UTS Institute for Sustainable Futures

Tanzania:
Energy Development Plan to decarbonize the Economy

prepared for Power Shift Africa

REPORT FOR PUBLIC CONSULTATION

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

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The energy scenario software for the long-term projections and economic parameters is based on the development 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

The authors have used all due care and skill to ensure the material is accurate as at the date of this report. UTS and the authors do not accept any responsibility for any loss that may arise by anyone relying upon its contents.

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Table of Contents

Report for Public Consultation

The energy report ***'Tanzania: 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 Tanzania 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 Tanzania. 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 Tanzania'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 Tanzania 1.5 °C (T-1.5°C) scenario is designed to calculate the efforts and actions required to achieve the ambitious objective of a 100% renewable energy system and to illustrate the options available to change the Tanzania'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 Tanzania'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 Tanzania 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).
- Effects of all scenarios on employment.
- 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 TANZANIA: COUNTRY OVERVIEW

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

The nation recognizes the importance of addressing climate change issues. Although the country currently does not have a stand-alone national climate change policy but rather climate change aspects have been integrated into sectorial and national policies. Furthermore, the country has a national climate change strategy 2021(NCCRS 2021) that provides an overarching framework guiding the nation on addressing climate change aspects together with the revised National Determined contribution 2021 that highlights the national commitments in climate change aspects. The NCCRS 2021 and NDC 2021 both have identified the energy sector as one of the key sectors that contributes to greenhouse gas emissions and is also vulnerable to the impacts of climate change. According to the World Resource Institute- Climate Analysis Indicators Tool (CAIT), Tanzania energy sector has a growing emission and in 2020 it emitted 17.96 Mt of CO2 as seen in Figure 1. Climate change impacts have greatly affected Tanzania in various ways among which are electricity rationing due to decreased output from hydropower plants as result of drought or delayed rainfall, destruction of infrastructures from floods and more.

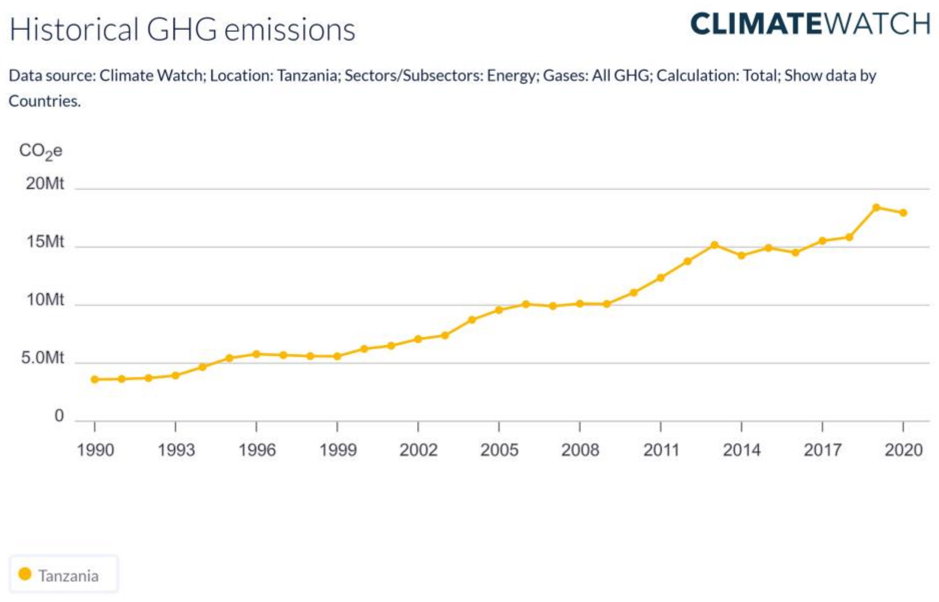

Figure 1: Historical GHG emission from the energy sector[2].

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[2] Source: Climate Watch Historical GHG Emissions. 2022. Washington, DC: World Resources Institute. Available online at: https://www.climatewatchdata.org/ghg-emissions accessed on 02-November 2023

2.1.1 POLITICAL CONTEXT

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

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

According to the Tanzania Mainland Energy Access and Use Situation Survey II (2020), for the year 2019/20; 78.4 percent of the Tanzania mainland total population have access to electricity comparing to 67.5 percent in a year 2016/17. The report reveals 11 percent increase in electricity access from the previous survey conducted in a year 2016/17.

In addition, the survey analysis showed urban - rural differentials in electricity access and that urban access to electricity rose from 97.3 percent to 99.6 percent, while in rural areas electricity access remained significantly lower as compared to urban areas and rose from 49.3 percent in a year 2016/17 to 68.9 percent in a year 2019/20. Such kind of differentials continue to create a room for sluggish in inclusiveness initiatives for fostering economic and socio ecological stewardship in rural communities.

Seven regions of Dar es Salaam, Kilimanjaro, Mwanza, Mbeya, Mara, Pwani and Geita were recorded with highest electricity access of 100, 93.6, 89.9, 89.0, 87.7, 85.8 and 84.4 percentages respectively, leaving Kigoma (56.3%), Manyara (58.1%), Shinyanga (61.7%), Songwe (61.9%) and Rukwa (64.8%) with least electricity access in the country.

Despite the growth there is need of more efforts to enable universal access to energy in Tanzania as per her inspiration, national and international commitment. Tanzania government have put more effort in increasing electricity access to many communities as it could be however household connected to electricity remains low. Tanzania Mainland Energy Access and Use Situation Survey II (2020) reports that only 37.7% of household in Tanzania mainland were connected to electricity by the year 2020. There were a 5.1% rise in electricity connectivity to household as compared to the year 2016/2017[3].

Tanzania has recognized the importance of renewable energy sources in reducing greenhouse gas emissions and ensuring energy security. The country has been investing in renewable energy projects, mostly being hydroelectric power together with growing investments in wind, solar and geothermal. The development of these sources aims to diversify the energy mix and reduce reliance on fossil fuels. For example, connecting Kigoma solar based 5 MW to the national grid and the commencement of construction of a 50 MW Kishapu Solar Power plant.

Tanzania Electric Supply Company Limited (TANESCO) is developing the Kishapu power plant whose generated electricity will be connected to the national grid. The solar farm will be constructed in stages up to its planned total capacity of 150 MW. This will be the nation's biggest grid-ready solar power plant when commissioned and operational.

In recognition of the contribution of un-sustainable biomass (charcoal and firewood) use in cooking accounting for nearly 85% of the national energy consumption. The government is in process of developing a national clean cooking vision that will be an inclusive national plan to address the increasing environmental impacts and the health, economic, and social consequences resulting from the use of unclean cooking solutions. The country has also developed the national charcoal strategy and action plan (2021-2031) which envision the charcoal value chains in Tanzania become sustainable, economically viable, and environmentally sound while improving livelihoods.

Furthermore, Tanzania has on-going policy initiatives which are the on-going development which are at different stages of development by November 2023. These include the National Renewable Energy strategy and Road Map, National Clean cooking vision, National Energy Efficiency Action Plan and Energy Sector Environment Action Plan. The finalization of these documents is expected to enable growth of renewable energy, clean cooking, energy efficiency and environmental sustainability of energy sector respectively.

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[3] Renewable Energy Baseline Data Assessment Report - SEED DATