)	Approximate Daily Household Consumption (in Wh/day for electric options or in kg/day for solid and gas-based fuels)	Approximate Daily Household Consumption [MJ/day]
Three Stones (Wood)	0	0	0	N/A	4.15–20.76 kg/day	68.48–342.54
Traditional Cooking Stove (Wood)	0–5	2.5	413	N/A	3.32–8.3 kg/day	54.78–136.95
Improved Cooking Stove (Wood)	5–65	35	5,775	N/A	2.08–5.53 kg/day	34.32–91.25
Three Stones (Charcoal)	0	0	0	N/A	1.92–4.81 kg/day	54.72–137.09
Traditional Cooking Stove (Charcoal)	0–10	5	825	N/A	1.6–4.01 kg/day	45.60–114.29
Improved Cooking Stove (Charcoal)	5–65	35	5,775	N/A	1.2–2.4 kg /day	34.20–68.40
Improved Cooking Stove (Wood-based Biomass Pellets)	16–80	48	7,920	N/A	1.76–3.96 kg/day	30.41–68.43
Improved Cooking Stove (Agro-waste Pellets)	16–80	48	7,920	N/A	2.42–5.44 kg/day	30.49–68.54
Single Burner Hot Plate	8–35	21.5	3,548	600–2000	1200–4000 Wh/day	4.32–14.40
Induction Hot Plate	45–95	67.5	11,138	1000–2300	2000–4600 Wh/day	7.20–16.56
Slow Cooker / Rice Cooker / Crock Pot	10–130	70	11,550	120–300	175–700 Wh/day	0.63–2.52
Electric Pressure Cooker	19–140	79.5	13,118	500–1000	160–340 Wh/day	0.58–1.22
Microwave Oven	50–100	75	12,375	600–1200	100–1200 Wh/day	0.36–4.32
Gas Stove (single burner)	20–60	40	6,600	N/A	0.3 kg/day	13.7
Gas Stove (double burner)	30–90	60	9,900	N/A	0.3 kg/day	13.7
Gas Stove (four burners)	40–100	70	11,550	N/A	0.3 kg/day	13.7

Table 9: Cooking energy demand by technology and household type in 2021, Kenya

	Demand per Household and Day [MJ/day]	Demand per Household and Year [MJ/year HH]								
		Rural—Phase 1	Rural—Phase 2	Rural—Phase 3	Semi-Urban 1	Semi-Urban 2	Urban Apartment 1	Urban Apartment 2	Urban House 1	Urban House 2
Wood + Bioenergy Fuel based cooking	96	2,920	3,504	4,380	17,520	4,380	4,380	4,380	5,840	8,760
Gas / NLG Fuel based cooking	13.7	417	500	625	2,500	625	625	625	833	1,250
Electric cooking	3.3	100	120	151	602	151	151	151	201	301

The daily and annual energy demands for the three main fuel-based cooking technologies are shown in Table 9. Based on these, a scenario for transitioning from fuel-based cooking to electricity-based cooking was developed (Table 10).

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

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

Table 10: Transition scenario from fuel-based to electricity-based cooking in Kenya under the K-1.5C pathway

	Share of Household with Wood and Bioenergy Fuel-based Cooking		Rural—Phase 1	Rural—Phase 2	Rural—Phase 3	Semi-Urban 1	Semi-Urban 2	Urban Apartment 1	Urban Apartment 2	Urban House 1	Urban House 2
Average energy demand by HH (Based on World Future Council 2019)			**2,920**	**3,504**	**4,380**	**17,520**	**4,380**	**4,380**	**4,380**	**5,840**	**8,760**
2020	75%	[MJ/a HH]	2,193	2,632	3,289	13,158	3,289	3,289	3,289	4,386	6,579
2025	75%	[MJ/a HH]	2,190	2,628	3,285	13,140	3,285	3,285	3,285	4,380	6,570
2030	75%	[MJ/a HH]	2,190	2,628	3,285	13,140	3,285	3,285	3,285	4,380	6,570
2035	75%	[MJ/a HH]	2,190	2,628	3,285	13,140	3,285	3,285	3,285	4,380	6,570
2040	50%	[MJ/a HH]	1,460	1,752	2,190	8,760	2,190	2,190	2,190	2,920	4,380
2045	20%	[MJ/a HH]	584	701	876	3,504	876	876	876	1,168	1,752
2050	10%	[MJ/a HH]	292	350	438	1,752	438	438	438	584	876
	Share of Household with Gas / NLG Fuel-based Cooking		Rural—Phase 1	Rural—Phase 2	Rural—Phase 3	Semi-Urban 1	Semi-Urban 2	Urban Apartment 1	Urban Apartment 2	Urban House 1	Urban House 2
Average energy demand by HH (Based on World Future Council 2019)			**417**	**500**	**625**	**2,500**	**625**	**625**	**625**	**833**	**1,250**
2020	24%	[MJ/a HH]	100	120	150	600	150	150	150	200	300
2025	24%	[MJ/a HH]	100	120	150	600	150	150	150	200	300
2030	24%	[MJ/a HH]	24	29	36	144	36	36	36	48	72
2035	20%	[MJ/a HH]	83	100	125	500	125	125	125	167	250
2040	15%	[MJ/a HH]	63	75	94	375	94	94	94	125	188
2045	10%	[MJ/a HH]	42	50	63	250	63	63	63	83	125
2050	0%	[MJ/a HH]	0	0	0	0	0	0	0	0	0
	Phase-in of Electric Cooking 2020–2050										
	Share of Households with Electric Cooking		Rural—Phase 1	Rural—Phase 2	Rural—Phase 3	Semi-Urban 1	Semi-Urban 2	Urban Apartment 1	Urban Apartment 2	Urban House 1	Urban House 2
Average energy demand by HH (Based on World Future Council 2019)			**100**	**120**	**151**	**602**	**151**	**151**	**151**	**201**	**301**
2020	1%	[kWh$_{electric}$/a HH]	1	1	1	5	1	1	1	2	3
2025	1%	[kWh$_{electric}$/a HH]	1	1	2	6	2	2	2	2	3
2030	1%	[kWh$_{electric}$/a HH]	1	1	2	6	2	2	2	2	3
2035	5%	[kWh$_{electric}$/a HH]	5	6	8	30	8	8	8	10	15
2040	35%	[kWh$_{electric}$/a HH]	35	42	53	211	53	53	53	70	105
2045	70%	[kWh$_{electric}$/a HH]	70	84	105	422	105	105	105	141	211
2050	90%	[kWh$_{electric}$/a HH]	90	108	136	542	136	136	136	181	271

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

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

There are already numerous electric cooking devices on Kenya’s market, including:

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

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

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

The supply-side barriers to e-cooking are:

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

Technical challenges of e-cooking 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 fuels will further increase the electric loads and require grid expansion and reinforcement to be implemented by electric grid operators.

Furthermore, current household electricity connections are often limited to 5-ampere meters, which significantly limits the load for each household, and the parallel operation of multiple appliances is not possible when electric stoves are used. 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 Kenya already have formulated policy frameworks, such as specific energy policies, acts, procedures, and/or guidelines, to support the increased utilization of electric cooking devices. These policies include support for additional renewable electricity generation to supply stoves.

However, the implementation of sustainable cooking technologies is challenging for rural households in regard to get access to those technologies, technology standards as well as financing.

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

2.5 INDUSTRY AND BUSINESS DEMANDS

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

Figure 6 shows that in the fiscal year 2020/21, food, beverages and tobacco services contributed most strongly to the growth of GDP (in the basic price), whereas machinery and transport equipment contributed the least. Moreover, for the largest sectors, the contribution of the food, beverages and tobacco industry to the economic growth rate in that fiscal year (FY) was 38 %, and the contribution of agriculture, forestry and fishing was 19 %.

In addition, Figure 7 presents the annual GDP growth rate from 2005 to 2020.

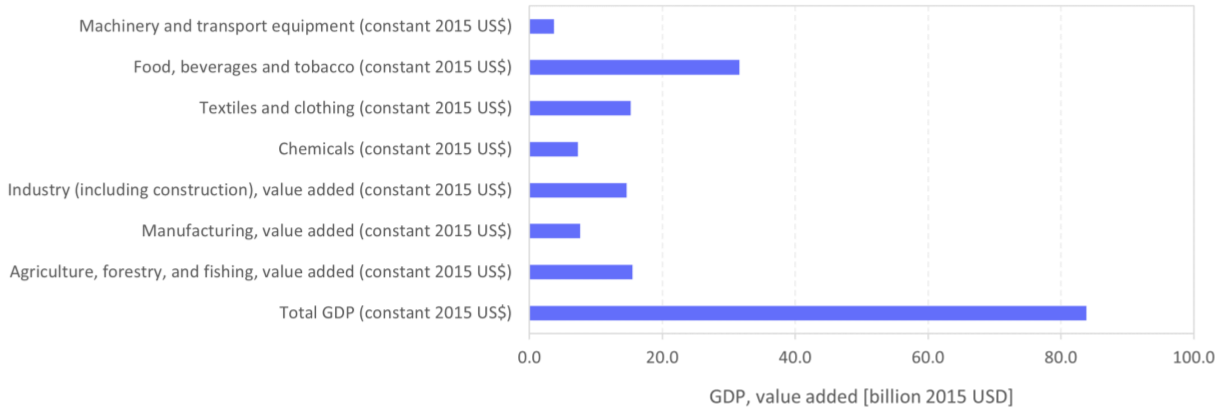

Figure 6: Contributions of sub-sectors to GDP growth

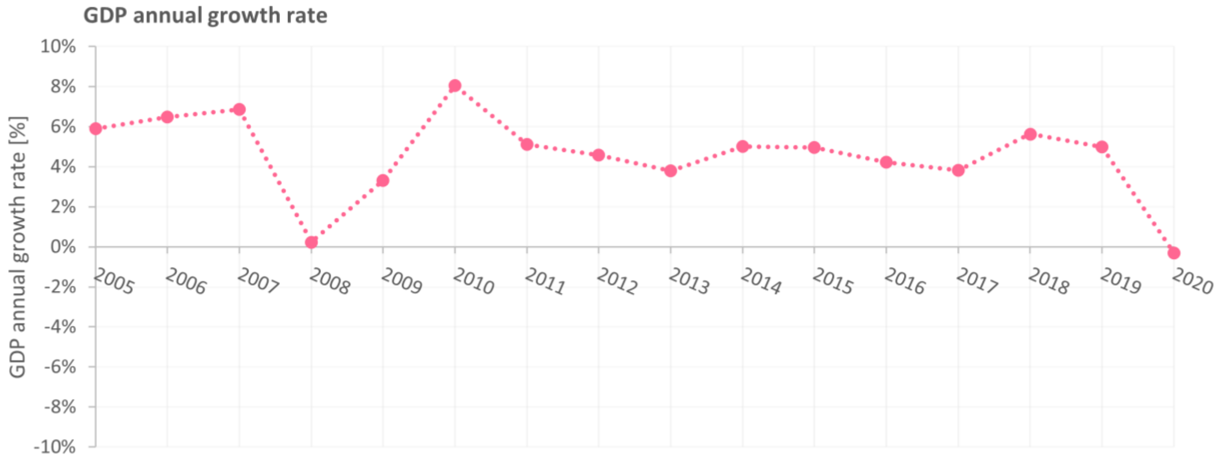

Figure 7: Gross domestic product (GDP) growth rate

2.6 TRANSPORT DEMAND

Kenya's transport sector is currently dominated by motorcycles, which account for 48% of all registered vehicles, whereas cars represent 31 % of the vehicle fleet. Other vehicles, such as light commercial vehicles LCV's (9%), Heavy good vehicles HGV's (5%), Buses and minibuses (3%) and trailers (2%), make-up 21% of the vehicle fleet, almost as large as that of cars. The remaining other motor vehicles are 2% of the vehicle fleet, which includes construction and industry vehicles, such as tractors, cranes, and excavators.

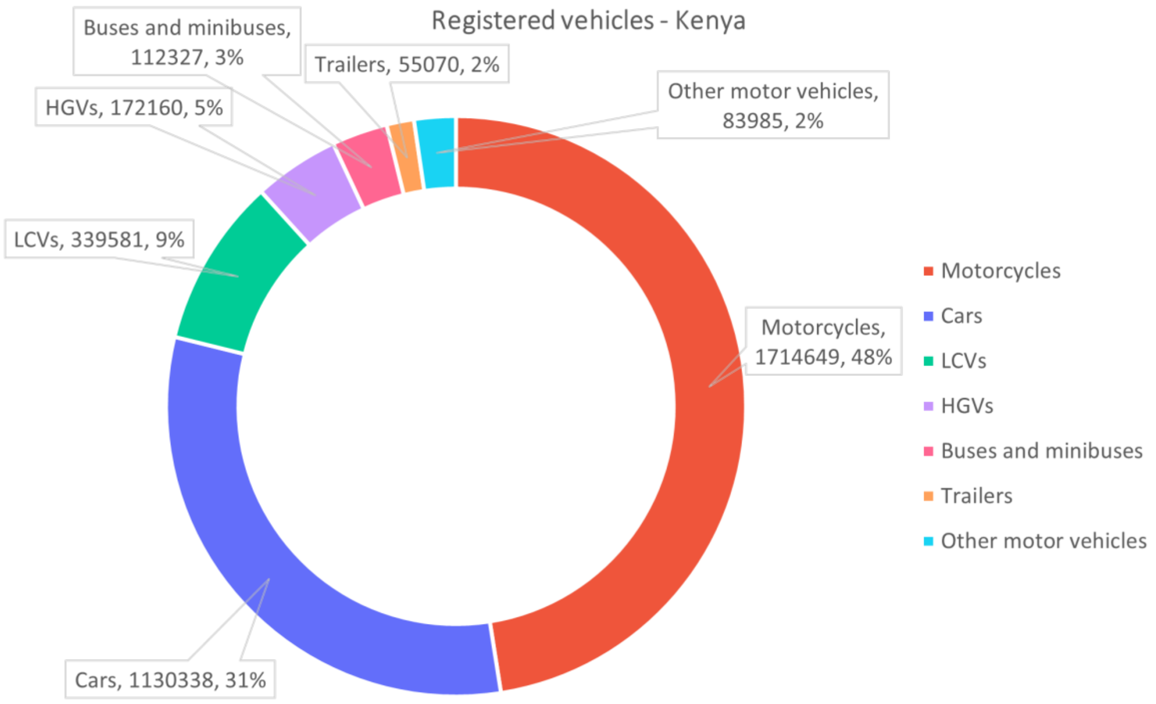

Figure 8: Categories of registered vehicles, with the percentages of the total number of registered vehicles (financial year 2019/2020). Source: [23]

To develop a future transport scenario, the technical parameters of all vehicle options are required to project the energy demands. The following section provides an overview of the vehicular energy intensities for passenger and freight transport. Based on these, the actual utilization—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 calibrating the 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 between around 20 kW to > 200 kW.

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

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[23] Dixon, J., Ondhowe, R., Rubadiri, M., Louis, N., Hine, J., Brand, C., Collett, K., Dalkmann, H., Sivakumar, A., & Hirmer, S. (2021). *Transport-Energy Database: Kenya* Zenodo. https://zenodo.org/record/6413982

2.6.1 TECHNICAL PARAMETERS—INDIVIDUAL TRANSPORT

Passenger transport by road is the commonest and most important form of travel (TUMI 2021)[24]. There are numerous technical options to 'move people with vehicles': bicycles, motorcycles, tricycles, city cars, and 4four-wheel-drive SUVs. Each vehicle has a very different energy intensity per km. Although this research project aims for high technological resolution, simplifications are required. Table 11 shows the energy intensities for the main vehicle types (electric and with internal combustion engines [ICE]), and forms the basis for the energy scenario calculations.

Table 11: Energy intensities of individual transport—road transport

Individual Transport			Passengers		Vehicle Demand	Consumption per Passenger	Energy demand
			Average Passengers per Vehicle	Assumed Occupation Rate	Average	Average	Assumption for Scenario Calculation
		Fuels			litre/100 km	litre/100 pkm	[MJ/pkm]
Scooters & motorbikes	2-wheeler	Gasoline	1	1	3.0	3.0	1.21
		Electricity			kWh$_{el}$/100 km	kWh$_{el}$/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
Cars		Fuels	0	0	litre/100 km	litre/100 pkm	[MJ/pkm]
	small	ICE–oil	2	1.8	5.0	2.8	1.12
	medium	ICE–oil	4	2	7.5	3.8	1.51
	large	ICE–oil	5	2	10.5	5.3	2.11
	small	ICE–gas	2	1.8	4.5	2.5	0.63
	medium	ICE–gas	4	2	7.0	3.5	1.41
	large	ICE–gas	5	2	10.0	5.0	1.25
	small	ICE–bio	2	1.8	5.0	2.8	0.91
	medium	ICE–bio	4	2	7.5	3.8	1.51
	large	ICE–bio	5	2	10.5	5.3	1.72
	small	Hybrid–oil	2	1.8	4.0	2.2	0.89
	medium	Hybrid–oil	4	2.5	6.0	2.4	0.96
	large	Hybrid–oil	5	2.5	8.5	3.4	1.37
		Electricity			kWh$_{el}$/100 km	kWh$_{el}$/100 pkm	[MJ/pkm]
	small	Battery	2	1.8	16.0	8.9	0.32
	medium	Battery	4	2	25.0	12.5	0.45
	large	Battery	5	2	32.5	16.3	0.59
	large	Fuel Cell	4	2	37.5	18.8	1.36

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

There are also significant regional differences, even within a province. Again, the parameters shown in Table 12 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 12: Energy intensities for public transport—road & rail transport

Public Transport			Passengers		Vehicle Demand	Consumption per Passenger	Energy Demand
			Average Passengers per Vehicle	Assumed Occupation Rate	Average	Average	Assumption for Scenario Calculation
Buses		Fuels			litre/100 km	litre/100 pkm	[MJ/pkm]
	small	Diesel	12	40%	8.8	1.8	0.73
	small	Bio	12	40%	8.8	1.8	0.60
	12 m	Diesel	75	40%	27.5	0.9	0.37
	12 m	Bio	75	40%	27.5	0.9	0.30
	large	Diesel	135	40%	57.5	1.1	0.43
		Electricity	0	0	kWh$_{el}$/100 km	kWh$_{el}$/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
Trains		Fuels	0	0	litre/100 km	litre/100 pkm	[MJ/pkm]
	Metros	Diesel	400	40%	150	0.9	0.38
	Metros	Bio	400	40%	150	0.9	0.31
	Commuter Trains	Diesel	600	40%	300	1.3	0.50
	Commuter Trains	Bio	600	40%	300	1.3	0.41
		Electricity	0	0	kWh$_{el}$/100 km	kWh$_{el}$/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 utilization rates of the load capacities vary significantly, and consistent data are not available for the calculated regional and global levels. Therefore, the assumed utilization rate greatly influences the calculated energy intensity per tonne–km (tkm). The average energy intensities per tkm used in the scenario are shown in Table 13 and are largely consistent with those from other sources in the scientific literature (EEA, 2021)[25]. The assumed energy intensities for electric and fuel cell/hydrogen freight vehicles are only estimates because this technology is still in the demonstration phase. Therefore, none of the scenarios factor in large shares of electric freight transport vehicles before 2035.

Table 13: Energy intensities freight transport—road & rail transport

Freight Transport			Maximum Load Capacity (tonnes)	Assumed Utilization Rate	Vehicle Demand	Consumption per tonne	Energy Demand
					Average	Average	Assumption for Scenario Calculation
Trucks		Fuels			litre/100 km	litre/tkm	[MJ/tonkm]
	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			kWh_{el}/100 km	kWh_{el}/ton-km	[MJ/tonkm]
	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/ton-km	[MJ/tonkm]
	Freight–740 m	Diesel	1,000	40%	300	0.8	0.30
	Freight–740 m	Bio	1,000	40%	300	0.8	0.25
		Electricity			kWh_{el}/100 km	kWh_{el}/ton-km	[MJ/tonkm]
	Freight–740 m	Electric	1,000	40%	5,840	14.6	0.53

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

2.6.4 UTILIZATION OF VEHICLES

In the second step, the utilization 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 with an 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 internal combustion engines (ICEs) and not electric drives are in use.

Table 14: Kenya—projected passenger and freight transport demand under the K-1.5C scenario

		2019	2020	2025	2030	2035	2040	2045	2050
Road: **Passenger** Transport Demand	[PJ/a]	144	144	118	111	68	62	57	58
Annual passenger kilometres	[million pkm]	40,404	40,404	42,465	44,631	46,908	49,301	51,816	54,459
Average energy intensity—passenger vehicles.	[MJ/pkm]	2.50	2.50	1.88	1.75	1.71	1.66	1.63	1.60
Annual demand variation:	[%/a]	-	-	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
kilometres per person per day	[km/person day]	769	751	741	706	680	658	646	647
Road: **Freight** Transport Demand	[PJ/a]	43	43	39	38	29	28	26	27
Annual freight kilometres	[million tkm]	28,764	28,764	32,348	33,998	35,732	37,555	39,470	41,484
Average energy intensity—freight vehicles	[MJ/tkm]	1.51	1.51	1.20	1.14	1.11	1.08	1.07	1.06
Annual demand Variations	[%/a]			1.00%	1.00%	1.00%	1.00%	1.00%	1.00%

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 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 14. 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 in 2030 and to 0.54 MJ in 2050.

The energy required by freight vehicles to move 1 tonne for 1 kilometre will decrease from around 1.5 MJ to 1.11 MJ by 2030 and to 0.68 MJ by 2050. Both reductions will only be possible with high shares of electric drives. Figure 9 and Figure 10 show the development of drive trains for passenger and freight transport vehicles over time. The electrification of large parts of these fleets is unavoidable if the transport sector is to be decarbonized. 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.

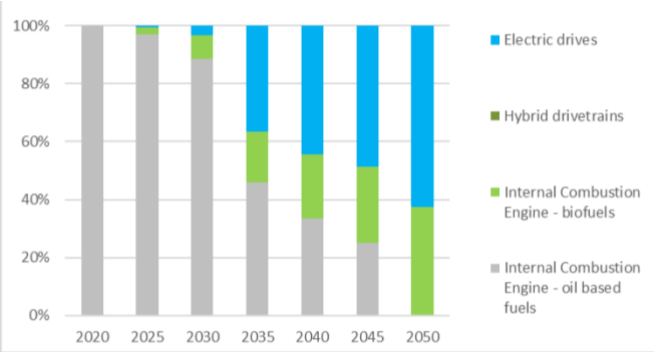

Figure 9: Passenger transport—drive trains by fuel

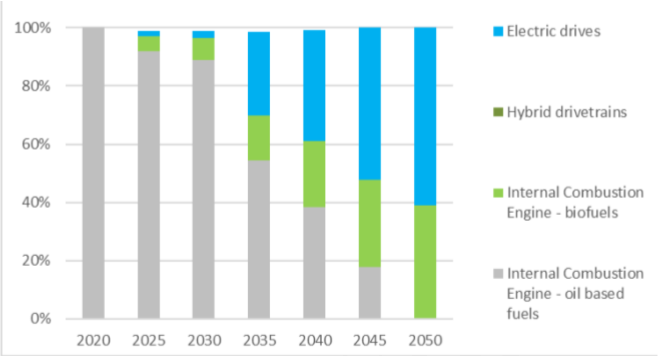

Figure 10: Freight transport—drive trains by fuel

Kenya submitted an updated Nation Determined Contribution (NDC) report to the UNFCCC on the 24th of December 2020[26]. The new NDC sets a target to reduce greenhouse gas emission by 2030 by 2030 compared to the 'Business-As-Usual' (BAU) scenario.

The NDC does not include a detailed transport pathway, but highlights the following priority mitigation activity for the transport sector: *'Low carbon and efficient transportation systems*

Therefore, the assumed trajectory for the transport sector (Figure 9 and Figure 10) i serves as a proposal for a transport sector concept for future decarbonization paths.

Based on these 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.

Supply-side barriers to e-vehicles

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

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[26] Republic of Kenya, Ministry of Environment and Forestry, Kenya's Updated Nationally Determined Contribution (NDC), December 2020, https://unfccc.int/sites/default/files/NDC/2022-06/Kenya%27s%20First%20%20NDC%20%28updated%20version%29.pdf

2.7 TECHNOLOGY AND FUEL COST PROJECTIONS

All cost projections in this analysis are based on a recent publication by Teske et al. (2019)[27]. 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 parameterization of the models requires many assumptions about the development of the characteristic technologies, such as specific investments and fuel costs. Therefore, because long-term projections are highly uncertain, we must define plausible and transparent assumptions based on background information and up-to-date statistical and technical information.

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

Moreover, efficiency measures generate costs that are usually difficult to determine, 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 electricity consumption avoided in our cost accounting.

During the last decade, fossil fuel prices have seen huge fluctuations. Figure 11 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)[28]. Therefore, fossil fuel price projections have also seen considerable variations (IEA 2017[28]; IEA 2013[29]) and this has influenced the scenario results.

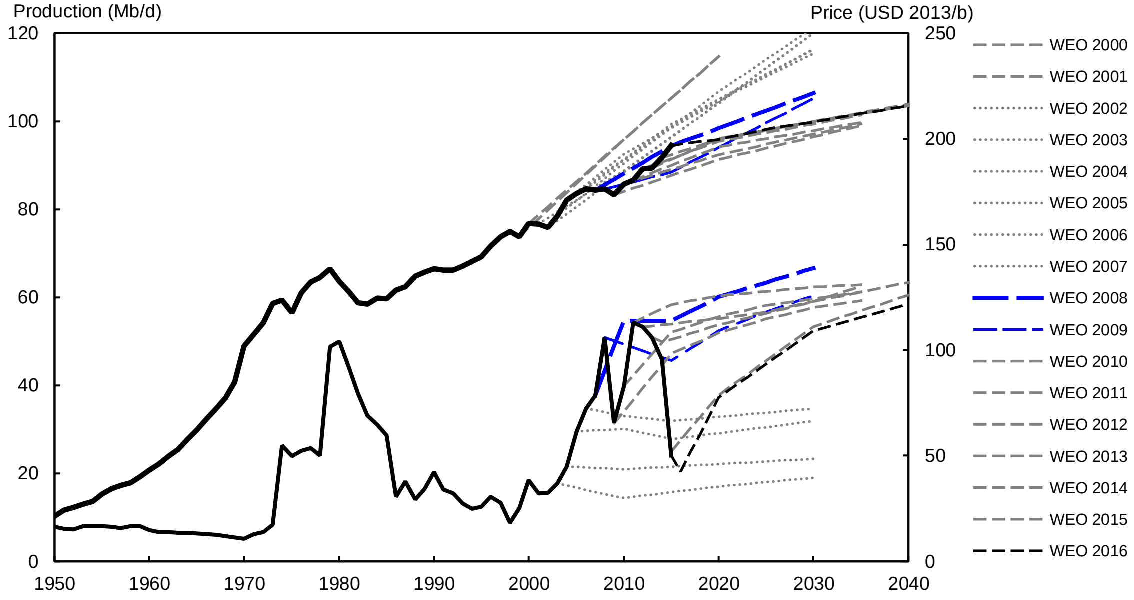

Figure 11: Historical development and projections of oil prices (bottom lines) and historical world oil production and projections (top lines) by the World Energy Outlook (WEO) published by the International Energy Agency (IEA), according to Wachtmeister et al. (2018)

Although oil-exporting countries have provided the best oil price projections in the past, institutional price projections have become increasingly accurate, with the IEA leading the way in 2018 (Roland Berger 2018)[30]. An evaluation of the oil price projections of the IEA since 2000 by Wachtmeister et al. (2018)[31] 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%–

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[27] 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.

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

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

[30] Roland Berger (2018) 2018 oil price forecast: who predicts best? Roland Berger study of oil price forecasts. https://www.rolandberger.com/en/Publications/pub_oil_price_forecast_2015.html. Accessed 10.9.2018 2018.

[31] 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

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[32]; Rubin et al. 2015[33]). Therefore, the reliability of cost projections largely depends on the uncertainty of future markets and the availability of historical data.

Fossil fuel technologies provide a large cost 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, also cost assumptions must be made with particular care.

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

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

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[32] 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

[33] 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)[34], which were based on a variety of studies, including the European Commission-funded NEEDS project (NEEDS 2009), projections of the European Renewable Energy Council (Zervos et al. 2010)[35], investment cost projections by the IEA (IEA 2014), and current cost assumptions by IRENA and IEA (IEA 2016c). We found that investment costs generally converged, except for PV. Therefore, for consistency, the power sector's investment and operation and maintenance costs are based primarily on the investment costs within WEO 2016 (IEA 2016c) up to 2040, including their regional disaggregation. We extended the projections until 2050 based on the trends in the preceding decade.

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)[36], 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 15 summarizes the cost trends for power technologies derived from the assumptions discussed above for Kenya. It is important to note that the cost reductions are not a function of time but of cumulative capacity (production of units), so dynamic market development is required to achieve a significant reduction in specific investment costs. Therefore, overall, we might underestimate the costs of renewables in the REFERENCE scenario compared with the *With the Existing Measures* (WEM) scenario and the K-1.5C pathway (see below).

However, our approach is conservative when we compare the REFERENCE scenario with the more ambitious renewable energy scenarios under identical cost assumptions. Fossil-fuel power plants have limited potential for cost reductions because they are at advanced stages of 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.

Table 15: Investment cost assumptions for power generation plants US Dollars (US$) and the local currency (KES/kW) by kW until 2050

Assumed Investment Costs for Power Generation Plants										
	2020		2025		2030		2040		2050	
Technology	[US$/kW]	[KES/kW]	[US$/kW]	[KES/kW]	[US$/kW]	[KES/kW]	[US$/kW]	[KES/kW]	[US$/kW]	[KES/kW]
Coal power plants	2,018	302,666	2,018	302,666	2,018	302,666	2,018	302,666	2,018	302,666
Diesel generators	908	136,200	908	136,200	908	136,200	908	136,200	908	136,200
Gas power plants	504	75,667	504	75,667	504	75,667	504	75,667	676	101,393
Oil power plants	938	140,740	918	137,713	898	134,686	865	129,768	827	124,093
Conventional Renewables										
Hydropower plants*	2,674	401,033	2,674	401,033	2,674	401,033	2,674	401,033	2,674	401,033
New renewables										
PV power plants	989	148,306	744	111,656	736	110,473	565	84,746	474	71,127
Onshore Wind	1,594	239,106	1,559	233,810	1,523	228,513	1,463	219,433	1,412	211,866
Offshore Wind	3,723	558,419	3,097	464,592	2,472	370,766	2,295	344,283	2,119	317,799
Biomass power plants	2,371	355,633	2,346	351,849	2,320	348,066	2,220	332,933	2,129	319,313

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

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[34] 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.

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

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

2.7.2 HEATING TECHNOLOGIES

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

Our cost assumptions are based on a previous survey of renewable heating technologies in Europe, which focused on solar collectors, geothermal energy, heat pumps, and biomass applications. Biomass and simple heating systems in the residential sector are already mature. However, more-sophisticated technologies that can provide higher shares of heat demand from renewable sources are still under development and rather expensive. Market barriers will slow the further implementation and cost reductions 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 16 presents the investment cost assumptions for heating technologies, disaggregated by sector. Geothermal heating shows the same high costs in all sectors. In Europe, deep geothermal applications are being developed for heating purposes at investment costs ranging from €500/kW$_{\text{thermal}}$ (shallow) to €3000/kW$_{\text{thermal}}$ (deep), with the costs strongly dependent on the drilling depth. The cost reduction potential is assumed to be around 30% by 2050. No data are available for the specific situation in Kenya. However, geothermal power and heating plants are not assumed to be built under any scenario.

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

We assume the appropriate differences between the sectors for biomass and solar collectors. There is a broad portfolio of modern technologies for heat production from biomass, ranging from small-scale single-room stoves 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 range from US$500–1300/kW, and large biomass heating systems are assumed to reach their cheapest cost in 2050 at around US$480/kW for industry. For all sectors, we assume a cost reduction of 20% by 2050.

In contrast, solar collectors for households are comparatively simple and will become cheap, at US$680/kW, by 2050. The costs of simple solar collectors for service water heating might have been optimized 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 16: Specific investment cost assumptions (in US$2015) for heating technologies in the scenarios until 2050

Investment Costs for Heat Generation Plants									
		2020		2030		2040		2050	
		[US$/kW]	[KES/kW]	[US$/kW]	[KES/kW]	[US$/kW]	[KES/kW]	[US$/kW]	[KES/kW]
Solar collectors	Industry	820	123,000	730	109,500	650	97,500	550	82,500
	In heat grids	970	145,500	970	145,500	970	145,500	970	145,500
	Residential	1,010	151,500	910	136,500	800	120,000	680	102,000
Geothermal		2,270	340,500	2,030	304,500	1,800	270,000	1,590	238,500
Heat pumps		1,740	261,000	1,640	246,000	1,540	231,000	1,450	217,500
Biomass heat plants		580	87,000	550	82,500	510	76,500	480	72,000
Commercial biomass heating systems	Commercial scale	810	121,500	760	114,000	720	108,000	680	102,000
Residential biomass heating stoves	Small scale / Rural	110	16,500	110	16,500	110	16,500	110	16,500

2.7.3 RENEWABLE ENERGY COSTS IN KENYA IN 2021

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

Table 17: Solar Home Systems – estimated costs

Solar Home Systems	[KES]	[$]	[US$/$kW_{peak}$]
10 W	6,900	46	4,572
20 W	12,900	86	4,322
50 W	23,850	159	3,186
55 W	25,950	173	3,152
60 W	27,600	184	3,059
80 W	31,500	210	2,629
100 W	37,500	250	2,495
Institutional Solar Power Systems	[KES]	[$]	[US$/$kW_{peak}$]
1000 W	341,550	2,277	2,277
2000 W	572,400	3,816	1,908

Source: UTS/ISF own research, March 2023

Table 18:Solar Dryer – estimated costs

Solar Dryers [1 sqft = 0.0929 m^2]	[KES]	[$]	[US$/$m^2$]
3–6 sqft (household) [	38,700	258	617
10–15 sqft (household)	87,900	586	505
> 21 sqft (institutional)	135,900	906	464

Source: UTS/ISF own research, March 2023

Table 19: Solar Cooker – estimated costs

Solar Cookers	[KES]	[$]
Parabolic—household	29,400	196
Parabolic—institutional	180,000	1,200

Source: UTS/ISF own research, March 2023

Table 20: Biomass stoves – estimated costs

Biomass Stoves	[KES]	[$]
Institutional improved stove—type 1	58,350	389
Institutional improved stove—type 2	61,200	408
Institutional improved stove—type 3	72,750	485
Natural draft stove	5,250	35
Forced draft stove	10,650	71
Improved metallic stove	14,550	97

Source: UTS/ISF own research, March 2023

2.7.4 FUEL COST PROJECTIONS

Fossil Fuels

Although fossil fuel price projections have seen considerable variations, as described above, we based our fuel price assumptions up to 2040 on *World Energy Outlook 2023* (IEA 2023). Beyond 2040, we extrapolated the price developments between 2035 and 2040 and present them in Table 27. Although these price projections are highly speculative, they provide prices consistent with our investment assumptions.

Table 21: Development projections for fossil fuel prices in US$2015 based on World Energy Outlook 2023 (STEPS) (IEA 2023)

Development Projections for Fossil Fuel Prices										
All Scenarios	2019		2025		2030		2040		2050	
	[US$/GJ]	[KES/GJ]	[US$/GJ]	[KES/GJ]	[US$/GJ]	[KES/GJ]	[US$/GJ]	[KES/GJ]	[US$/GJ]	[KES/GJ]
Oil	8.5	1,275	12	1,800	11	1,650	10	1,500	10.5	1,575
Gas	9.8	1,470	20	3,000	10	1,500	11	1,650	12	1,800
Coal	3.2	480	3.5	525	4	600	3.8	570	3.5	525

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)[37] 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.[37] 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 Kenya in 2021

Table 22: Biogas prices—small quantities—in Kenya by region

Biogas	2 m^3		4 m^3		6 m^3		8 m^3	
	[KES]	[$]	[KES]	[$]	[KES]	[$]	[KES]	[$]
Household— low cost assumption	61,650	411	88,050	587	101,400	676	113,400	756
Household— average cost	72,150	481	97,050	647	112,275	749	122,475	817
Household— high cost assumption	82,650	551	106,050	707	123,150	821	131,550	877

Source: UTS/ISF own research – March 2023

Table 23: Biogas prices—medium quantities—in Kenya by region

Biogas	12.5 m^3		40 m^3		60 m^3		100 m^3	
	[KES]	[$]	[KES]	[$]	[KES]	[$]	[KES]	[$]
Household— low cost assumption	325,650	2,171	938,250	6,255	1,245,600	8,304	1,816,800	12,112
Household— average cost	356,475	2,377	996,150	6,641	1,433,250	9,555	2,088,225	13,922
Household— high cost assumption	387,300	2,582	1,054,050	7,027	1,620,900	10,806	2,359,650	15,731

Source: UTS/ISF own research – March 2023

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[37] 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 Kenya: Renewable Energy Potential

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

3.1 THE [R]E SPACE METHODOLOGY

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

The [R]E Space methodology is part of the One Earth Climate Model (OECM) methodology to map solar energy potential and onshore energy potential. Open-source data and maps from various sources were collected and processed to visualize the country, its regions, and districts. Further demographic data related to the population and poverty were plotted on the maps together with transmission networks and power plants. The main data sources and assumptions made for this mapping are summarized in Table 24.

Table 24: Kenya—[R]E 24/7—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[38]
Digital Elevation Model (DEM)	For both wind and solar analyses, any land with a slope of > 30% was excluded from all scenarios.	SRTM Digital Elevation Data Version 4 [39]
Population and Population Density	A population census was conducted in 2019 by the Kenya National Bureau of Statistics (KNBS), and a preliminary report is available.	Kenya National Bureau of Statistics (KNBS)
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 [40]
Power Plants, Transmission Lines, and Network	Solar and wind potential of areas ≤ 10 km from transmission lines was considered (Scenario 2).	Kenya Electricity Network 2020 / Kenya Power and Lighting Company / The World Bank[41]
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 [42]
Wind Speeds	Wind speeds ≥ 5 m/s were considered at a height of 100 m.	Global Wind Atlas [43]

The [R]E Space mapping procedure is summarised in Figure 12. The land areas available for potential solar and wind power generation were calculated and visualized at the national and provincial levels using ArcGIS. The land-cover map, elevation (digital elevation model: DEM), World database of protected areas, solar irradiation (direct normal irradiation: DNI) and wind speed data were obtained from the website cited above as raster data, and were all 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 24, and then combined into one binary map by overlaying all the raster data. This map integrates all the criteria listed cited above in one map with a value of 1 (land included in the potential area) or a value of 0 (land not included in the potential area).

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[38] Copernicus Global Land Cover – 2019: https://land.copernicus.eu/global/products/lc
[39] SRTM Digital Elevation Data Version 4: https://srtm.csi.cgiar.org/
[40] World Database on Protected Areas: https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA
[41] Kenya – Power Stations (2017): https://energydata.info/dataset/kenya-kenya-electricity-network, Kenya - Primary Substations (2020): https://energydata.info/dataset/kenya-primary-substations, Kenya - Kenya Electricity Network (2020): https://energydata.info/dataset/kenya-kenya-electricity-network
[42] Global Solar Atlas: https://globalsolaratlas.info/map
[43] 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 area in the integrated raster data using a mask layer generated from the 'erase' function. For scenario 2 (see Figure 21), 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 Kenya, and the potential provided is a conservative estimate and may ultimately be larger.

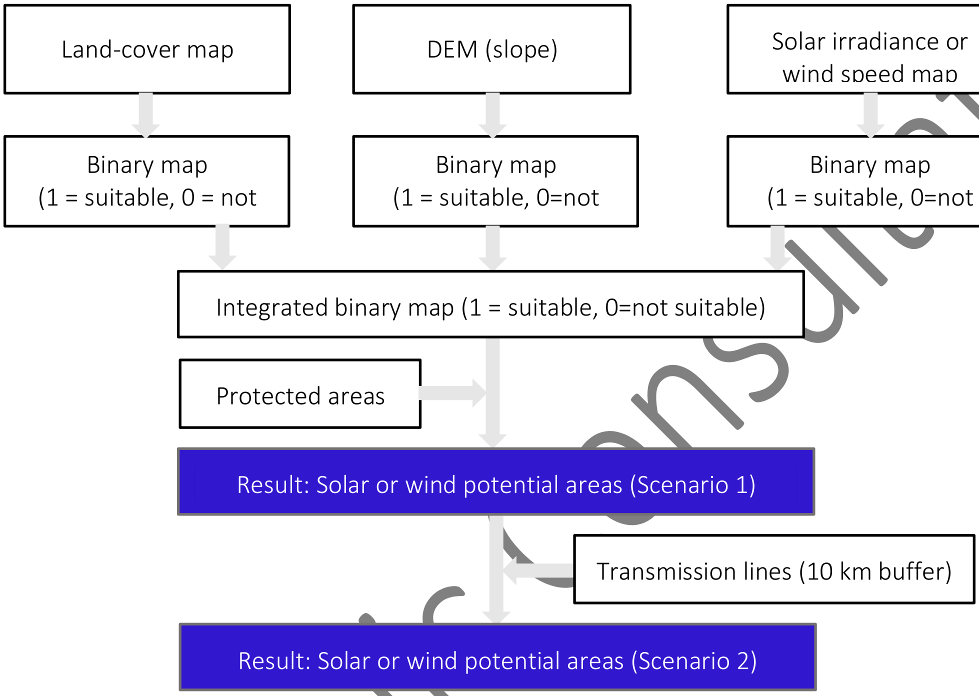

Figure 12: [R]E Space Methodology—solar potential analysis and wind potential analysis

3.2 MAPPING METHODOLOGY FOR OFFSHORE WIND

Offshore wind energy potential is also mapped for two scenarios for Kenya. The open-source data and maps from various sources were collected and processed to visualize the offshore potentials.

Table 25: Kenya—Offshore wind —GIS-mapping—data sources

Data	Assumptions	Source
Gridded Bathymetry Data - Water depth	For offshore wind map, two scenarios are generated: areas with water depth > 50m and areas with water depth > 500m were excluded from all scenarios.	GEBCO_2023 Grid [44]
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
Ports	100km radius from ports are marked on the map.	World Port Index 2019[45]
Maritime boundaries		Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM) (Version: 11)[46]
Wind Speeds	Wind speeds ≥ 6 m/s were considered at a height of 100 m.	Global Wind Atlas

The mapping procedure for offshore wind potential involved gridded bathymetry data or water depth, World database of protected areas for marine and costal protected areas, and wind speed data (≥6m). Similar to [R]E Space methodology, all data 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 25, and then combined into one binary map by overlaying all the raster data. Data from World Port Index 2019 was used to map the location of ports and its 100km radius.

3.3 MAPPING KENYA

Kenya has large untapped potential for renewable energy and over 80% of Kenya's electricity is generated from renewable sources in 2021. Geothermal remains the most significant source supplying 41 % of the country's electricity in 2021, followed by Hydro (30%)[47]. Wind produced (16%) comes the third place, being counted 1.2TWh in 2020, while solar PV produced less than 1% of the electricity [47].

3.3.1 SOLAR POTENTIAL

The average annual solar irradiation (DNI) level in Kenya is 746 – 2,366 kWh/m^2 per day, and the higher end of that range is in the western part of the country.
Kenya's solar potential has been mapped under two different scenarios.

Scenario 1. Available land—excluding protected areas (PA), extreme topography (slope > 30% (mountainous areas, S30), and certain land-cover classes, including closed forests, wetlands, moss and lichen, snow and ice, and water (permanent water bodies) (LU).

Scenario 2. See 1, with additional restriction that excludes areas ≤ 10 km from existing transmission lines (PT10).

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[44] GEBCO_2023 Grid: https://www.gebco.net/data_and_products/gridded_bathymetry_data/

[45] World Port Index 2019: https://msi.nga.mil/Publications/WPI

[46] Maritime Boundaries Geodatabase: http://comlmaps.org/how-to/layers-and-resources/boundaries/maritime-boundaries-geodatabase/

[47] U.S. International Trade Administration. (2022). Kenya - Country Commercial Guide. https://www.trade.gov/country-commercial-guides/kenya-energy-electrical-power-systems

Table 26: Kenya’s potential for solar photovoltaic

Scenarios	1. LU + PA + S30		2. LU + PA + S30 + PT10	
Regions	Solar Potential Area (km^2)	Solar Potential (GW)	Solar Potential Area (km^2)	Solar Potential (GW)
1. South Coast	59,165	1,479	21,015	525
2. North Coast	122,068	3,052	3,396	85
3. Northern	75,198	1,880	2,393	60
4. Eastern Central	41,102	1,028	33,909	848
5. Central	9,498	237	8,937	223
6. North Western	86,802	2,170	9,411	235
7. Western Central	55,532	1,388	42,464	1,062
8. Lake Zone	18,864	472	18,721	468
TOTAL	**468,229**	**11,706**	**140,247**	**3,506**

Figure 13 shows the results of a spatial analysis indicating the solar potential areas under Scenario 1 (LU + PA + S30). The scenario provides 468,229 km^2 of areas with solar potential and a total potential for utility-scale solar PV capacity of 11,706GW. Scenario 1 excludes all protected areas and areas with slopes > 30%, because installing solar panels in steep mountainous areas is unrealistic. Open forests, shrubs, herbaceous vegetation, bare/spare vegetation, agricultural land, and urban/built-up land-cover classes in the Copernicus Global Land Cover 2019 dataset (Buchhorn et al., 2020) are included. However, certain land-cover classes (e.g., closed forests, wetlands, water bodies, snow and ice) are excluded in the scenarios selected for the consideration of solar energy potential.

Figure 14 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 140,247 km^2. This is because most electricity and road infrastructure is currently developed in the south-western region of the country (i.e. Central, Eastern Central, Western Central, and Lake Zone). Under Scenario 2, utility-scale solar farms in Kenya can potentially harvest 3,506 GW of solar PV.

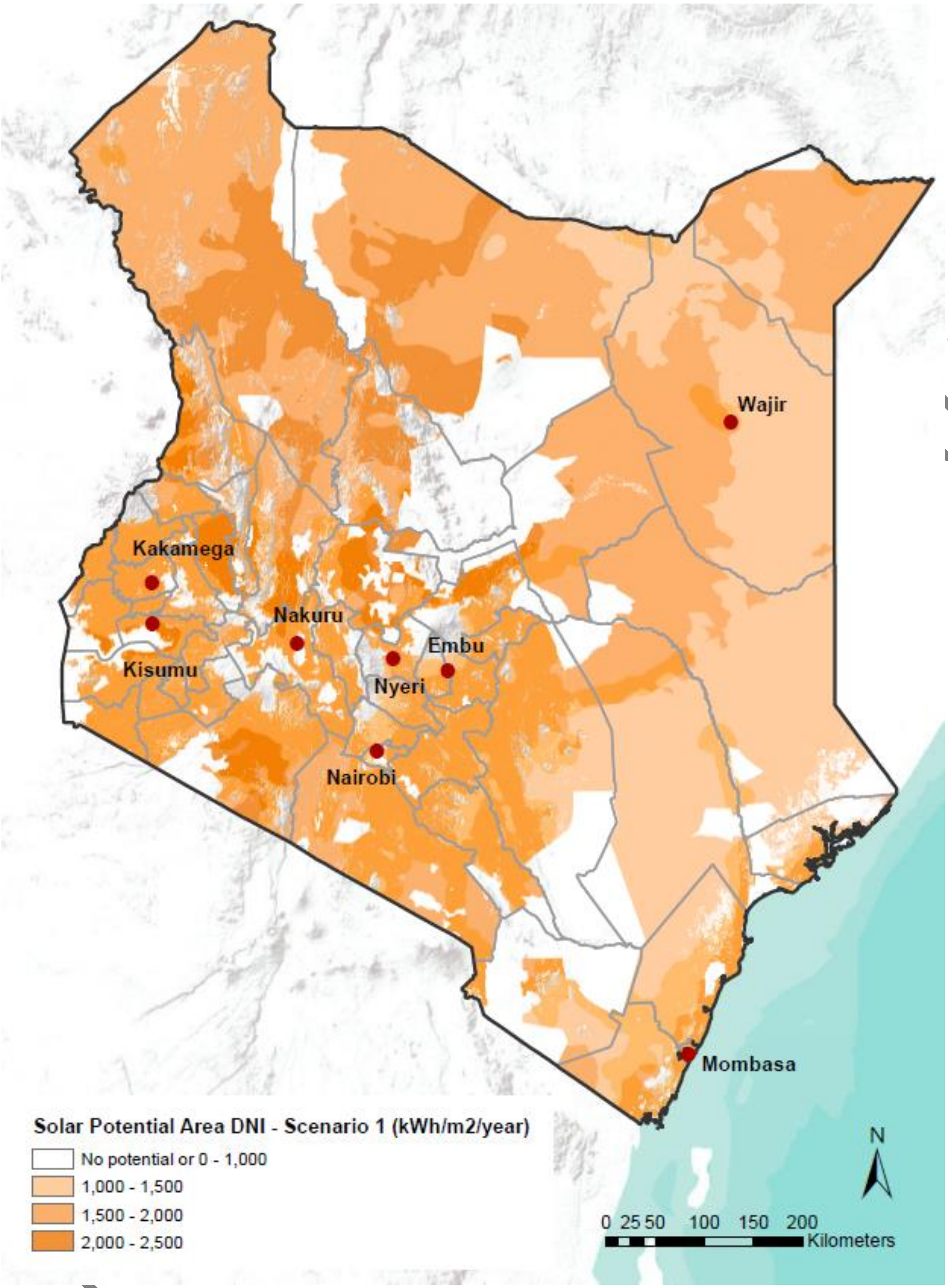

Figure 13: Kenya—Solar Potential Areas (Scenario 1: LU + PA + S30)

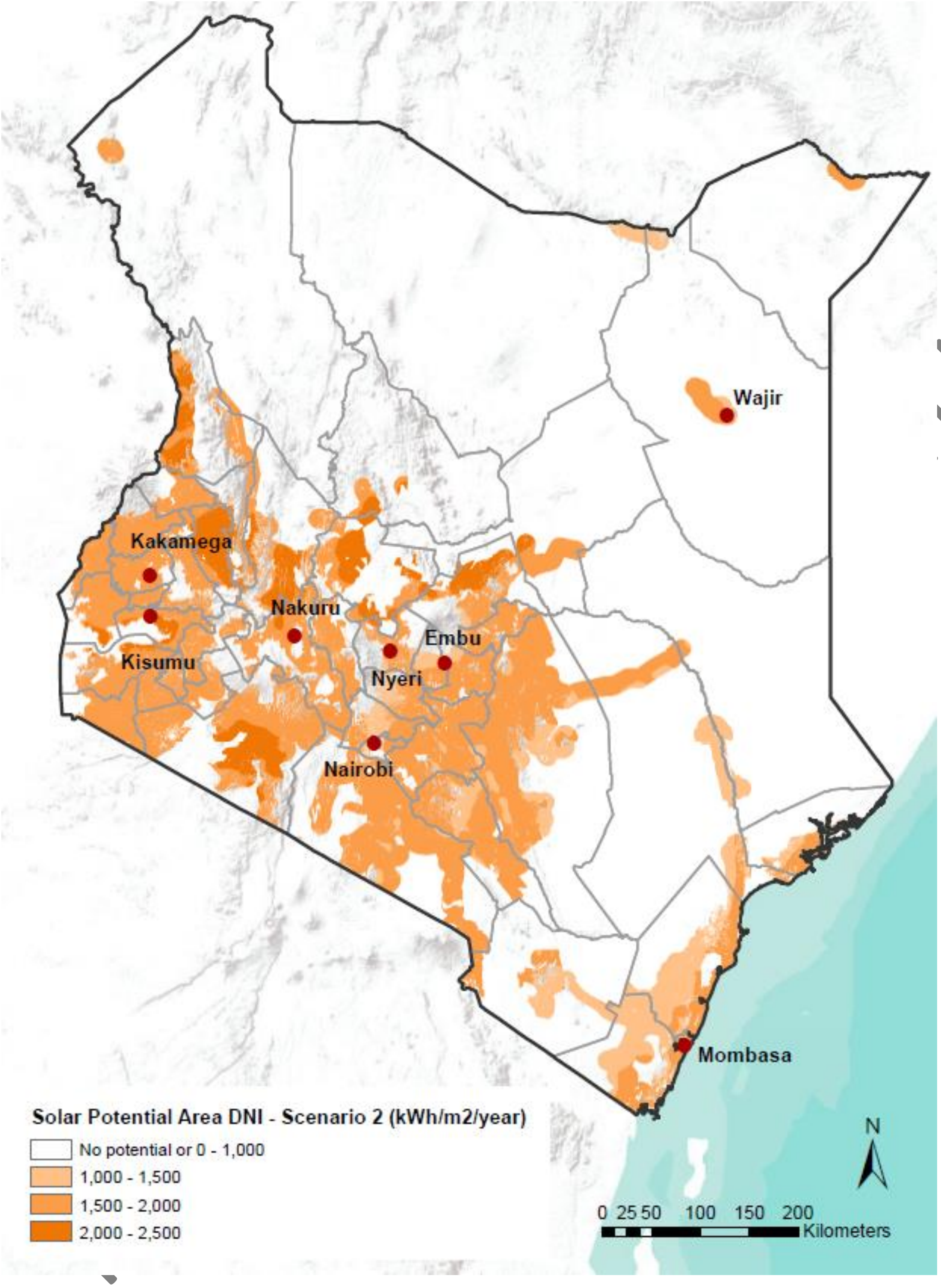

Figure 14: Kenya—Solar Potential Areas (Scenario 2: LU + PA + S30 + PT10)

3.3.2 ONSHORE WIND POTENTIAL

The overall onshore wind resources on land are significantly lower in Kenya compared with the solar potential. The wind speeds in Kenya range from 0.9 to 20.6 m/s at 100 m height, and high-wind-speed areas are predominantly located in the mid-northern region (Global Wind Atlas). In this analysis, we have included only areas with an average annual wind speed of ≥ 5 m/s. Kenya's wind potential has been mapped under two different scenarios. The current use of wind energy in Kenya involves utility scale wind turbines in the range up to 10 kilowatts, operated both on- and off-grid as battery chargers.

'Scenario 1': Available land—restricted by protected areas (PA), topography (slope > 30% [mountain areas], S30), and existing land use, including forests and urban areas (LU).

'Scenario 2': See 1, with the additional restriction excluding areas ≤ 10 km from existing transmission lines (PT10).

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

Table 27 shows that the overall total wind potential under all restrictions is 1,635GW for Scenario 1. Overall, the spatial analysis identified slightly limited wind potential in Kenya, especially under Scenario 2 (270GW), because there are limited areas with an annual wind speed of ≥ 5 m/s and most of these areas are not located within close proximity to transmission lines (≤ 10 km).

Table 27: Kenya's potential for utility-scale onshore wind power

Scenarios	1. LU + PA + S30		2. LU + PA + S30 + PT10	
Regions	Onshore Wind Area (km^2)	Onshore Wind Potential (GW)	Onshore Wind Area (km^2)	Onshore Wind Potential (GW)
1. South Coast	54,785	274	18,560	93
2. North Coast	119,782	599	2,768	14
3. Northern	70,861	354	2,119	11
4. Eastern Central	15,061	75	10,516	53
5. Central	1,977	10	1,861	9
6. North Western	42,372	212	1,344	7
7. Western Central	21,063	105	15,755	79
8. Lake Zone	1,008	5	1,008	5
TOTAL	**326,908**	**1,635**	**53,930**	**270**

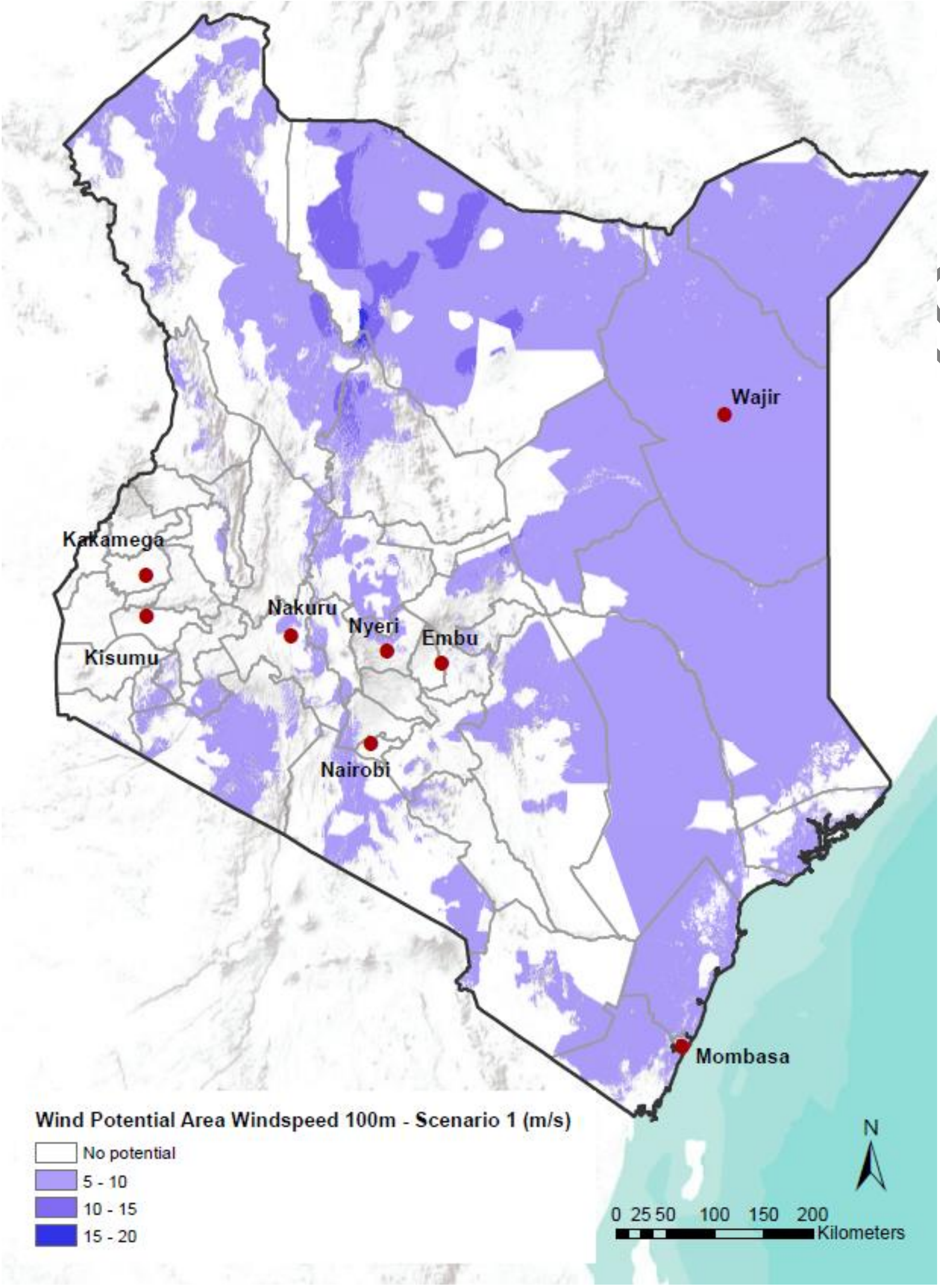

Figure 15: Kenya—Onshore Wind Potential Areas (Scenario 1: LU + PA + S30

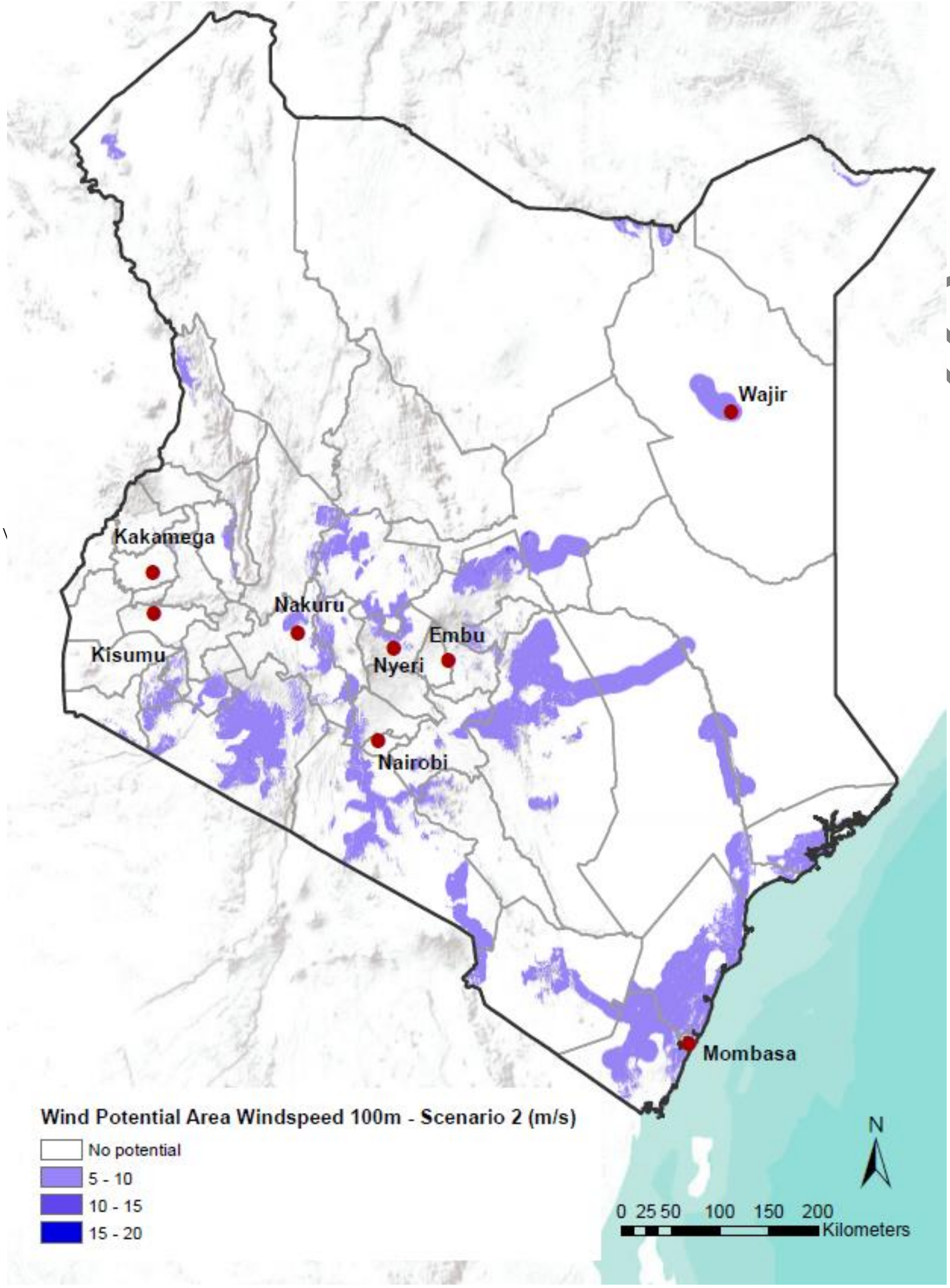

Figure 16: Kenya—Onshore Wind Potential Areas (Scenario 2: LU + PA + S30 + PT10)

3.3.3 OFFSHORE WIND POTENTIAL

The wind speeds in the offshore areas in Kenya range from 4.9 to 7.6 m/s at 100 m height. For offshore wind analysis, we have included areas with an average annual wind speed of ≥ 6 m/s, as offshore wind projects usually require higher wind speed than onshore wind due to its economic viability. Kenya's wind potential has been mapped under two different scenarios.

'Scenario 1': Available offshore areas—restricted by protected areas (PA), and water depth (≤50m, WD50) (PA + WD50).

'Scenario 2': Available offshore areas—restricted by protected areas (PA), and water depth (≤500m, WD50) (PA + WD500).

The overall total offshore wind potential is 2,408 MW (2.4 GW) for Scenario 1 and 3,383 MW (3.4 GW) for Scenario 2. Figure 17 and 18 show the offshore wind potential areas for Scenario 1 and Scenario 2.

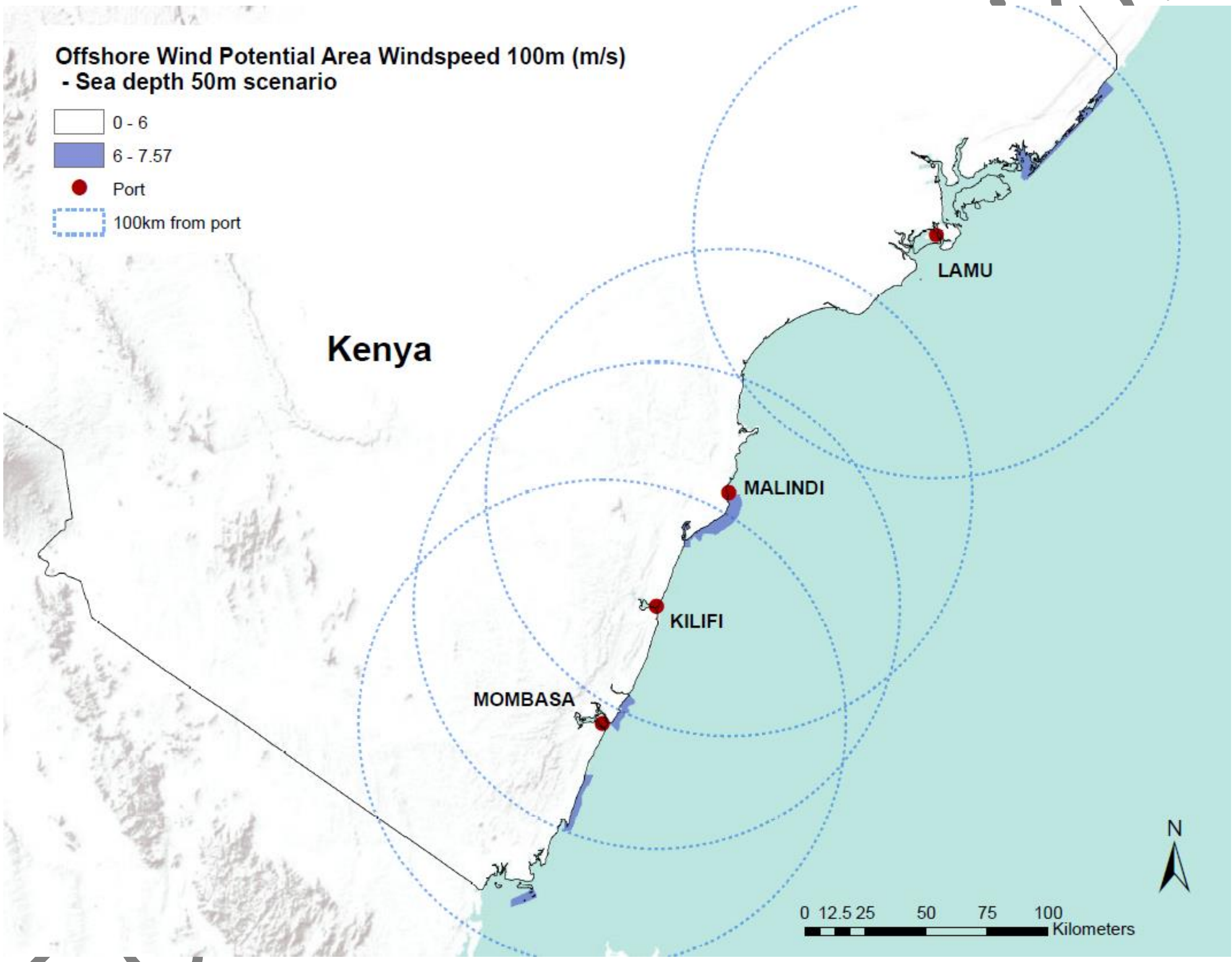

Figure 17: Kenya's offshore wind potential – Scenario 1

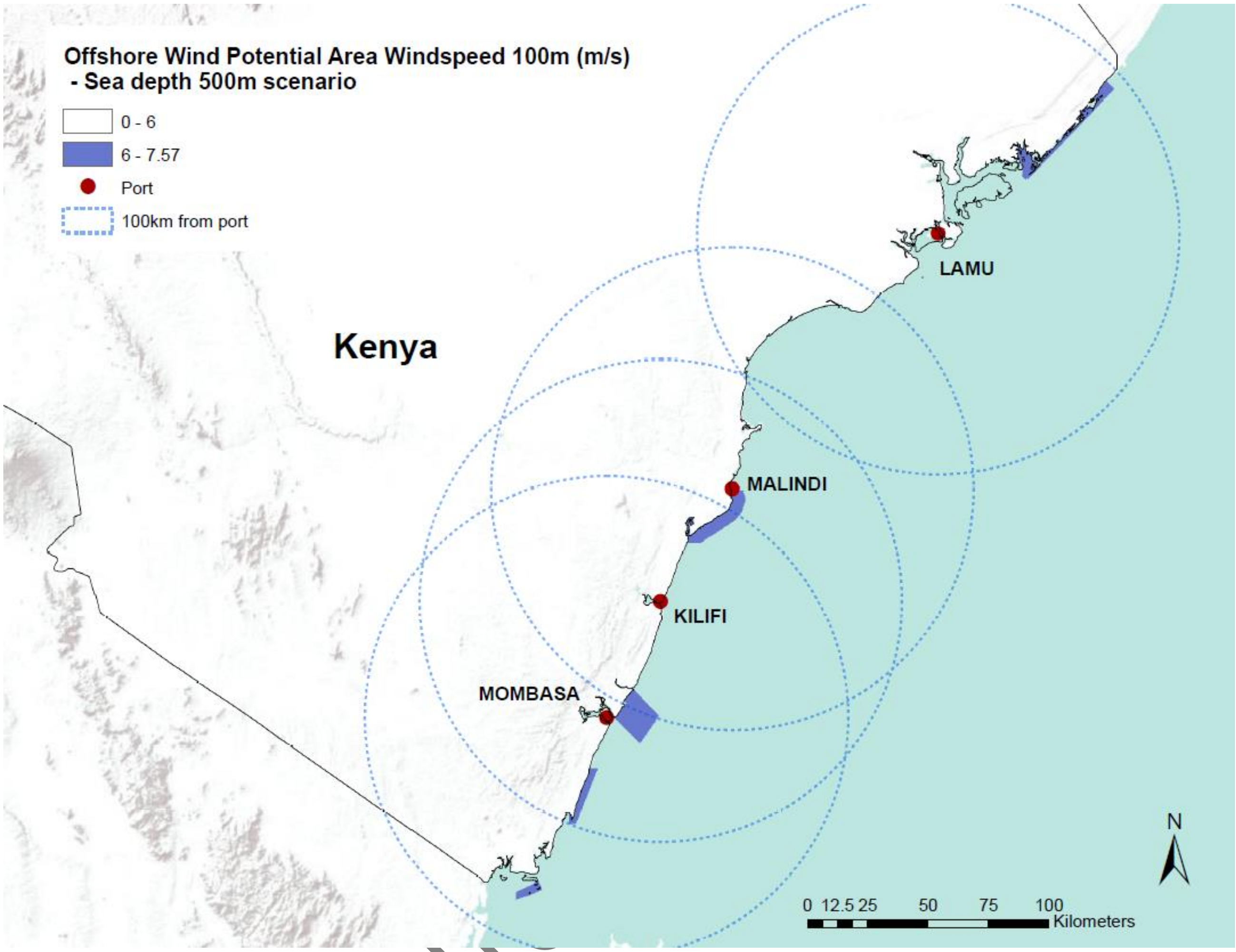

Figure 18: Kenya's offshore wind potential – Scenario 2

Main challenge for utility-scale solar PV is the availability of land and policy stability

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

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

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

3.3.4 ASSUMPTIONS FOR HYDROGEN AND SYNFUEL PRODUCTION

In the Kenya 1.5 °C (K-1.5C) 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, producing an additional electricity demand that will be supplied by extra renewable power production capacity, predominantly solar PV and hydropower. Renewable hydrogen and synthetic fuels are essential for a variety of sectors.

- In the industry sector, hydrogen is an additional renewable fuel option for high-temperature applications, supplementing biomass in industrial processes whenever the direct use of renewable electricity is not applicable.
- The transport sector will also rely increasingly on hydrogen as a renewable fuel, where battery-supported electric vehicles reach their limits and where limited biomass potential restricts the extension of biofuel use. However, future hydrogen applications may be insufficient to replace the whole fossil fuel demand, especially in aviation, heavy-duty vehicles, and navigation. The K-1.5C 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 meet with biofuels because their potential is limited.

4 Areas of Forest Loss in Kenya

The Food and Agriculture Organization of the United Nations (FAO) is a specialized agency that leads international efforts to abolish hunger and improve nutrition and food security. The FAO has published extensive food production data and other data related to agriculture and forestry. According to the FAO[48], the forest area in Kenya in 2020 was 36,111 km^2 (including 34,583 km^2 of naturally regenerated forest), which is a 6.4 % decrease from 1990 and a 8.8% decrease from 2000, respectively. These increases resulted in negative carbon emissions from the forest sector (Table 28).

Table 28: Extent of forest areas and net emissions from forested land in Kenya (FAO)

	Extent of Forest	
Year	Areas (km^2)	Change from 1990
1990	38,585	-
2000	39,612	2.7 %
2010	36,163	-6.3%
2020	36,111	-6.4%

Source: Extent of forest (FAO Global Forest Resources Assessment Country Reports 2020); Net emissions / removals (FAOSTAT)

Global Forest Change also reported that between 2001 to 2021 Kenya has lost 3,684 km2 of tree cover (equivalent to 11% decrease in tree cover since 2000) which generated 180 Mt of CO_2e emissions. This includes loss of 498 km^2 of humid primary forest between 2002 to 2021, and forest has been cleared mostly with the expansion of agricultural during that period[49]. The loss of forest areas in Kenya were also visualized with ArcGIS. The spatial dataset by Hansen et al. (2013) was used to highlight forest loss (2001–2021) using ArcGIS (Figure 19). Areas of forest loss are mostly found in southeast regions (e.g. Baringao, Nakuru, Nandi, Kericho, and Narok) and coastal areas (e.g. Kwale, Kilifi, Lamu). Table 29 shows the areas of forest loss (km^2), which were also estimated from Hansen et al.[50] together with the estimated CO2e emissions since 2000 (the baseline year of this dataset).

Table 29: Kenya—areas of forest loss (km^2) 2001–2019) and estimated CO2e emissions from the forest loss

Years	Area (km^2)	CO_2e emissions (kilotonnes)
2001–2005	826	38,684
2006–2010	1,064	49,837
2011–2015	797	40,335
2016–2021	997	51,708
TOTAL areas of forest loss (2001–2021)	3,684	180,564

Source: Global Forest Change.

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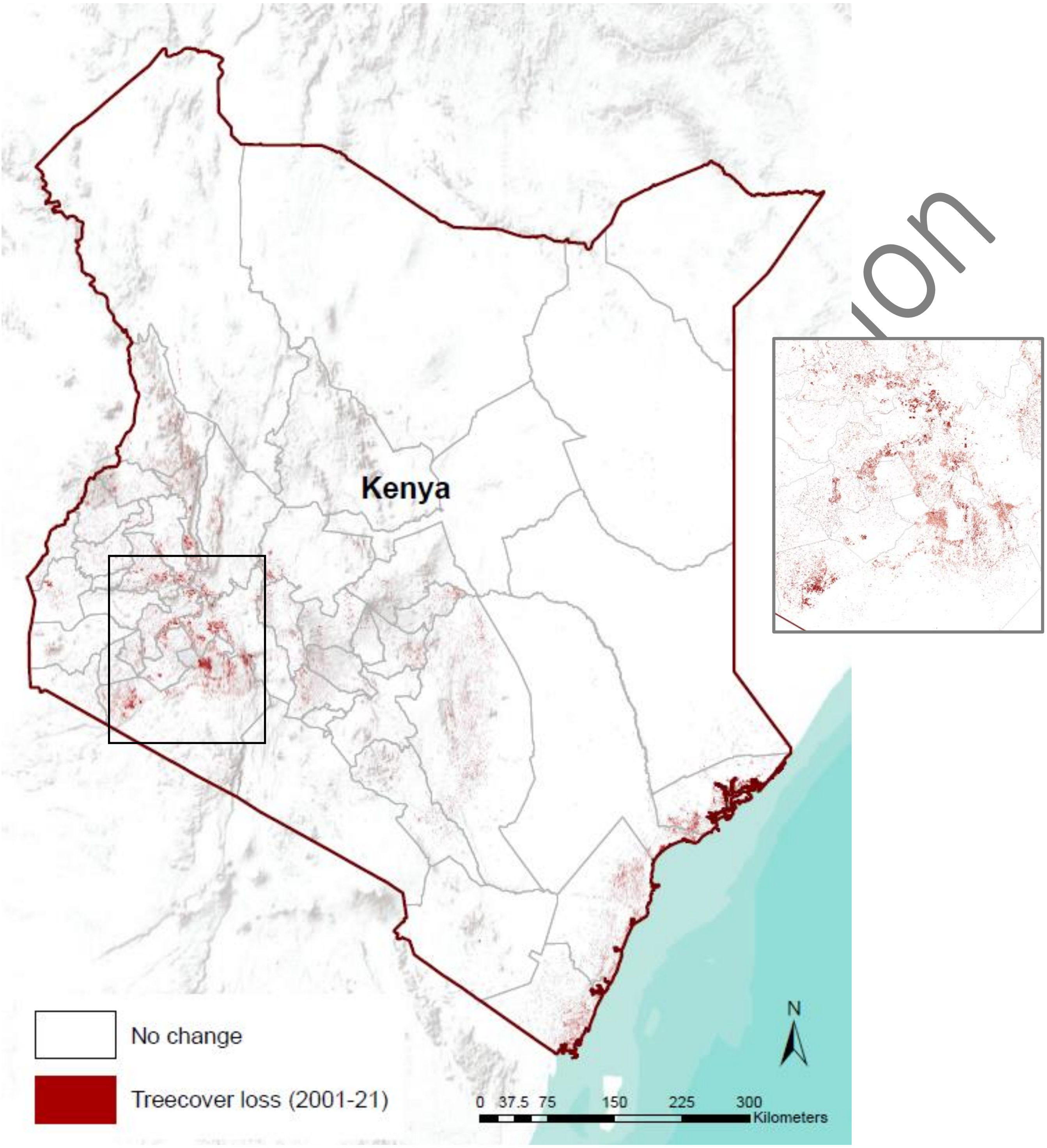
[48] FAO Global Forest Resources Assessment 2020 (Kenya): https://www.fao.org/3/cb0019en/cb0019en.pdf

[49] Global Forest Change (Kenya): https://www.globalforestwatch.org/dashboards/country/KEN/?map=eyJjYW5Cb3VuZCI6dHJ1ZX0%3D

[50] Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850-53. Data available on-line at: https://glad.earthengine.app/view/global-forest-change.



Source: generated ISF using data from Hansen et al 2013

Figure 19: Areas of forest loss in Kenya 2001–2021)

5 Key Results—Long-term Scenario

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

With lower solar PV and onshore wind prices, renewables have become an economic alternative to building new hydro- and gas power plants. Consequently, renewables achieved a global market share of over 80% of all newly built power plants in 2021[51]. Kenya 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 role of future energy utilities, centralized fossil-fuel-based power generation, population and GDP, firm capacity, and future costs.

- **Policy stability:** This research assumes that Kenya 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, which 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 maximize 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*[52]
- **Firm capacity:** The scale of each technology deployed and the combination of technologies in the three scenarios target the firm capacity. Firm capacity is the "proportion of the maximum possible power that can reliably contribute towards meeting the peak power demand when needed."[53] Firm capacity is important to ensure a reliable and secure energy system. Note that variable renewable energy systems still have a firm capacity rating, and the combination of technology options increases the firm capacity of the portfolio of options (see also the 'security of energy supply' point in the REFERENCE scenarios).
- **Cost assumptions:** The cost assumptions are documented in Section 2.

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[51] REN21 – Global Status report 2021.
[52] World Bank, (2023), Reviewed on: https://data.worldbank.org/indicator/SP.POP.TOTL
[53] http://igrid.net.au/resources/downloads/project4/D-CODE_User_Manual.pdf

5.1 THE REFERENCE SCENARIO

There are a few energy and / or electrification plans for Kenya available.

Thus, the One Earth Climate Model builds on existing information. Table 31 provides an overview to the published energy scenarios and / or energy plans including the National Determined Contribution (NDC). In order to compare the One Earth Climate Model for Kenya, a new reference has been developed as a direct comparison with published energy plans is not possible due to the different sectorial breakdown and technical resolutions.

Table 30: Kenya – literature review published energy scenarios and parameters

	Kenya - Parameter	Analysis		
Nr.	Key graphs made from our own modelling results:	One Earth Climate Model	Info IEA, Africa Energy Outlook 2019 1. Stated policy scenario 2. Africa case	Kenya: National Determined Contribution (NDC)
1.	Final Energy demand until 2050, split by sector (Transport, Industry, Residential)	yes	Only 2018 and 2040 numbers	
2.	Development Electricity demand until 2050m TWh/a (Transport, Industry, Residential)	yes	Yes	
3.	Heat demand final energy [PJ/a] until 2050, (Industry, Residential)	yes	No	
4.	Development road transport final energy [PJ/a] until 2050 (Road passenger, freight passenger)	yes	No	
5.	Breakdown of electricity generation capacity [GW] until 2050 (split by source PV, wind, biomass, hydrogen, fossil fuels)	yes	No	
6.	Energy supply cooking heat supply [PJ/a] until 2050 (split by source of solar collectors, heat pumps, electric direct heating etc.etc)	yes	Only 2018 and 2030 numbers	
7.	Installed capacity renewable heat generation [GW] until 2050 (split by source)	yes	No	
8.	Transport energy supply by energy source [PJ/a] until 2050 (split by elec., hydrogen, natural gas, synfuels, biofuels, fossil)	yes	No	
9.	Total primary energy demand by energy source [PJ/a] until 2050 (split by wind , solar , etc)	yes	Yes	
10.	Co2 emissions per sector [Mt/a] until 2050 (Industry, Buildings, Transport, Power generation, Other)	yes	No	30%-32% emission reduction by 2030 to 143 Mt CO2e
11.	Investment cost [billion $/a] until 2050	yes	No	
12.	Shares of cumulative investment in power generation 2020-2050	yes	Yes, cumulative investment of 2019 – 2040, for fuels, heating, but also networks	
13.	Cumulative investment heating technologies 2020-2050	yes	No	
14.	Installed PV capacities up to 2050	yes	No	

5.1.1 ASSUMPTIONS FOR THE KENYA 1.5 °C SCENARIO

The Kenya 1.5 °C (K-1.5C) 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 K-1.5C 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 potential, costs, and recent trends in renewable energy deployment. Communities will play a significant role in the expanded use of renewables, particularly in terms of project development, the inclusion of the local population, and the operation of regional and/or community-owned renewable power projects.
- **Fossil -fuel phase-out:** The operational lifetime of gas power plants is approximately 30 years. In both scenarios, coal power plants will be phased out early, followed by gas power plants.
- **Future power supply:** The capacity of large hydropower remains relatively flat in Kenya 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 the 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:** Kenya's sustainable level of biomass use is assumed to be limited to 830 PJ—precisely the amount of bioenergy used in 2020. However, low-tech biomass use, such as inefficient household wood burners, is largely replaced in the K-1.5C scenario by state-of-the-art technologies, primarily highly efficient heat pumps and solar collectors. This results in an overall lowering of the total biomass use to 131 PJ.
- **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). Because Kenya's hydrogen generation potential is limited, it is assumed that hydrogen and synthetic fuels will be imported. Furthermore, hydrogen utilization will be limited to the industry sector only and is not expected to contribute more than 5% of industry's energy supply by 2050.

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

The resulting final energy demand for transportation is lower than that under the 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 K-1.5C.

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

The K-1.5C scenario also models a shift in the heating sector towards the increased direct use of electricity because of the enormous and diverse potential for renewable power and the limited availability of renewable fuels for high-temperature process heat in industry. Increased implementation of a district heating infrastructure (interconnections of buildings in central business districts), bio-energy-based heat generation, and solar collectors and heat pumps for office buildings and shopping centres in larger cities are assumed, leading to a growth in 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 shares of variable renewable power generation, principally by solar PV, will require the implementation of smart grids and the fast interconnection of micro- and mini-grids with regional distribution networks, storage technologies such as batteries and pumped hydro, and other load-balancing capacities. Other infrastructure requirements will include an increasing role for on-site renewable process heat generation for industries and mining, and the generation and distribution of synthetic fuels.

5.1.2 ASSUMPTIONS FOR THE KENYA REFERENCE SCENARIO

The REFERENCE case for Kenya has been developed based on the Kenya 1.5˚C scenario but assumed an implementation delay of 15 years. The REFERENCE case is similar – but not identical - to the BAU scenario in Kenya's National Determined Contribution submission from 2021.

The key differences are:

1. **Heating a sector:** The phase-out of coal, oil and gas is delayed for the residential, service and industry sector by 15 years. Accordingly, electric heat pumps and solar collector systems will remain niche technologies until 2040 but will grow afterwards and increase their shares by 2050.
2. **Transport sector:** Electric mobility will experience significant delays while transport demand will increase as projected in the 1.5C scenario. Vehicles with internal combustion engines (ICE) will remain dominate until 2040. Market shares for electric vehicles will start to grow from 2040 onwards significantly. Furthermore, biofuels are increased in the road transport sector.
3. **Power supply:** The delayed electrification in the heating and transport sector will lead to a slower growth of power demand compared to the 1.5˚C scenario. Additionally, it is assumed that renewable power generation will not fill the gap of increased electricity demand due to delayed implementation and fossil fuel-based power generation will therefore increases.

5.2 KENYA—ENERGY PATHWAY UNTIL 2050

The following section provides an overview of the key results of three different energy scenarios for Kenya. 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 K-1.5C scenario was designed to demonstrate the efforts and actions required to achieve the ambitious objective of a 100 percent 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 possible concepts and actions needed to implement technical pathways to achieve measurable results.

5.2.1 KENYA—FINAL ENERGY DEMAND

The projections for population development, GDP growth, and energy intensity are combined to project the future development pathways for Kenya's final energy demand. These are shown in Figure 20 for the reference (REF) and K-1.5C scenarios. In the REF scenario, the total final energy demand will increase by 88% from 613 PJ/a to 1,157 PJ/a from 2020 to 2050. In comparison, in the K-1.5C scenario, the total final energy demand increases by 50% from 613 PJ/a to 922 PJ/a. The K-1.5C scenario will reduce any additional costs by a higher proportion of electric cars.

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 in both scenarios (Figure 20). The residential sector will remain dominant in 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 in all three scenarios.

The energy demand of the transport sector will decrease 30% by 2050 under the REFERENCE scenario, whereas it will decrease 53% under the K-1.5C scenario. The main reason for the significant difference in growth projections is the high rates of electrification in the latter two pathways.

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

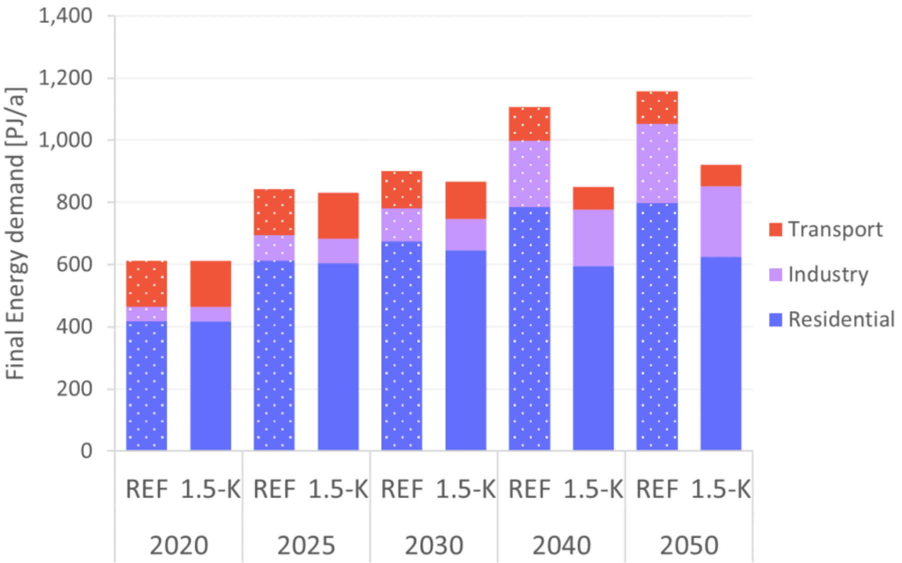

Figure 20: Projection of the total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)

The increased projected electrification of the heating, cooking, and transport sectors, especially under the K-1.5C scenario, will lead to a significantly increased electricity demand (see Figure 21).

The K-1.5C pathway will accelerate the electrification of the heating, cooking, and transport sectors compared to other pathways, and aims to replace more fossil and biofuels with electricity. By 2050, Kenya's electricity demand will increase to 176 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 K-1.5C, around 13 TWh will be used for electric vehicles and rail transport in 2050.

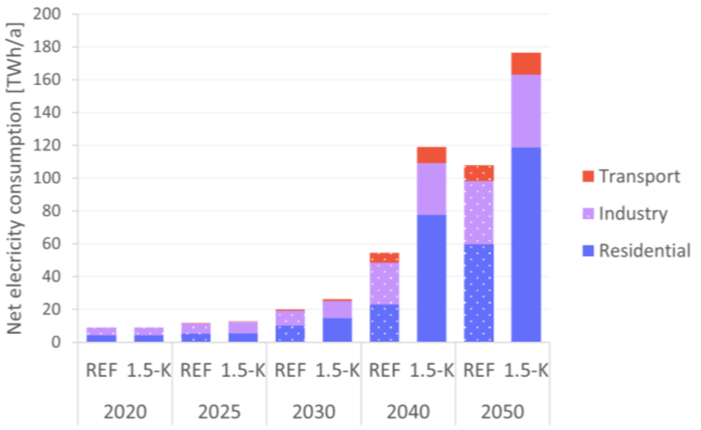

Figure 21: Development of electricity demand by sector

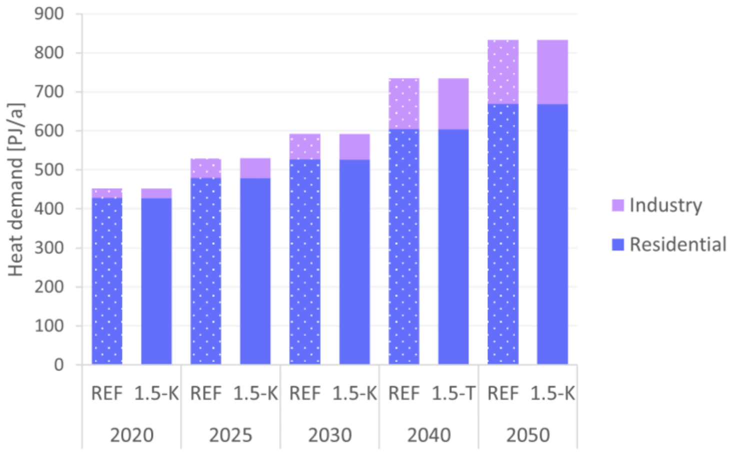

Figure 22: Development of the final energy demand for heat by sector

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

As a result, the K-1.5C pathway will lead to an annual heat demand of around 833 PJ/a.

The projected development of the road transport sector (see Figure **23**) is very similar between different pathways for Kenya. More details of the assumptions made for the transport sector projections, broken down into freight and passenger transport, are documented in Section 2.6.

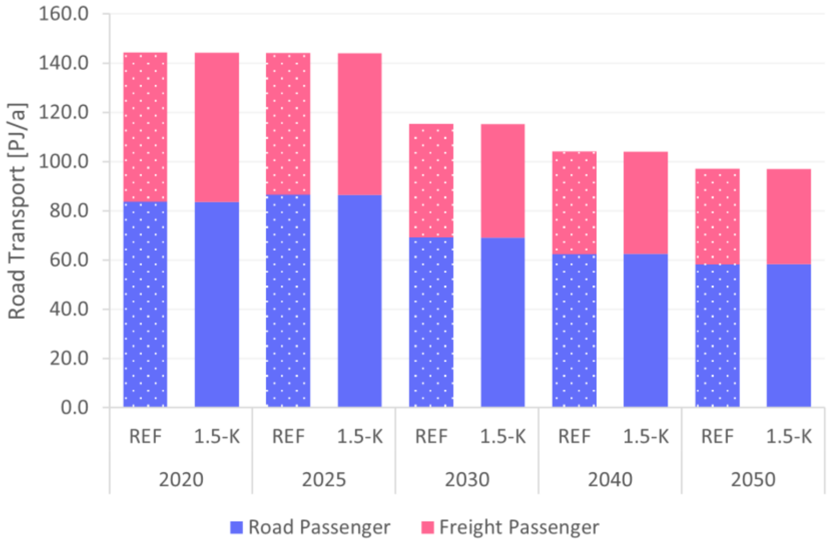

Figure 23: Development of the road transport energy demand for passengers and freight

5.2.2 ELECTRICITY GENERATION

5.2.2.1 Electricity generation, capacity, and breakdown by technology

The development of the electricity supply sector is characterized 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 K-1.5C scenario will greatly benefit new renewables, whereas hydropower will continue to generate bulk electricity for industry and export.

By 2025, the share of new renewable electricity production will reach 82% and increase to 100% by 2050 under the K-1.5C scenario. The installed capacity of new renewables will reach about 15 GW in 2030 and 111 GW in 2050.

Table 34 shows the comparative evolution of Kenya’s power generation technologies over time. Solar PV will be the main power source. The continuing growth of solar PV and additional wind power capacities will lead to a total capacity of 146 GW, compared with 3 GW hydropower under the K-1.5C scenario. It will lead to a high share of variable power generation and demand-side management, and the management of electric vehicle charging and other storage capacities, such as stationary batteries and pumped 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.

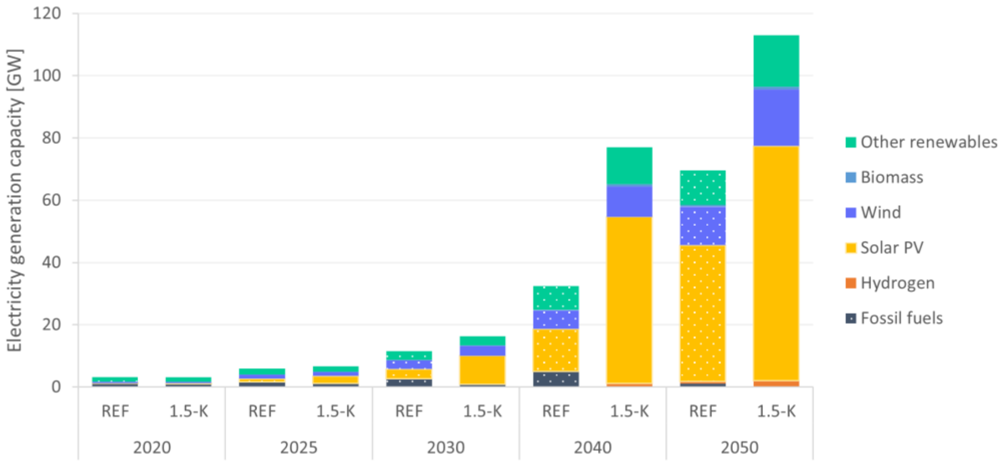

Figure 24: Breakdown of electricity generation by technology

Table 31: Projection of renewable electricity generation capacities

Generation Capacity [GW]			2020	2030	2035	2040	2050
Hydro	REF	GW	1	1	2	3	3
	K-1.5C	GW	1	1	2	2	2
Biomass	REF	GW	0.022	0.106	0.189	0.288	0.6
	K-1.5C	GW	0.022	0.139	0.336	0.629	0.9
Wind	REF	GW	0	3	3	6	12
	K-1.5C	GW	0	3	7	10	18
PV	REF	GW	0	3	7	14	44
	K-1.5C	GW	0	9	26	53	75
Total	REF	GW	3	12	21	32	70
	K-1.5C	GW	3	16	41	77	113

5.2.3 ENERGY SUPPLY FOR COOKING AND INDUSTRIAL PROCESS HEAT

Today, bio-energy meets around 78% of Kenya'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. In the K-1.5C 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) because its efficiency is low. Under K-1.5C, the use of heat pumps as one of the leading new heating supply technologies will accelerate, and direct electric heating, such as radiators, will be introduced, but only as an interim measure between 2025 and 2030. These will be exchanged for heat pumps at the end of their lifetimes.

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

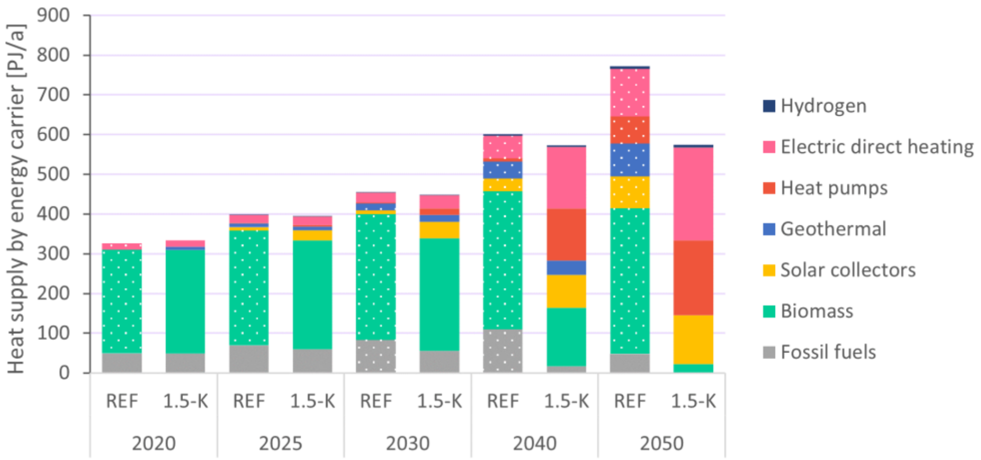

Figure 25: Projection of heat supply by energy carrier (REFERENCE and K-1.5C scenarios)

Table 32: Projection of renewable heat supply (cooking and process heat)

Supply (in PJ/a)		2020	2025	2030	2040	2050
Biomass	REF	260	289	317	348	366
	K-1.5C	260	273	284	146	22
Solar Collectors	REF	0	9	10	33	80
	K-1.5C	0	26	41	83	123
Heat Pumps (electric & geothermal)	REF	0	1	2	8	67
	K-1.5C	0	4	16	131	188
Geothermal	REF	0	8	9	18	37
	K-1.5C	0	10	17	42	83
Direct Electric Heating	REF	16	20	25	58	120
	K-1.5C	16	21	34	154	234
Total	REF	326	395	446	577	725
	K-1.5C	326	395	448	578	658

Table 32 shows the development of different renewable technologies for heating in Kenya over time. Biomass will remain the main contributor, with increasing investments in highly efficient modern biomass technology. Moreover, the installed capacity is presented in Table **33**. 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 K-1.5C scenario includes many efficient heat pumps, which can also be used for demand-side management and load flexibility (see also Section 6.6.2.).

Table 33: Installed capacities for renewable heat generation

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

5.2.4 TRANSPORT

A key target in Kenya 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 64% of the transport under the K-1.5C scenario. The K-1.5C scenario will achieve the total decarbonization of the transport sector in Kenya by 2050. More details about the assumptions made to calculate the transport demand and supply development are documented in Section 0.

Table 34: Projection of transport energy demands by mode

Transport mode		Unit	2020	2025	2030	2040	2050
Rail	REF	[PJ/a]	3	3	4	3	4
	K-1.5C	[PJ/a]	3	3	4	3	4
Road	REF	[PJ/a]	144	144	115	104	97
	K-1.5C	[PJ/a]	144	144	114	67	62
Domestic Aviation	REF	[PJ/a]	2	2	2	3	4
	K-1.5C	[PJ/a]	2	2	2	3	4
Total	REF	[PJ/a]	149	149	121	110	105
	K-1.5C	[PJ/a]	149	149	120	73	70

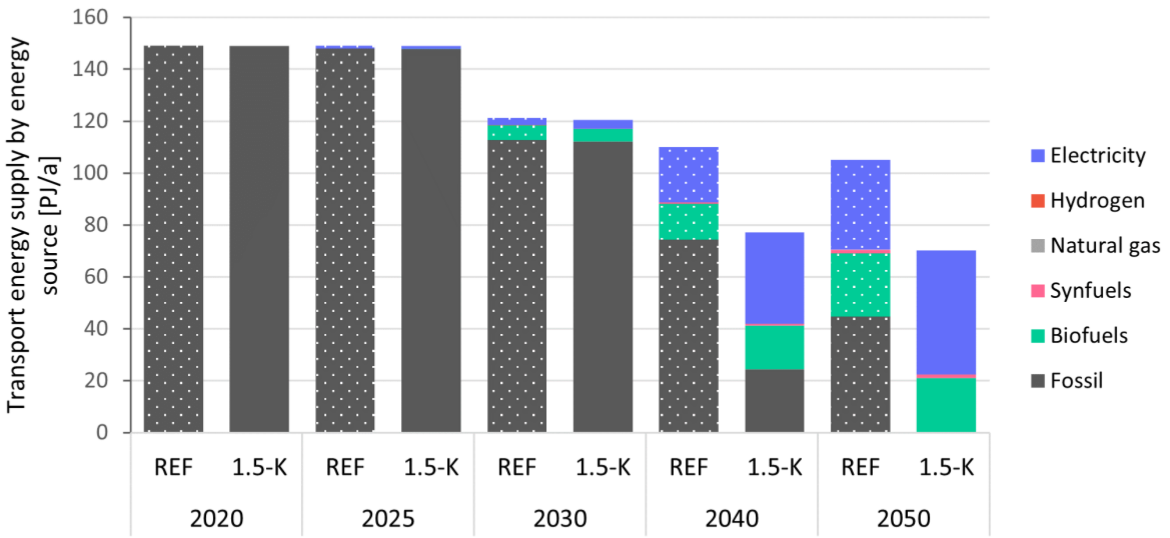

Figure 26: Final energy consumption by transport under two scenarios

5.2.5 PRIMARY ENERGY CONSUMPTION

Based on the assumptions discussed above, the resulting primary energy consumption from the K-1.5C is shown in Figure 27. The K-1.5C scenario will result in primary energy consumption of around 1210 PJ in 2050.

The K-1.5C 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 IN the K-1.5C scenario (including non-energy consumption).

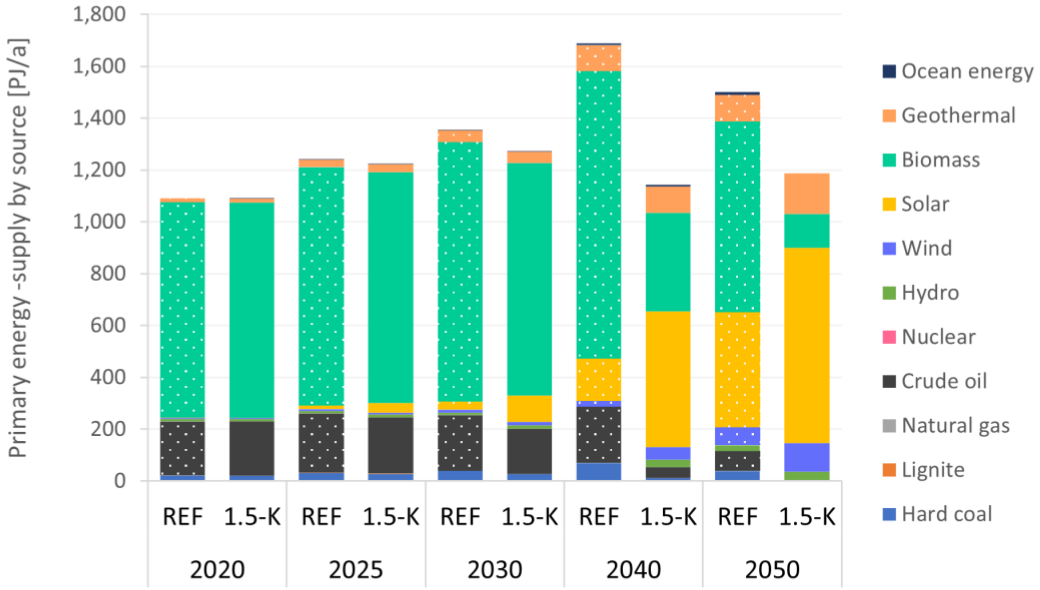

Figure 27: Projection of total primary energy demand by energy carrier (including electricity import balance)

5.2.6 CO_2 EMISSIONS TRAJECTORIES

The K-1.5C 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 (see Figure 28). In 2050, full decarbonization of Kenya's energy sector will be achieved under the K-1.5C scenario.

In the K-1.5C scenarios, the cumulative emissions will sum to 358 Mt for 2005 till 2050 compared to 421 Mt CO2 for the REF scenario.

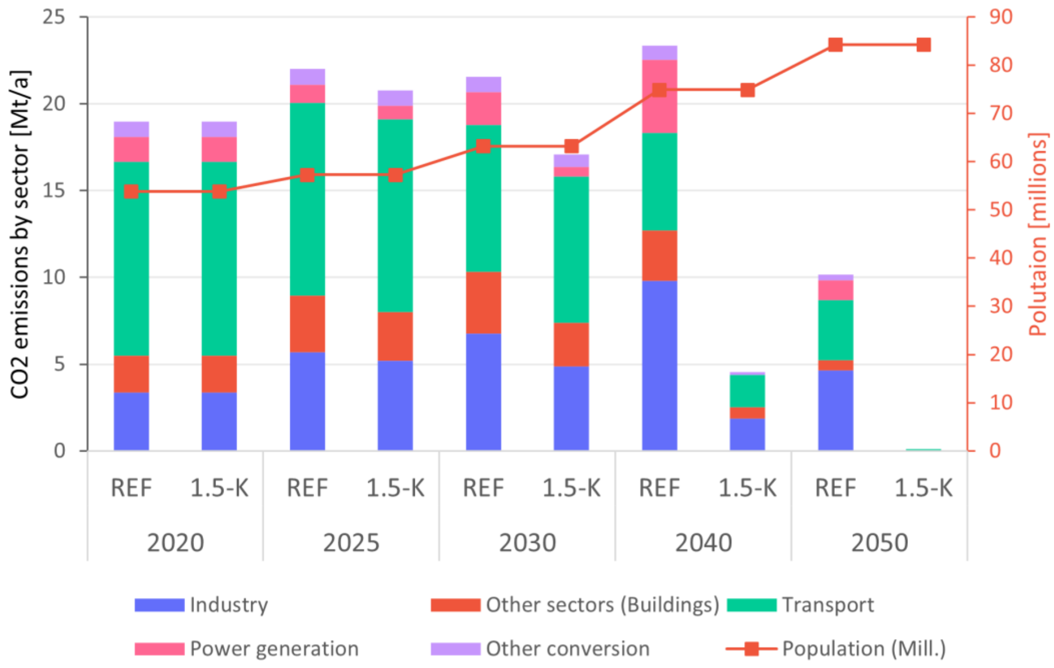

Figure 28: Development of CO_2 emissions by sector

5.2.7 COST ANALYSIS

5.2.7.1 Future costs of electricity generation

Figure 29 shows that introducing new-generation capacities will increase the average electricity generation due to new investments, and consequently, additional capital costs will be required.

The solar PV capacity will increase 535-fold under the K-1.5C scenario. The reason for high generation capacity is the far-reaching electrification strategy to replace fossil fuel with electricity for cooking, heating, and transport.

The K-1.5C will lead to around higher electricity generation costs between 2030 and 2040, before cost advantages will be reached again due to accelerated investment in renewable electricity: full cost of generation is about 4.93 KES/kWh (0.032$/kWh) under the K-1.5C scenario in 2030, when no consideration is given to the integration costs for storage or other load-balancing measures. However, the higher average generation costs under the K-1.5C scenario will only be temporary and are expected to fall rapidly around 2050, leading to lower generation around 2040 than under both other scenarios. By 2050, the K-1.5C scenario will lead to average electricity generation costs of 4.71 KES/kWh (0.031 US$ cent/kWh).

Kenya's total electricity supply costs will increase with the increasing electricity demand. The K-1.5C pathway has the highest total electricity costs, but these will directly replace bioenergy and oil fuel costs.

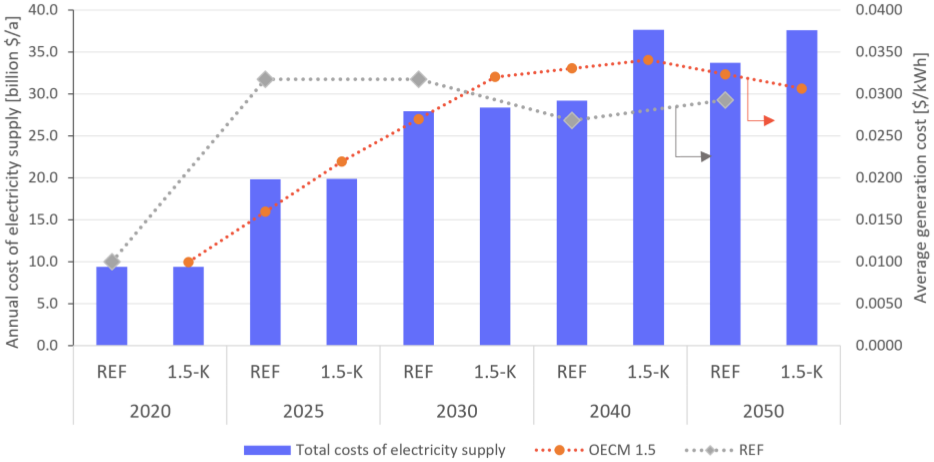

Figure 29: Development of total electricity supply costs and specific electricity generation costs

Investments in power generation

Kenya will invest in new power generation—mainly solar PV. Here, the main difference between the K-1.5C scenario and the other scenarios is the investment in other technologies—primarily solar PV. The onshore wind potential of Kenya is 1,635GW (Scenario 1) or 270GW (Scenario 2) and the wind speeds ranges 0.9 to 20.6 m/s at 100 m height. The electrification of remote villages under the K-1.5C pathway is mainly based on solar PV power mini-grids with (battery) storage systems. However, wind energy systems can and should play a role in some limited locations. 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.

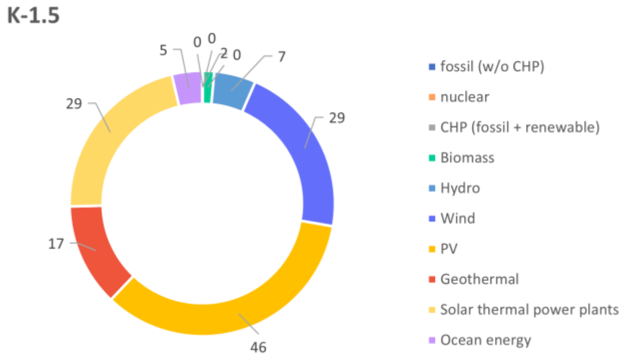

Figure 30: Shares of cumulative investment in power generation, K-1.5C scenario, 2020 to 2050 [billion $]

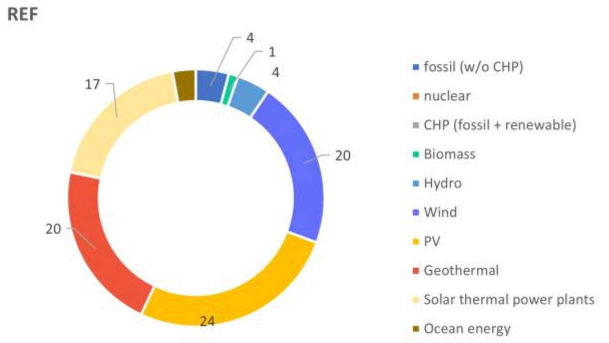

Figure 31: Shares of cumulative investment in power generation, REF scenario, 2020 to 2050 [billion $]

The additional investment in solar PV under the K-1.5C scenario will amount to around 21 trillion KES (US$135 billion) over 30 years. This electricity will primarily be used to replace biomass for cooking and heating and to charge various electric vehicles, from two- and three-wheeler vehicles to cars and small delivery trucks.

Table 35: Investment costs in new power generation in the K-1.5C scenarios and REF scenario (exchange rate: 1 KES = 0.0065 US Dollar, 29th December 2023)

K-1.5C	2020-–2050	
	[trillion KES]	[billion US$]
Hydro	1	7
Biomass	0	2
PV	7	46
Wind	4	29
Fossil & other	0	0
Total	**21**	**135**
REFERENCE	2020-–2050	
	[trillion KES]	[billion US$]
Hydro	1	4
Biomass	0	1
PV	4	24
Wind	3	20
Fossil & other	1	4
Total	**14**	**93**

5.2.7.2 Future investments in the heating sector

The main difference between the K-1.5C pathway and other pathways is the significant variety in bio-energy use and the diversification of heating technologies. Electrical heat pumps, geothermal heat pumps, and solar thermal applications for space and water heating and drying will lead to a considerable reduction in 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 for the K-1.5C scenario, compared to cumulative investments for the REF scenario (see Figure 33).

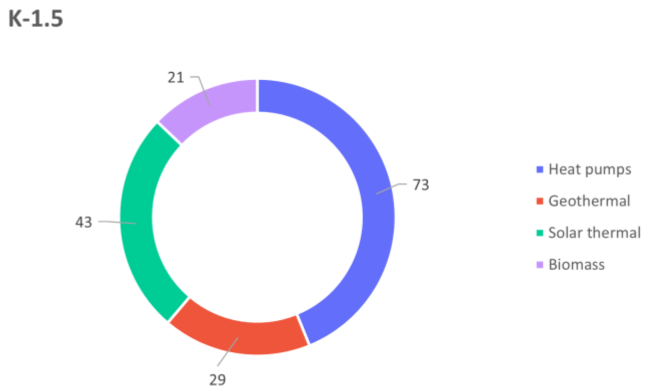

Figure 32: Cumulative investment in the heating technologies (generation) under the K-1.5C scenario, [billion $] for 2020-2050

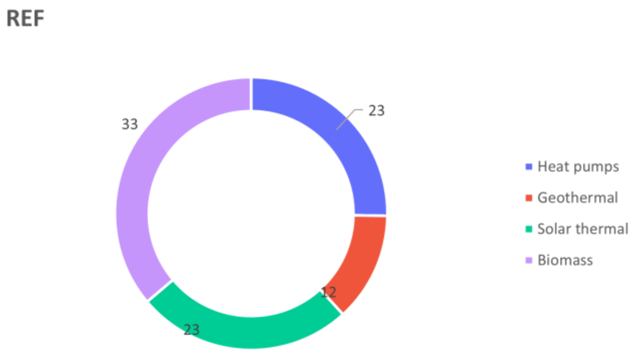

Figure 33: Cumulative investment in the heating technologies (generation) under the REF scenario, [billion $] for 2020-2050

Table 36 shows the cumulative investment and fuel costs in the heating sector for the K-1.5C scenario and the REF scenario. The overall heat sector costs—investment and fuel costs—over the entire scenario period until 2050 will be 13.7 trillion USD for the K-1.5C scenario.

Table 36: Kenya—heating, electricity and fuel: cumulative investment and fuel costs in 2020–2050

K-1.5C scenario, cost 2020-2050	[trillion KES]	[billion US$]
Cumulative heating investment	25	166
Cumulative fuel cost	2071	13,459
Cumulative electricity cost	21	135
Total	**2117**	**13760**
REFERENCE scenario	[trillion KES]	[billion US$]
Cumulative heating investment: 2020–2050	14	92
Cumulative fuel cost	2033	13,216
Cumulative electricity cost	14	93
Total	**2061**	**13400**

5.2.8 INVESTMENT AND FUEL COST SAVINGS=

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

All three sectors 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 Kenya. Under the most ambitious electrification strategy of the K-1.5C pathway, total investment will be 2,690 trillion KES (US$ 17,488 billion).

Fuel cost savings in the heating sector until 2040 alone will be able to re-finance the additional investments in power generation. Table 37 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 the local currency; **Error! Reference source not found.** shows them in US dollars.

Additional power generation investments will be compensated by fuel costs savings in the decade that they are made. Across the entire scenario period, fuel cost savings under the K-1.5C scenario will be 574 trillion KES (US$ 3,728 billion), more than 27 times higher than the additional investment in power generation until 2050. Whereas fuel cost predictions are subject to a great deal of uncertainty, the clear result makes the cost-effectiveness of electrification very clear.

Table 37: Accumulated fuel costs for heat generation under the REF and K-1.5C scenarios in billion USD and KES

REFERENCE		2021–2030		2031–2040		2041–2050		2021–2050		2020–2050 average per year	
		Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD
Power	Total	2	15	6	40	6	38	14	93	0	3
Heat	Total	4	26	3	21	7	45	14	92	0	3
Transport	Total	2079	13516	0	0	0	0	2662	17303	89	577
	Summed Fuel Costs	2086	13557	0	0	13	0	2690	17487	90	583
K-1.5C		2021–2030		2031–2040		2041–2050		2021–2050		2020–2050 average per year	
		Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD	Trillion KES	Billion USD
Power	Total	3	17	12	77	6	41	21	135	1	5
Heat	Total	6	38	10	66	9	61	25	166	1	6
Transport	Total	1488	9671	0	0	0	0	2071	13459	69	449
	Summed Fuel Costs	1496	9727	22	143	16	102	2117	13760	71	459

6 Kenya: Power Sector Analysis

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

6.1 POWER SECTOR ANALYSIS—METHODOLOGY

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

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

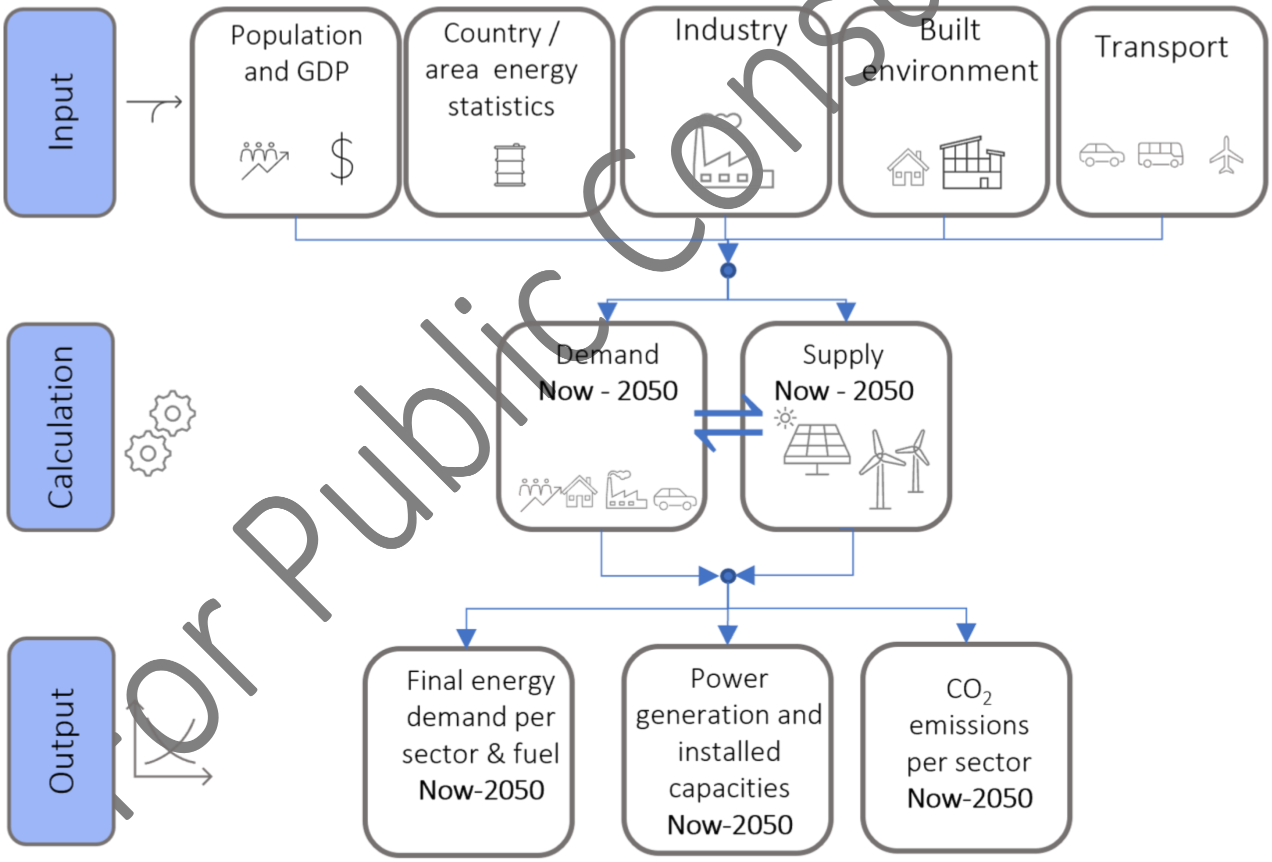

Figure 34: Overview—Energy demand and load curve calculation module

6.1.1 METEOROLOGICAL DATA

Variable power generation technologies are dependent on the local solar radiation and wind regime. Therefore, all the installed capacities in this technology group are connected to cluster-specific time series. The data were derived from the database *renewable.ninja* (RE-N DB 2018)[54], which allows the hourly power output from wind and solar power plants at specific geographic positions throughout the world to be simulated. Weather data, such as temperature, precipitation, and snowfall, for the year 2019 were also available. To utilize climatization technologies for buildings (air-conditioning, electric heating), the demand curves for households and services were connected to the cluster-specific temperature time series.

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

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

Once the representative sites were chosen, the hourly output values for typical solar arrays and wind farms were selected from the database of Stefan Pfenninger (at ETH Zurich) and Iain Staffell (renewable.ninja see above). The model methodology used by the renewable.ninja database is described by Pfenninger and Staffell (2016a and 2016b)[55], and is based on weather data from global re-analysis models and satellite observations (Rienecker and Suarez 2011[56]; Müller and Pfeifroth, 2015[57]).

It is assumed that the utility-scale solar sites will be optimized, so the tilt angle was selected within a couple of degrees of the latitude of the representative site. For the roof-top solar calculations, this was left at the default of 35° because it is likely that the panels will match the tilt of the roof.

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

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

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

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

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

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

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

6.1.2 POWER DEMAND PROJECTION AND LOAD CURVE CALCULATION

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

- Households;
- industry and business and
- transport.

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

- electrical applications in use.
- demand pattern (24 h).
- meteorological data
  - sunrise and sunset, associated with the use of lighting appliances.
  - temperature and rainfall, associated with climatization requirements.
- efficiency progress (base year 2018 for 2020 until 2050, in 5-year steps.
  - possibility that the electricity intensity data for each set of appliances will change, e.g., change from compact fluorescent lamp (CFL) light bulbs to light-emitting diodes (LEDs) as the main technology for lighting.

6.1.3 THE OECM 24/7 DISPATCH MODULE

The OECM 24/7 dispatch module simulates the physical electricity supply with an interchangeable cascade of different power generation technologies. The cascade starts with the calculated load in megawatts for a specific hour.

The first-generation technology in the exogenous dispatch order provides all the available generation, and the remaining load is supplied by the second technology until the required load is entirely met.

In the case of oversupply, the surplus variable renewable electricity can either be moved to storage, moved to other regions (including export to other countries if specified in modelling assumptions), or—if neither option is available—curtailed. Non-variable renewable sources will reduce output.

In the case of undersupply, electricity will be supplied either from available storage capacities, from neighbouring clusters, or from dispatch power plants.

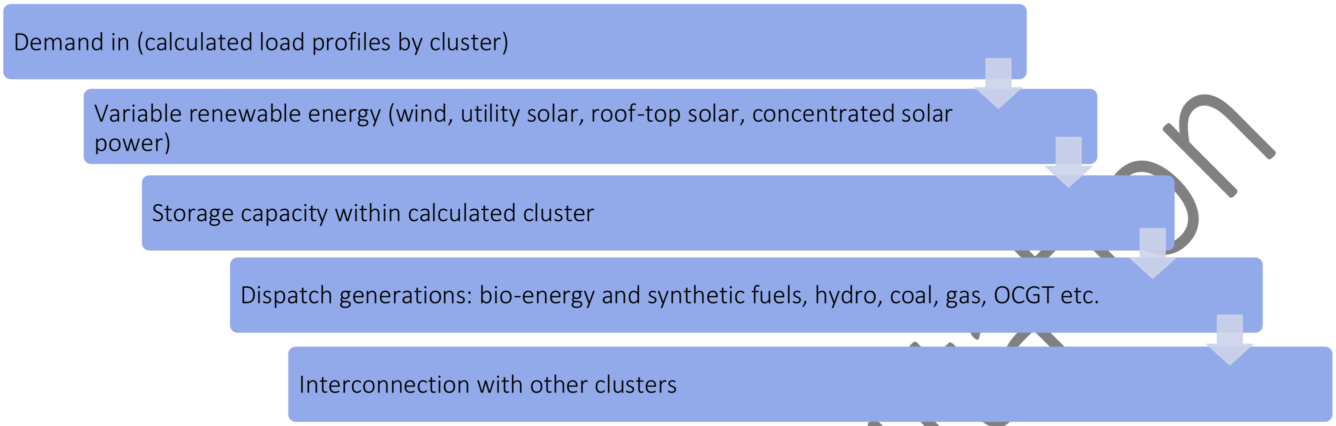
The key objective of the modelling is to calculate the load development by region, modifying the residual load (load minus generation), theoretical storage, and interconnection requirements for each cluster and for the whole survey region. The theoretical storage requirement is provided as the "storage requirement to avoid curtailment". The economic battery capacity is a function of the storage and curtailment costs, as well as the availability of dispatch power plants and their costs. This analysis focuses on the technical storage requirements.

Figure 35 provides an overview of the dispatch calculation process. The dispatch order can be changed in terms of the order of renewables and the dispatch power plant, as well as in terms of the order of the generation categories: variable, dispatch generation, or storage.

The following key parameters are used as input: generation capacity by type, the demand projection and load curve for each cluster, interconnections with other clusters, and meteorological data, from which solar and wind power generation are calculated with hourly resolution.

The installed capacities are derived from the long-term projections described in Section 5 and the resulting annual generation in megawatt hours is calculated based on meteorological data (in the cases of solar and wind power) or dispatch requirements.

Figure 35: Dispatch order within one cluster



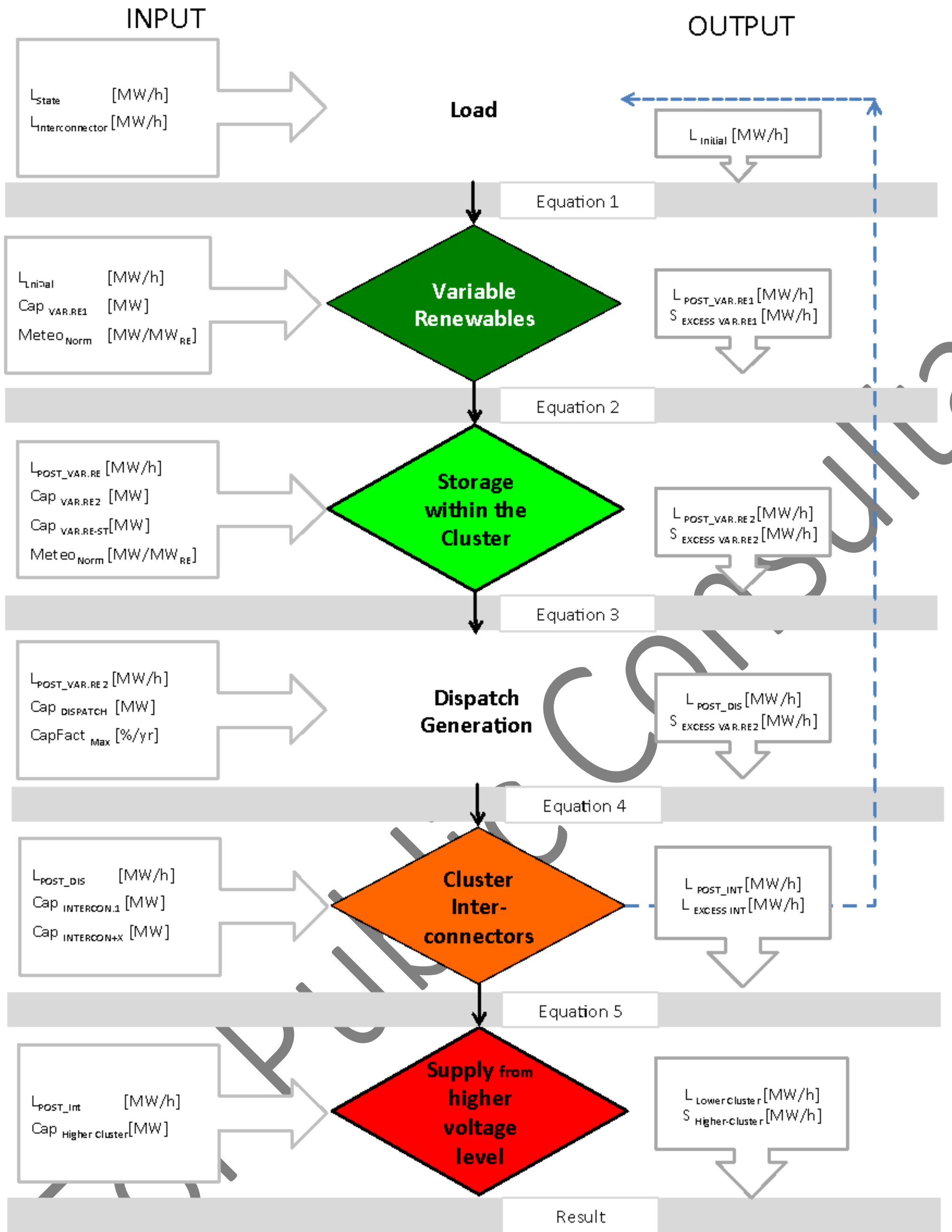
Overview: input and output— OECM 24/7 energy dispatch model

Figure 36 gives an overview of the input and output parameters and the dispatch order. Although the model allows changes in the dispatch order, a 100% renewable energy analysis always follows the same dispatch logic. The model identifies excess renewable production, which is defined as the potential wind or solar PV generation that exceeds the actual hourly demand in MW during a specific hour. To avoid curtailment, the surplus renewable electricity must be stored with some form of electrical storage technology or exported to a different cluster. Within the model, excess renewable production accumulates through the dispatch order. If storage is present, it will charge the storage within the limits of the input capacity. If no storage is included, this potential excess renewable production is reported as 'potential curtailment' (pre-storage). It is assumed that a certain number of behind-the-meter consumer batteries will be installed, independently of the system requirements.

Limitations

The calculated loads are not optimized regarding local storage, the self-consumption of decentralized producers of solar PV electricity, or demand-side management. Therefore, the calculated loads may be well below the calculated values.

Figure 36: Overview—Input, output, and dispatch order



6.2 KENYA: DEVELOPMENT OF POWER PLANT CAPACITIES

Kenya has substantial untapped renewable energy potential, as described in Section 3. Geothermal and hydropower plants provide the bulk of the grid-connected electricity generation, followed by onshore wind and diesel generator which provide similar shares of the remaining electricity, whereas solar PV generators still have a small share. However, solar PV generators will expand rapidly and provide increasing electricity, both grid-connected and off-grid in micro-grids, especially in remote areas of the country, where the national power grid will not reach villages in the coming years. In this analysis, we contribute to the debate on the role that decentralized renewable electricity generation—mainly solar PV, onshore wind but also mini-hydro, geothermal and biomass energy-based generators—can play in the future.

In terms of Kenya's renewable electricity potential, the vast majority of future generation will be solar PV and onshore wind. Due to significant geothermal resources, Kenya can increase its geothermal generation capacity even further. Hydropower plants have already been one of the major contributors of the power sector for decades and will continue to expand its role. Whereas sustainable biomass resources are limited. While the offshore wind resources are good, it is assumed that onshore wind has more economic advantages for Kenya. However, it is a viable future option. The potential for geothermal heating systems (heat pumps) for low-temperature heating is significant as well.

Therefore, the capacity for solar PV installations will increase substantially under the K-1.5C pathway. The average solar photovoltaic market will range around 1,800 MW per year between 2021 and 2035 and increase to around 4,600 MW per year between 2036 and 2005. Kenya's wind power market is projected to increase its annual market volume to around 1,000 MW by 2030 and 1,500 MW between 2035 and 2045 making it an important local industry. Kenya's hydropower plant capacity will grow by a factor of 3 from around 1,000 MW in 2021 to 3,000 MW in 2050. Finally the geothermal energy capacity increases to 5,000 MW by 2050, by a factor of 5.

Kenya's renewable potential is exceptionally diverse and not only limited to solar and wind power. Therefore, under the K-1.5C pathway, the full range of renewable technology will be utilized (Table 38).

Table 38:Kenya—average annual changes in installed power plant capacity (main technologies)

Power Generation: average annual changes in installed capacity [MW/a]							Average annual	
	2021–2025	2026–2030	2031–2035	2036–2040	2041–2045	2046–2050	2021-2035	2021-2050
biomass	13	15	43	65	39	27	24	34
hard coal	0	0	0	0	0	0	0	0
lignite	0	0	0	0	0	0	0	0
fuel cell	1	9	64	157	125	54	25	69
natural gas	0	0	0	0	0	0	0	0
oil	42	-130	-50	-211	0	0	-46	-58
diesel	0	0	0	0	0	0	0	0
hydro	15	36	138	142	27	83	63	74
wind onshore	193	368	914	1,737	1,318	654	491	864
wind offshore	89	142	158	214	181	73	130	143
PV	606	1,508	3,425	4,619	2,936	514	1,846	2,268
geothermal	66	95	152	243	51	119	104	121
Total CHP plants	0	0	0	0	0	0	0	0
biomass & waste	0	0	0	0	0	0	0	0
hard coal	0	0	0	0	0	0	0	0
lignite	0	0	0	0	0	0	0	0
fuel cell	0	0	0	0	0	0	0	0
gas	0	0	0	0	0	0	0	0
geothermal	0	0	0	0	0	0	0	0
oil	0	0	0	0	0	0	0	0

However, there will be a rapid increase in the electricity demand with the high electrification rates in the transport and heating sectors. After 2035, a significant share of Kenya's solar market will provide electricity for households and electric mobility. By 2030, solar PV will generate around 15 TWh— close to Kenya's projected electricity demand in 2025. By 2050, wind power and solar PV will provide over 70 % of the country's electricity demand, which is projected to increase 10 -fold relative to 2021.

6.3 KENYA: UTILIZATION OF POWER GENERATION CAPACITIES

Table 39 and Table 40 show the installed capacities for roof-top and utility -scale solar PV under the K-1.5C scenario in 2030 and 2050, respectively. The distributions are based on the regional solar potentials and the regional electricity demands, with the aim of generating electricity where the demand is located. Whereas roof-top solar PV power generation is modular and can be installed close to the consumer or even integrated into buildings, utility-scale solar PV is usually further away from settlements and close to medium- or high-voltage power lines. Furthermore, solar power plants (= utility-scale PV) have double-digit megawatt capacities, on average. The best solar resources are in the south of the country along the border with India.

Table 39: Kenya K-1.5C pathway—Installed photovoltaic capacities by region (2030)

K-1.5C pathway 2030	South Coast	North of Coast	Northern	Eastern Central	Central	North Western	Western Central	Lake Zone
	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]
Photovoltaic (roof-top)	687	395	116	967	1,568	401	1,623	1,792
Photovoltaic (utility-scale)	229	132	39	322	523	134	541	597

Table 40: Kenya K-1.5C pathway—installed photovoltaic capacities by region (2050)

K-1.5C pathway 2050	South Coast	North of Coast	Northern	Eastern Central	Central	North Western	Western Central	Lake Zone
	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]
Photovoltaic (roof-top)	4,611	2,652	775	6,489	10,521	2,689	10,892	12,024
Photovoltaic (utility-scale)	1,537	884	258	2,163	3,507	896	3,631	4,008

The K-1.5C scenario aims for an even distribution of variable power plant capacities across all regions by distributing roof-top and utility-scale solar PV power-generation facilities accordingly. In this analysis, we have assumed that 75% of the solar PV installations are roof-top and 25% are utility-scale power plants. The distribution is based on the population in each of the sub-regions. Compared with the vast solar potential, wind generation will be very limited and will not compensate for differences in seasonal generation. However, to diversify the generation mix to reduce the seasonal storage requirements, the wind resources of Kenya should be used to the highest possible degree.

The coastal regions and the northern part of Kenya host only minor parts of the country's generation capacities, mainly solar and wind power. Thus, the share of variable generation in 2020 is very high. Most of the hydro and geothermal power plants are in the central regions of Kenya, which is shown has high shares of dispatchable renewables in Table 41. Fossil fuel power plants – mainly oil and gas – are located on the South Coast and in Central Kenya.

The projections for 2030 and 2050 show an increase of variable renewables in regions with higher dispatchable capacities, while dispatchable increase in regions where there are currently no capacities. On average, Kenya will have around 60% to 65% variable renewables with the rest of dispatchable power plants.

Table 41: Kenya—power system shares by technology group

Power Generation Structure in Percentage of Annual Supply [%/a]		K-1.5C		
		Variable Renewable	Dispatch Renewable	Dispatch Fossil
South Coast	2020	14%	1%	85%
	2030	72%	13%	15%
	2050	80%	20%	0%
North of Coast	2020	100%	0%	0%
	2030	77%	23%	0%
	2050	75%	25%	0%
Northern	2020	100%	0%	0%
	2030	77%	23%	0%
	2050	74%	26%	0%
Eastern Central	2020	5%	95%	0%
	2030	49%	51%	0%
	2050	61%	39%	0%
Central	2020	1%	2%	96%
	2030	53%	9%	38%
	2050	85%	15%	0%
North Western	2020	29%	71%	0%
	2030	64%	36%	0%
	2050	67%	33%	0%
Western Central	2020	5%	74%	22%
	2030	44%	51%	5%
	2050	60%	40%	0%
Lake Zone	2020	20%	80%	0%
	2030	82%	18%	0%
	2050	82%	18%	0%

The significant regional differences in the power system shares—the ratio between dispatchable and non-dispatchable variable power generation—will require a combination of increased interchange, storage facilities, and demand-side management incentives.

Table 42 shows the system-relevant technical characteristics of the various generation types. Future power systems must be structured according to the generation characteristics of each technology to maximize their synergy. Power utilities can encourage sector coupling—between industry, transport, and heating—to utilize various demand-side management possibilities and to maximize the cross-benefits. The integration of large shares of variable power generation will require a more flexible market framework. Those power plants requiring high-capacity factors because of their technical limitations regarding flexibility ("base-load power plants") might not be desirable to future power system operators. Therefore, capacity factors will become more a technical characteristic than an economic necessity. Flexibility is a commodity that increases in value over time.

Table 42: System-relevant generation types

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

6.4 KENYA: DEVELOPMENT OF LOAD, GENERATION, AND RESIDUAL LOAD

Table 43 shows the calculated annual demand, maximum and minimum loads, and the calculated average load by region for 2021. The results are based on the K-1.5C pathway projections. To validate the data, we compared our results with the real-time data published by the local grid operator.

The statistical data for each province for 2021 were not available at the time of writing, so the values are estimates and may vary by ±10% for each data point. However, the published online data for Kenya's power sector is within the same order of magnitude. The calculation of the maximum, minimum, and average loads for the base year (2020/21) are important to calibrate the OECM and to compare the values with future projections.

Table 43: Kenya—calculated load, generation, and residual load in 2020/21

Real Load (rounded)—measured by grid operators in 2018	Electricity Generation [TWh/a]	Maximum Load (Domestic) [MW]	Maximum Generation [MW]	Minimum Load [MW]	Average Load [MW]
South Coast	827	0.12	0.19	0.06	0.08
North of Coast	156	0.04	0.17	0.01	0.03
Northern	64	0.01	0.12	0.01	0.01
Eastern Central	1,019	0.16	0.16	0.07	0.11
Central	3,279	0.41	0.4	0.22	0.3
North Western	294	0.06	0.16	0.02	0.04
Western Central	2,011	0.30	0.3	0.15	0.21
Lake Zone	1,534	0.27	0.08	0.11	0.16
Kenya total	9,184	1.37	1.58	0.65	0.94

Table 44 shows that according to calculation, the average load will increase by a factor of approximately 3–4 in each province over the next decade. By 2050, the overall electricity load of Kenya will increases by a factor 8.6 relative to that of 2020, with variations between 6 and 10.

The increase in load is attributable to the increase in the overall electricity demand with the electrification of cooking, heating, and cooling, which constitutes an increase of the living standards of all Kenya's households as they acquire more residential appliances. Furthermore, the growth of the commercial and industrial sectors of Kenya and the electrification of transport will lead to a sharp increase in the electricity demand and therefore the overall power load. This increased load will require an expansion of Kenya’s power distribution and transmission grid, both within Kenya and as interconnections with neighbouring countries—especially Tanzania.

The calculated load for each province depends on various factors, including the local industrial and commercial activities. A detailed analysis of the planned expansion of economic activity for each province was beyond the scope of this research and the results are therefore estimates. The residual load is the difference between the power generation and the demand—a negative residual load indicates an oversupply, whereas a positive value implies an undersupply.

The development of power generation is assumed to grow proportionally to the growth in demand in each province. A more detailed assessment of the exact locations of power generation is required to optimize the required expansion of transmission grids. To reduce the residual load to avoid an over- and/or undersupply for each province, either increased grid capacity or more storage systems will be required.

Table 44: Kenya—projection of load, generation, and residual load until 2050

Kenya Development of Load and Generation		K-1.5C			
		Maximum Load	Maximum Generation	Maximum Residual Load	Peak Load Increase
		[MW]	[MW]	[MW]	[%]
South Coast	2020	0.12	0.19	-0.07	100%
	2030	0.48	1.06	-0.58	400%
	2050	2.80	9.6	-6.8	2333%
North of Coast	2020	0.04	0.17	-0.13	100%
	2030	0.19	1.14	-0.95	475%
	2050	0.97	8.98	-8.01	2425%
Northern	2020	0.01	0.12	-0.11	100%
	2030	0.06	1.05	-0.99	600%
	2050	0.32	6.71	-6.39	3200%
Eastern Central	2020	0.16	0.16	0	100%
	2030	0.64	0.87	-0.23	400%
	2050	3.64	6.06	-2.42	2275%
Central	2020	0.41	0.4	0.01	100%
	2030	1.50	0.81	0.69	366%
	2050	9.30	4.7	4.6	2268%
North Western	2020	0.06	0.16	-0.1	100%
	2030	0.23	1.14	-0.91	383%
	2050	1.27	7.12	-5.85	2117%
Western Central	2020	0.30	0.3	0	100%
	2030	1.16	1.33	-0.17	387%
	2050	6.73	9.14	-2.41	2243%
Lake Zone	2020	0.27	0.08	0.19	100%
	2030	1.08	0.82	0.26	400%
	2050	5.99	5.72	0.27	2219%
Kenya	2020	1.37	1.58	-0.21	100%
	2030	5.34	8.22	-2.88	426%
	2050	31.02	58.03	-27.01	2385%

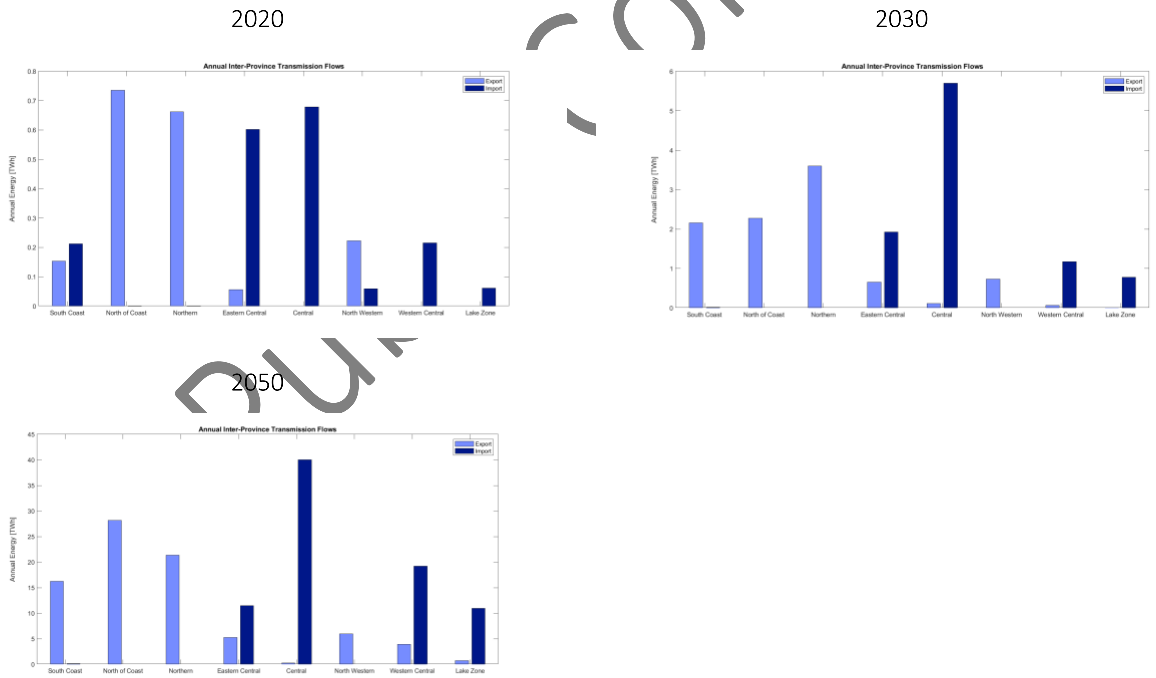
Increased electric mobility will require additional capacity in the power grid to accommodate the higher charging loads for vehicles. Our analysis shows that with the smart distribution and management of electric vehicle charging stations, additional transmission lines will be required. The high share of solar PV will lead to high generation peaks during summer months and low generation capacities during winter. To manage the generation peaks of solar PV generators, utility-scale installations will require on-site storage capacity, whereas roof-top PV will require increased 'behind-the-meter' storage facilities (see Section 6.6).

6.5 KENYA: DEVELOPMENT OF INTER-REGIONAL EXCHANGE OF CAPACITY

The inter-regional exchange of capacity is a function of the load development and generation capacity in all seven provinces. The OECM distributes generation capacity according to the regional load and the conditions for power generation. The locations of existing hydropower plants are fixed, and the installation of new capacities will depend upon geographic conditions and the nature conservation requirements. Kenya's significant potential for additional hydropower and geothermal power stations provides flexibility in choosing the right location for additional generation capacity. To prevent unnecessary expansion of the electricity grid, the projected increase in the regional electricity demand and additional electricity export plans should inform the expansion of the local power generation capacity.

Solar and wind power generation, as well as decentralized bio-energy power and/or micro-hydropower plants, is modular and can be distributed according to the load in the first place. However, as the share of variable renewable electricity increases, and load management either via demand side or battery charging/discharging planning, will be increasingly important. Hydropower and geothermal power plants will remain to play an important role in Kenya's power generation industry.

Careful planning of the distribution of the renewables electricity generation capacities to match the local demand will be very important. Furthermore, charging devices for electric vehicles should be operated within a load management scheme.


2020

2030

2050

Figure 37: Kenya—maximum inter-regional exchange capacities, additional to the required grid capacity expansion in response to load increase, under the K-1.5C scenario

The K-1.5C scenario prioritizes the security of supply with local generation, while utilizing electricity import and export to surrounding countries for the management of generation. Utility-scale solar PV installations, as well as small- and medium-sized decentralized power generation, will interact with local demand-side management and storage facilities (see Section 6.6)—from dedicated *energy communities*—on low- and medium-voltage levels, which will reduce upgrades of the distribution grid. It was beyond the scope of this project to quantify this effect, which requires additional research.

Figure 37 shows the calculated exchange capacities between the eight defined sub-regions of Kenya in 2020, 2030, and 2050. The amount of exchanged electricity increases significant between all regions. The coastal regions develop towards electricity generation region, exporting to the demand centres in the centre of the country. The Central, Western and Lake Zone regions will increase the required electricity import almost be factor 10. A detailed local assessment is required of whether a new power grid interconnection can be built, or if regional micro-grids with increased storage capacity are a better solution. Stand-alone micro-grids are the preferred option because the construction of transmission grids will be impractical, especially in region Kenya's with a low population density in the northern and north coast region.

Limitations

The calculated loads are not optimized regarding local storage, self-consumption by decentralized producers of solar PV electricity, or demand-side management. Therefore, the calculated loads may differ from the actual values. Furthermore, the calculated export/import loads to neighbouring countries are simplified and combined into a single value. Peak load and peak generation events do not occur at the same time, so their values cannot be simply summed. Moreover, peak loads can vary across all regions and appear at different times. Therefore, to sum all the regional peak loads will only provide an indication of the peak load for the whole country. The maximum residual load[58] shows the maximum undersupply in a region and indicates the maximum load that will be imported into that region. This event can only be several hours long, so the interconnection capacity might not be as high as the maximum residual load indicates. Optimizing the interconnections for all regions was beyond the scope of this analysis. To guarantee the security of supply, the residual load of a region must be supplied by one or more of the following options:

- imports from other regions through interconnections.
- battery storage facilities on-site at solar PV installations and for electric vehicles.
- available back-up capacities, such as gas peaking plants.
- load and demand-side management.

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

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

6.5.1 ANNUAL VARIATIONS OF RENEWABLE ENERGY GENERATION

Solar and wind power generation has different annual variation pattern which are dependent on the climate zone and geographical location. This section provides a high-level analysis about the electricity import and/or export needs under the K-1.5C scenario with high shares of variable power generation. Electricity demand ('load') and generation ('supply') must be balanced at all times. If local generation cannot meet demand, electricity must either be imported from other regions or taken from existing storage facilities. If the generation is higher than the load, the surplus electricity can either be exported to other regions, stored, the load increased, or production reduced. The term 'curtailment' is defined as the forced reduction of electricity generation (see also 6.4). In order to determine the annual distribution -of Kenya's solar and wind power generation, generation and expected load are simulated in a one -hourly resolution (8760 h/a).

Figure 38 shows the analyse results in weekly values. During times of high generation, generation exceeds the demand (green line), the red line shows when demand exceeds generation. State of the art power system operation of renewable power generation dominated grid, utilize a combination of demand and generation side management, export and import from neighbouring regions and a cascade of different storage technologies such as batteries, hydro pump storage and hydrogen/synthetic fuel production later used for e.g. industrial processes heat or feedstock for the chemical industry.

Figure 38 shows the weekly values of inter-province transmission requirements under the K-1.5C scenario by 2050, which is a function of the import and export requirements on the national level.

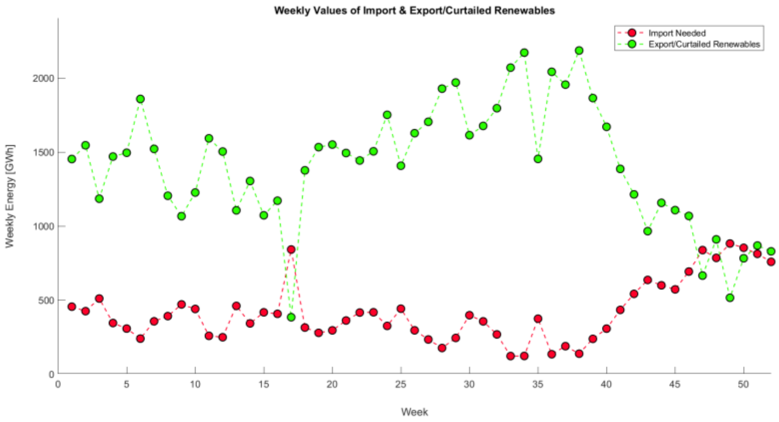

Figure 38: Kenya: Weekly values of electricity import & export – 2050

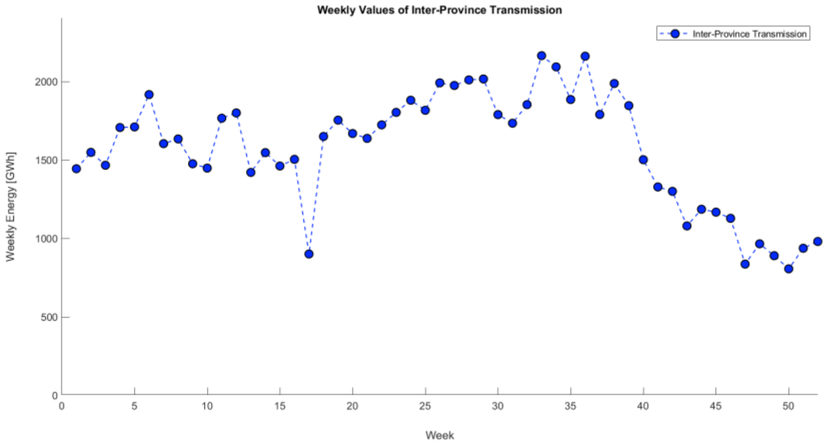

Figure 39: Kenya: Weekly values of Interprovince Transmission – analysis for 2050

The analysis shows that between 30th November and 8th December – based on historical meteorological data (6.1.1) – power generation from both wind and solar is on the lowest level within the entire year. This coincides with Kenya's second rainy season. The other extreme – a period with very high-power generation rates – has been determined around August, a season with relative cool temperatures and sunny periods. The purple area (Figure 40and Figure 41) shows charging (negative values) and discharging (positive values) of storage systems. Brown areas specify times with dispatch needs (import or export of electricity) and green areas are renewable power generation. Finally, the white areas which indicate periods of unmet demand are further investigated. Thus, the analysis of local annual solar and wind power generation variation serves as the first step in determining the technical storage requirements.

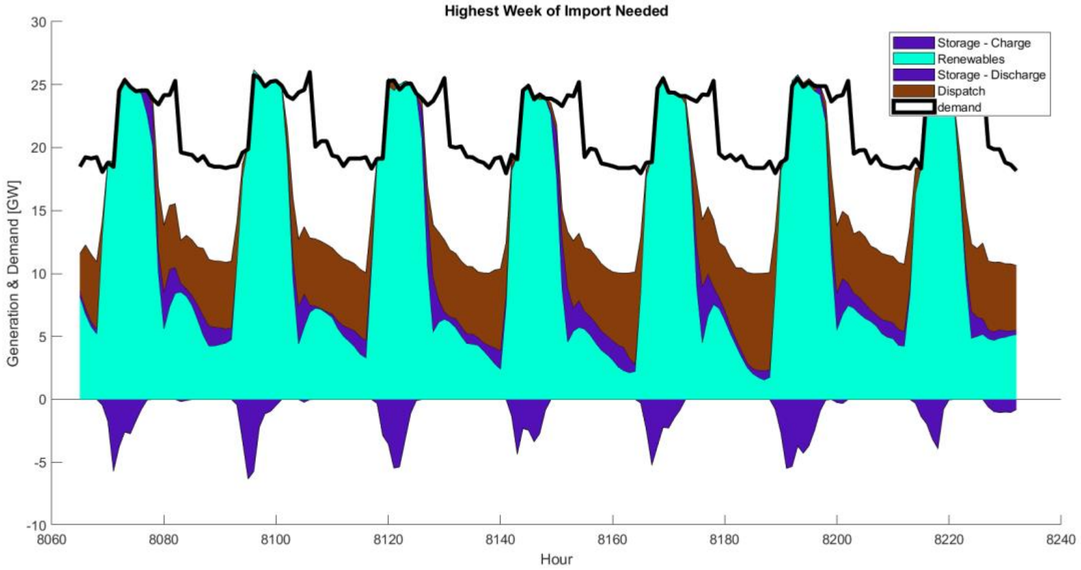

Figure 40: Kenya - lowest renewable electricity production under the K-1.5C scenario in 2050

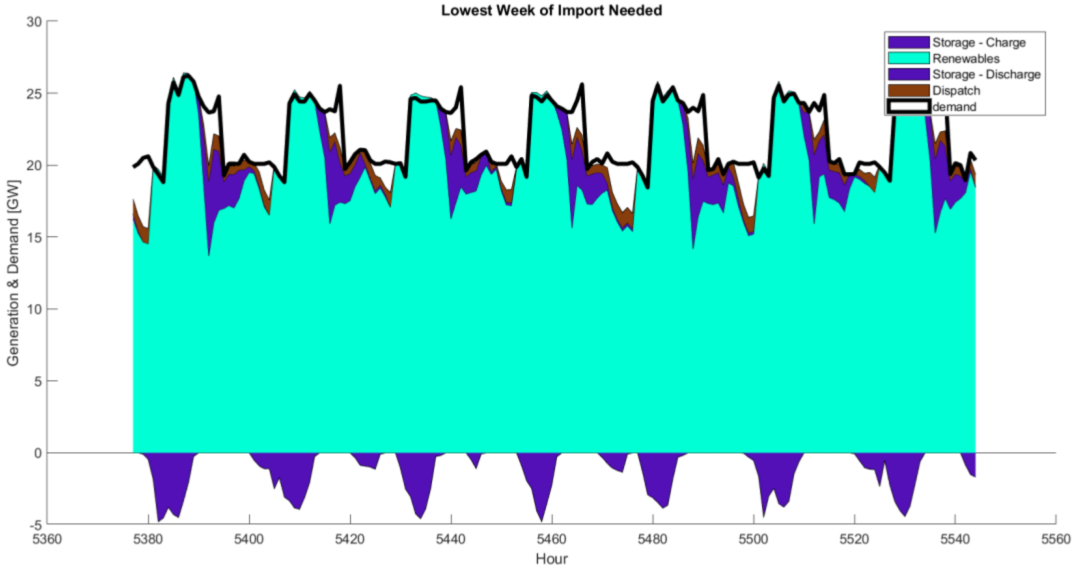

Figure 41: Kenya - highest renewable electricity production under the K-1.5C scenario in 2050

6.6 STORAGE REQUIREMENTS

6.6.1 INTRODUCTION

The quantity of storage required will be largely dependent upon the storage costs, grid expansion possibilities, and the generation mix itself. In terms of grid expansion, the geographic situation greatly influences the construction costs; crossing mountains, rivers, or swamps is significantly more expensive than crossing flat lands (Wendong 2016)[59]. Furthermore, the length of the permission process and whether people will be displaced by grid expansions may make storage economically preferable to grid expansion, even though the current transmission costs are lower per megawatt-hour than the storage costs. Cebulla et al. (2018)[60] reported that "in general terms, photovoltaic-dominated grids directly correlate to high storage requirements, in both power capacity and energy capacity. Conversely, wind-dominated scenarios require significantly lower storage power and energy capacities, if grid expansion is unlimited or cheap". In an analysis of 400 scenarios for Europe and the USA, they also found that once the share of variable renewables exceeds 40% of the total generation, the increase in electrical energy storage power capacity is about 1–2 GW for each percentage of variable renewable power generation in wind-dominated scenarios and 4–9 GW in solar-PV-dominated scenarios.

When variable power generation shares exceed 30%, storage requirements increase. The share of variable generation will exceed 30% between 2025 and 2030 under both Energy [R]evolution scenarios in all regions. Therefore, a smart grid integration strategy that includes demand-side management and the installation of additional decentralized and centralized storage capacities must be established.

Over the past decade, the cost of batteries, especially lithium batteries, has declined significantly. However, solar PV costs have also declined significantly. Storage is economic when the cost per kilowatt-hour is equal to or lower than the cost of generation. Therefore, if storage costs are high, curtailment could be economic. However, there are several reasons for curtailment, including transmission constraints, system balancing, and economic reasons (NREL 2014)[61]. The California Independent System Operator (CISO)[62] defines economic curtailment during times of oversupply as a market-based decision. "During times of oversupply, the bulk energy market first competitively selects the lowest cost power resources. Renewable resources can 'bid' into the market in a way to reduce production when prices begin to fall. This is a normal and healthy market outcome. Then, self-scheduled cuts are triggered and prioritized using operational and tariff considerations. Economic curtailments and self-scheduled cuts are considered 'market-based'".

6.6.2 DETERMINATION OF STORAGE DEMANDS

Kenya currently operates a large fleet of run-of-river hydropower plants with no pump storage capacity. However, according to the Global Pumped Hydro Atlas (ANU 2022)[63], Kenya has good storage sites with a potential of at least 2 GWh per million people. The utilization of this potential by implementing additional water reservoir storage capacities and pumped hydro storage (PHS) facilities will put Kenya in a comfortable position to integrate large amounts of variable solar PV and wind power generation. There are three types of hydropower plants:

I. Run-of-river power plants, which use the available volumes of passing river water and have limited possibilities to regulate the output; winter is usually the time with the lowest production volumes.
II. Storage power plants, which are 'run-of-river' power stations with a water storage reservoir on the intake side. Power generation can be increased and reduced within the water reservoir capacity to complement the variable demand and/or solar generation.
III. Pumped hydro storage (PHS) power plants, which have a water storage reservoir on both sides (in-take and out-flow) and can pump water after electricity generation back into the in-take reservoir. PHS plants can operate as a short-, medium-, or long-term electricity storage technology. Historically, PHS systems have been

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[59] Wendong (2016), Wei, Wendong et al. Regional study on investment for transmission infrastructure in China based on the State Grid data,10.1007/s11707-016-0581-4, Frontiers of Earth Science, June 2016.
[60] Cebulla et al. (2018), How much electrical energy storage do we need? A synthesis for the U.S., Europe, and Germany, Journal of Cleaner Production, February 2018, https://www.researchgate.net/publication/322911171_How_much_electrical_energy_storage_do_we_need_A_synthesis_for_the_US_Europe_and_Germany/link/5a782bb50f7e9b41dbd26c20/download
[61] Wind and Solar Energy Curtailment: Experience and Practices in the United States; Lori Bird, Jaquelin Cochran, and Xi Wang, National Renewable Energy Laboratory (NREL), March 2014, https://www.nrel.gov/docs/fy14osti/60983.pdf
[62] Impacts of renewable energy on grid operations, factsheet, https://www.caiso.com/Documents/CurtailmentFastFacts.pdf
[63] ANU (2022), Australian National University, 100% Renewable Energy Group, Global Pumped Hydro Energy Storage Atlas, https://re100.eng.anu.edu.au/global/

used to balance inflexible nuclear power plants, which must operate in base-load mode, and to hedge against price fluctuations on power markets.

In this analysis, we assume that 'peak-shaving' is used to avoid peak generation events. The term 'peak-shaving' refers to the reduction in the solar or hydro generation capacity in times of high production. Peak-shaving involves pro-actively managing solar generation by reducing the output, e.g., from utility-scale PV, to eliminate short-term spikes. These spikes only appear for a limited time—from minutes to hours—and significantly increase the actual grid or storage capacity because the capacity must cope with the highest peak.

With peak-shaving, this peak can be reduced with only a minor effect on the overall annual generation because peak events are relatively infrequent. The assumed "economic curtailment rate" for the N-1.5°C pathway will increase to 5% relative to the annual generation (in GWh/a) for solar PV for the years until 2030, and to 10% between 2031 and 2050. However, economic curtailment rates are dependent upon the available grid capacities and can vary significantly, even within Kenya. Curtailment will be economic when the power generated by a PV power plant exceeds the demand for only a few hours a day and this event occurs rarely across the year. Therefore, the expansion of storage capacities will not be economically justifiable.

To build up the additional required storage capacity, we assume that a percentage of the solar PV capacity will be installed with battery storage. The suggested solar battery system must be able to store the entire peak capacity for 4 full load hours. The N-1.5°C scenario requires that all utility-scale solar PV and 75% of all roof-top PV systems built after 2030 must be equipped with a battery or other storage technology systems.

The estimates provided for storage requirements also presuppose that variable renewables such as solar PV and wind will be first in the dispatch order, ahead all other types of power generation. Priority dispatch is the economic basis for investment in utility-scale solar PV and wind projects. The curtailment rates or storage rates will be significantly higher when priority dispatch is given to, for example, hydro power plants in 'baseload' generation mode.

This case has not been calculated because it would involve a lack of investment in solar in the first place. With decreasing storage costs, as projected by Bloomberg (2019)[64], interconnections may become less economically favourable than batteries. The storage estimates provided are technology neutral and do not favour any specific battery technology.

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

Table 45 shows the storage required to avoid curtailment above 10% of the annual generation for Kenya under the K-1.5°C scenario without peak-shaving. With a share of around 33% of dispatchable power generation in 2050, and an increasing share of stand-alone grids storage, capacities need to grow according to the solar photovoltaic shares.

Battery storage is mainly used in distribution grids and stand-alone-grids, while the expansion of hydro pump storage is entirely grid connected for seasonable storage on the medium and high voltage transmission grid and to provide power system relevant support such as ancillary services.

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

Table 45: Kenya: Calculated electricity storage capacities by technology and year

Storage Capacity	Units	2020	2025	2030	2035	2040	2045	2050
Battery	[MW]	0	500	3,000	5,500	8,000	10,500	13,000
Hydro Pump storage	[MW]	0	0	400	800	1,200	1,600	2,000
H2	[MW]	0	10	13	3	5	11	22
Total	[MW]	0	510	3,413	6,303	9,205	12,111	15,022

6.6.3 COST DEVELOPMENT—BATTERY STORAGE TECHNOLOGIES

Battery technologies have developed significantly over the past decade, and the global annual market increased from 700 MW in 2015 to close to 16,000 MW in 2021 (IEA-BAT 2020)[65]. The market is split roughly equally between grid-scale storage and 'behind-the-meter' storage for solar PV projects. The rapidly growing demand for electric vehicles has significantly accelerated the development of battery technologies, and manufacturing capacities have grown by double digits, with costs decreasing accordingly. The battery costs per kilowatt-hour storage capacity decreased from US$668 (KES 100,000) in 2013 to US$137 (KES 20,550) in 2020—a reduction of 79% over the past 7 years. Bloomberg New Energy Finance estimates that battery costs will decline further to around US$58 (KES 8700) by 2030.

6.6.4 FURTHER RESEARCH REQUIRED

A calculation of the required investment costs in storage technologies that will be needed after 2030 and by 2050 would entail such high uncertainty that such estimates seem meaningless. Furthermore, a more-detailed storage technology assessment for the K-1.5C scenario based on the specific situation of Kenya—with its unique potential for stand-alone grid that get interconnected with the expanding national grid over time between 2030 and 2050 is required.

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[65] IEA-BAT (2020) IEA Energy Storage – website viewed October 2022, https://www.iea.org/reports/grid-scale-storage

7 Kenya: Data Annex

Kenya 1.5˚C

Electricity generation [TWh/a]	2020	2025	2030	2035	2040	2045	2050
Power plants	10	17	37	85	156	200	229
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	0	0	0	0	0
of which from H2	0	0	0	1	3	5	6
- Oil	1	1	1	1	0	0	0
- Diesel	0	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	1	1	3	4	4
- Hydro	3	3	4	6	8	9	10
- Wind	1	4	9	18	27	39	49
of which wind offshore	0	1	2	4	7	9	9
- PV	0	4	15	41	84	108	119
- Geothermal	4	5	0	11	17	18	20
- Solar thermal power plants	0	0	1	7	14	18	20
- Ocean energy	0	0	0	1	2	3	3
Combined heat and power plants	0	0	0	0	0	0	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	0	0	0	0	0
of which from H2	0	0	0	0	0	0	0
- Oil	0	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0
CHP by producer							
- Main activity producers	0	0	0	0	0	0	0
- Autoproducers	0	0	0	0	0	0	0
Total generation	10	18	38	86	158	203	232
- Fossil	1	1	1	1	0	0	0
- Hard coal (& non-renewable waste)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
- Lignite	0.000	0.000	0.000	0.000	0.000	0.000	0.000
- Gas	0.000	0.000	0.000	0.000	0.000	0.000	0.000
- Oil	1.236	1.361	0.910	0.735	0.000	0.000	0.000
- Diesel	0.000	0.000	0.000	0.000	0.000	0.000	0.000
- Nuclear	0.000	0.000	0.000	0.000	0.000	0.000	0.000
- Hydrogen	0.000	0.015	0.152	1.103	3.443	5.303	6.111
- of which renewable H2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
- Renewables (w/o renewable hydrogen)	8	16	37	85	158	203	232
- Hydro	3	3	4	6	8	9	10
- Wind	1	4	9	18	27	39	49
- PV	0	4	15	41	84	108	119
- Biomass (& renewable waste)	0	0	1	1	3	4	4
- Geothermal	4	5	8	11	17	18	20
- Solar thermal power plants	0	0	1	7	14	18	20
- Ocean energy	0	0	0	1	2	3	3
Distribution losses	2	1	2	5	9	11	13
Own consumption electricity	0	1	2	5	9	11	13
Electricity for hydrogen production	0	2	7	13	20	26	29
Electricity for synfuel production	0	0	0	0	0	0	0
Final energy consumption (electricity)	8	13	26	64	120	154	178
Variable RES (PV, Wind, Ocean)	1	7	23	59	113	150	171
Share of variable RES	15%	41%	62%	69%	72%	74%	74%
RES share (domestic generation)	87%	92%	98%	99%	100%	100%	100%

Transport - Final Energy [PJ/a]	2020	2025	2030	2035	2040	2045	2050
road	144	144	114	72	67	64	62
- fossil fuels	144	144	108	36	23	10	0
- biofuels	0	0	5	10	12	15	18
- synfuels	0	0	0	0	0	0	0
- natural gas	0	0	0	0	0	0	0
- hydrogen	0	0	0	0	0	0	0
- electricity	0	0	2	26	32	39	44
rail	3	3	4	4	3	3	4
- fossil fuels	3	3	3	2	0	0	0
- biofuels	0	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0	0
- electricity	0	1	1	2	3	3	4
navigation	0	0	0	0	0	0	0
- fossil fuels	0	0	0	0	0	0	0
- biofuels	0	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0	0
aviation	2	2	2	2	3	3	4
- fossil fuels	2	1	2	1	1	1	0
- biofuels	0	0	0	1	1	2	3
- synfuels	0	0	0	0	1	1	1
total (incl. pipelines)	149	149	120	78	73	71	70
- fossil fuels	149	148	112	39	24	11	0
- biofuels (incl. biogas)	0	0	5	11	13	17	21
- synfuels	0	0	0	0	1	1	1
- natural gas	0	0	0	0	0	0	0
- hydrogen	0	0	0	0	0	0	0
- electricity	0	1	3	28	35	42	48
total RES	0	1	8	39	49	60	70
RES share	0%	1%	7%	50%	67%	85%	100%

Heat supply and air conditioning [PJ/a]	2020	2025	2030	2035	2040	2045	2050
District heating plants	0	0	0	0	0	0	0
- Fossil fuels	0	0	0	0	0	0	0
- Biomass	0	0	0	0	0	0	0
- Solar collectors	0	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0	0
Heat from CHP 1)	0	0	0	0	0	0	0
- Fossil fuels	0	0	0	0	0	0	0
- Biomass	0	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0
Direct heating	324	395	448	562	578	622	658
- Fossil fuels	58	60	56	43	18	5	0
- Biomass	251	273	284	303	146	83	22
- Solar collectors	0	26	41	64	83	98	123
- Geothermal	0	10	17	26	42	60	83
- Heat pumps 2)	0	4	16	55	131	166	188
- Electric direct heating	16	19	28	57	121	163	181
- Hydrogen	0	0	0	1	4	6	7
Total heat supply3)	324	395	448	562	578	622	658
- Fossil fuels	58	60	56	43	18	5	0
- Biomass	251	273	284	303	146	83	22
- Solar collectors	0	26	41	64	83	98	123
- Geothermal	0	10	17	26	42	60	83
- Heat pumps 2)	0	4	16	55	131	166	188
- Electric direct heating (incl. process heat)	16	21	34	69	154	205	234
- Hydrogen	0	0	0	1	4	6	7
RES share (including RES electricity)	82%	84%	87%	92%	97%	99%	100%
electricity consumption heat pumps (TWh/a)	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Installed Capacity [GW]	2020	2025	2030	2035	2040	2045	2050
Total generation	3	7	16	41	77	100	113
- Fossil	1	1	1	1	0	0	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas (w/o H2)	0	0	0	0	0	0	0
- Oil & Diesel	1	1	1	1	0	0	0
- Diesel	0	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0	0
- Hydrogen (fuel cells, gas power plants, ga	0	0	0	0	1	2	2
- Renewables	2	6	15	39	76	98	111
- Hydro	1	1	1	2	3	3	3
- Wind	0	1	3	7	10	14	18
of which wind offshore	0	0	1	1	2	3	3
- PV	0	2	9	26	53	68	75
- Biomass (& renewable waste)	0.022	0.069	0.139	0.336	0.629	0.8	0.9
- Geothermal	1	1	1	1	2	2	3
- Solar thermal power plants	0	0	1	3	6	8	9
- Ocean energy	0	0	0	0	1	1	2
Variable RES (PV, Wind, Ocean)	1	4	12	33	64	84	95
Share of variable RES	18%	54%	77%	81%	83%	84%	84%
RES share (domestic generation)	66%	82%	95%	97%	99%	98%	100%

Final Energy Demand [PJ/a]	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-Energy use)	744	837	872	873	858	904	934
Total Energy use 1)	740	832	866	866	850	894	922
Transport	147	149	120	78	73	71	70
- Oil products	146	148	112	39	24	11	0
- Natural gas	0	0	0	0	0	0	0
- Biofuels	0	0	5	11	13	17	21
- Synfuels	0	0	0	0	1	1	1
- Electricity	0	1	3	28	35	42	48
RES electricity	0	1	3	28	35	42	48
- Hydrogen	0	0	0	0	0	0	0
RES share Transport	0%	1%	7%	50%	67%	85%	100%
Industry	59	78	100	150	181	206	226
- Electricity	17	25	37	71	114	138	160
RES electricity	15	23	36	70	114	138	160
- Public district heat	0	0	0	0	0	0	0
RES district heat	0	0	0	0	0	0	0
- Hard coal & lignite	21	29	28	32	11	5	0
- Oil products	20	22	20	13	8	0	0
- Gas	0	0	0	0	0	0	0
- Solar	0	2	5	8	10	14	16
- Biomass	0	0	8	20	25	29	26
- Geothermal	0	1	2	4	6	8	10
- Hydrogen	0	0	1	2	7	12	13
RES share Industry	26%	33%	51%	70%	90%	97%	100%
Other Sectors	535	605	646	638	595	616	626
- Electricity	9	20	54	129	279	369	427
RES electricity	8	19	52	128	279	369	427
- Public district heat	0	0	0	0	0	0	0
RES district heat	0	0	0	0	0	0	0
- Hard coal & lignite	0	0	0	0	0	0	0
- Oil products	28	23	19	7	2	0	0
- Gas	0	0	0	0	0	0	0
- Solar	0	24	37	56	72	84	107
- Biomass + Charcoal	497	529	521	423	205	111	18
- Geothermal	0	10	16	22	36	52	74
- Hydrogen	0	0	0	0	0	0	0
RES share Other Sectors	94%	96%	97%	99%	100%	100%	100%
Total RES	520	608	685	774	804	878	922
RES share	70%	73%	79%	89%	95%	98%	100%
Non energy use	5	5	5	7	9	11	12
- Oil	5	5	5	7	8	10	12
- Gas	0	0	0	0	0	0	0
- Coal	0	0	0	0	0	0	0

Energy-Releated CO2 Emissions [Million tons/a]	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	1	1	1	0	0	0	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	0	0	0	0	0
- Oil + Diesel	1	1	1	0	0	0	0
Combined heat and power plants	0	0	0	0	0	0	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	0	0	0	0	0
- Oil	0	0	0	0	0	0	0
CO2 emissions power and CHP plants	1	1	1	0	0	0	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	0	0	0	0	0
- Oil + Diesel	1	1	1	0	0	0	0
CO2 intensity (g/kWh)	0	0	0	0	#REF!	0	0
without credit for CHP heat	0	0	0	0	0	0	0
- CO2 intensity fossil electr. generation	534	575	622	677	0	0	0
- CO2 intensity total electr. generation	69	45	15	6	0	0	0
CO2 emissions by sector	18	20	16	9	4	1	0
0	0%	0%	0%	0%	0%	0%	0%
- Industry 1)	4	5	5	4	2	1	0
- Other sectors 1)	2	3	3	2	1	0	0
- Transport	11	11	8	3	2	1	0
- Power generation 2)	1	1	1	0	0	0	0
- Other conversion 3) - part of industry & tr	1	1	1	0	0	0	0
Population (Mill.)	54	57	63	69	75	80	84
CO2 emissions per capita (t/capita)	0	0	0	0	0	0	0

Primary Energy Demand [PJ/a]	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy-use)	1,094	1,227	1,276	1,134	1,151	1,203	1,210
- Fossil (excluding on-energy use)	230	246	202	111	53	17	0
- Hard coal	21	28	28	32	11	5	0
- Lignite	0	1	0	0	0	0	0
- Natural gas	0	0	0	0	0	0	0
- Crude oil	209	218	174	79	42	11	0
- Nuclear	0	0	0	0	0	0	0
- Renewables	859	975	1,069	1,017	1,089	1,176	1,198
- Hydro	9	11	13	21	30	32	37
- Wind	5	7	14	34	50	80	110
- Solar	1	38	100	272	522	659	752
- Biomass	830	890	896	620	381	272	131
- Geothermal	15	30	45	66	101	123	157
- Ocean energy	0	0	1	3	6	10	11
Total RES	859	975	1,068	1,016	1,087	1,173	1,194
RES share	79%	80%	84%	90%	95%	99%	100%

Kenya

REFERENCE

Electricity generation [TWh/a]	2020	2025	2030	2035	2040	2045	2050
Power plants	14	28	42	64	90	118	157
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	0	0	0	0	0
of which from H2	0	0	0	0	0	0	2
- Oil	2	3	5	7	7	3	1
- Diesel	0	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0	0
- Biomass (& renewable waste)	0	1	1	1	2	2	3
- Hydro	4	5	4	4	5	5	7
- Wind	2	5	9	10	18	26	36
of which wind offshore	0	1	2	4	5	7	8
- PV	0	3	6	13	25	47	74
- Geothermal	6	11	0	23	27	25	20
- Solar thermal power plants	0	0	1	5	8	10	14
- Ocean energy	0	0	0	1	1	1	2
Combined heat and power plants	0	0	0	0	0	0	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	0	0	0	0	0
of which from H2	0	0	0	0	0	0	0
- Oil	0	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0
CHP by producer							
- Main activity producers	0	0	0	0	0	0	0
- Autoproducers	0	0	0	0	0	0	0
Total generation	14	28	42	64	91	119	159
- Fossil	2	3	5	7	7	3	1
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	0	0	0	0	0
- Oil	2	3	5	7	7	3	1
- Diesel	0	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	2
- of which renewable H2	0	0	0	0	0	0	0
- Renewables (w/o renewable hydrogen)	12	25	38	58	84	116	158
- Hydro	4	5	4	4	5	5	7
- Wind	2	5	9	10	18	26	36
- PV	0	3	6	13	25	47	74
- Biomass (& renewable waste)	0	1	1	1	2	2	3
- Geothermal	6	11	15	23	27	25	20
- Solar thermal power plants	0	0	1	5	8	10	14
- Ocean energy	0	0	0	1	1	1	2
Distribution losses	3	2	2	3	5	6	9
Own consumption electricity	0	2	2	4	5	6	8
Electricity for hydrogen production	0	2	7	11	16	20	24
Electricity for synfuel production	0	0	0	0	0	0	0
Final energy consumption (electricity)	11	22	31	46	66	87	118
Variable RES (PV, Wind, Ocean)	2	8	16	24	43	74	112
Share of variable RES	15%	27%	37%	37%	48%	62%	71%
RES share (domestic generation)	87%	88%	89%	89%	93%	98%	99%

Transport - Final Energy [PJ/a]	2020	2025	2030	2035	2040	2045	2050
road	144	144	115	107	104	100	97
- fossil fuels	144	144	108	84	73	59	45
- biofuels	0	0	6	11	13	16	22
- synfuels	0	0	0	0	0	0	0
- natural gas	0	0	0	0	0	0	0
- hydrogen	0	0	0	0	0	0	0
- electricity	0	0	2	13	18	26	31
rail	3	3	4	4	3	3	4
- fossil fuels	3	3	3	2	0	0	0
- biofuels	0	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0	0
- electricity	0	1	1	2	3	3	4
navigation	0	0	0	0	0	0	0
- fossil fuels	0	0	0	0	0	0	0
- biofuels	0	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0	0
aviation	2	2	2	2	3	3	4
- fossil fuels	2	1	2	1	1	1	0
- biofuels	0	0	0	1	1	2	3
- synfuels	0	0	0	0	1	1	1
total (incl. pipelines)	149	149	121	113	110	107	105
- fossil fuels	149	148	113	87	74	59	45
- biofuels (incl. biogas)	0	0	6	11	14	18	24
- synfuels	0	0	0	0	1	1	1
- natural gas	0	0	0	0	0	0	0
- hydrogen	0	0	0	0	0	0	0
- electricity	0	1	3	15	21	29	35
total RES	0	1	8	25	34	47	60
RES share	0%	1%	7%	22%	31%	44%	57%

Heat supply and air conditioning [PJ/a]	2020	2025	2030	2035	2040	2045	2050
District heating plants	0	0	0	0	0	0	0
- Fossil fuels	0	0	0	0	0	0	0
- Biomass	0	0	0	0	0	0	0
- Solar collectors	0	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0	0
Heat from CHP 1)	0	0	0	0	0	0	0
- Fossil fuels	0	0	0	0	0	0	0
- Biomass	0	0	0	0	0	0	0
- Geothermal	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0
Direct heating	331	400	453	523	589	643	740
- Fossil fuels	64	73	88	120	116	98	51
- Biomass	251	289	317	340	348	346	369
- Solar collectors	0	9	10	11	33	55	81
- Geothermal	0	8	10	13	18	28	37
- Heat pumps 2)	0	1	2	3	9	29	69
- Electric direct heating	16	18	20	21	25	35	68
- Hydrogen	0	0	0	1	4	7	7
Total heat supply3)	331	400	453	523	589	643	740
- Fossil fuels	64	73	88	120	116	98	51
- Biomass	251	289	317	340	348	346	369
- Solar collectors	0	9	10	11	33	55	81
- Geothermal	0	8	10	13	18	28	37
- Heat pumps 2)	0	1	2	3	9	29	69
- Electric direct heating (incl. process heat)	16	20	26	35	60	81	125
- Hydrogen	0	0	0	1	4	7	7
RES share (including RES electricity)	80%	81%	80%	76%	79%	84%	93%
electricity consumption heat pumps (TWh/a)	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Installed Capacity [GW]	2020	2025	2030	2035	2040	2045	2050
Total generation	5	11	17	29	44	65	94
- Fossil	2	3	4	6	6	3	1
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas (w/o H2)	0	0	0	0	0	0	0
- Oil & Diesel	2	3	4	6	6	3	1
- Diesel	0	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0	0
- Hydrogen (fuel cells, gas power plants, ga	0	0	0	0	0	0	1
- Renewables	3	8	13	23	38	62	92
- Hydro	1	2	1	1	1	2	2
- Wind	1	2	3	3	6	8	12
of which wind offshore	0	0	1	1	1	2	2
- PV	0	2	6	12	22	43	68
- Biomass (& renewable waste)	0.031	0.118	0.160	0.243	0.344	0.5	0.6
- Geothermal	1	2	2	3	4	3	3
- Solar thermal power plants	0	0	1	2	3	4	6
- Ocean energy	0	0	0	0	1	1	1
Variable RES (PV, Wind, Ocean)	1	4	9	16	29	52	81
Share of variable RES	23%	40%	52%	55%	66%	81%	86%
RES share (domestic generation)	68%	72%	77%	79%	86%	96%	99%

Final Energy Demand [PJ/a]	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-Energy use)	765	890	951	1,065	1,165	1,228	1,213
Total Energy use 1)	760	884	945	1,057	1,156	1,217	1,200
Transport	147	149	121	113	110	107	105
- Oil products	146	148	113	87	74	59	45
- Natural gas	0	0	0	0	0	0	0
- Biofuels	0	0	6	11	14	18	24
- Synfuels	0	0	0	0	1	1	1
- Electricity	0	1	3	15	21	29	35
RES electricity	0	1	2	13	20	28	34
- Hydrogen	0	0	0	0	0	0	0
RES share Transport	0%	1%	7%	22%	31%	44%	57%
Industry	75	99	130	203	254	282	305
- Electricity	26	35	50	80	122	154	180
RES electricity	22	31	45	71	113	150	179
- Public district heat	0	0	0	0	0	0	0
RES district heat	0	0	0	0	0	0	0
- Hard coal & lignite	25	35	44	69	76	64	42
- Oil products	25	26	31	41	34	29	11
- Gas	0	0	0	0	0	0	0
- Solar	0	1	1	2	3	10	14
- Biomass	0	2	2	4	5	4	33
- Geothermal	0	1	2	4	6	8	11
- Hydrogen	0	0	1	3	8	13	14
RES share Industry	30%	35%	38%	41%	53%	66%	82%
Other Sectors	538	636	693	741	792	827	790
- Electricity	13	42	56	71	91	127	207
RES electricity	12	37	50	63	84	124	206
- Public district heat	0	0	0	0	0	0	0
RES district heat	0	0	0	0	0	0	0
- Hard coal & lignite	0	0	0	0	0	0	0
- Oil products	28	28	31	33	28	23	8
- Gas	0	0	0	0	0	0	0
- Solar	0	8	9	9	30	45	67
- Biomass + Charcoal	497	551	590	620	630	613	481
- Geothermal	0	7	8	8	12	19	27
- Hydrogen	0	0	0	0	0	0	0
RES share Other Sectors	94%	95%	95%	95%	96%	97%	99%
Total RES	531	639	715	809	925	1,034	1,091
RES share	70%	72%	76%	77%	80%	85%	91%
Non energy use	5	5	6	8	10	12	13
- Oil	5	5	6	8	10	11	13
- Gas	0	0	0	0	0	0	0
- Coal	0	0	0	0	0	0	0

Energy-Releated CO2 Emissions [Million tons/a]	2020	2025	2030	2035	2040	2045	2050
Condensation power plants	1	2	3	5	5	2	1
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	0	0	0	0	0
- Oil + Diesel	1	2	3	5	5	2	1
Combined heat and power plants	0	0	0	0	0	0	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	0	0	0	0	0
- Oil	0	0	0	0	0	0	0
CO2 emissions power and CHP plants	1	2	3	5	5	2	1
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	0	0	0	0	0	0	0
- Oil + Diesel	1	2	3	5	5	2	1
CO2 intensity (g/kWh)	0	0	0	0	#REF!	0	0
without credit for CHP heat	0	0	0	0	0	0	0
- CO2 intensity fossil electr. generation	534	575	622	677	743	824	924
- CO2 intensity total electr. generation	69	68	67	73	55	21	8
CO2 emissions by sector	20	22	22	26	24	17	10
0	0%	0%	0%	0%	0%	0%	0%
- Industry 1)	5	6	7	11	11	9	5
- Other sectors 1)	2	3	4	4	3	2	1
- Transport	11	11	8	7	6	5	3
- Power generation 2)	1	2	3	5	5	2	1
- Other conversion 3) - part of industry & tr	1	1	1	1	1	1	0
Population (Mill.)	54	57	63	69	75	80	84
CO2 emissions per capita (t/capita)	0	0	0	0	0	0	0

Primary Energy Demand [PJ/a]	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-energy-use)	1,120	1,303	1,422	1,615	1,766	1,811	1,567
- Fossil (excluding on-energy use)	242	278	274	311	292	208	122
- Hard coal	25	34	44	69	76	64	42
- Lignite	0	1	0	0	0	0	0
- Natural gas	0	0	0	0	0	0	0
- Crude oil	217	243	230	242	215	144	80
- Nuclear	0	0	0	0	0	0	0
- Renewables	873	1,020	1,142	1,297	1,465	1,592	1,432
- Hydro	13	19	15	15	16	18	24
- Wind	7	12	17	10	27	45	73
- Solar	1	18	41	102	190	316	477
- Biomass	830	922	1,004	1,071	1,112	1,090	739
- Geothermal	22	49	65	97	116	117	111
- Ocean energy	0	0	1	2	3	5	7
Total RES	873	1,019	1,142	1,296	1,463	1,590	1,430
RES share	78%	79%	81%	81%	83%	88%	92%

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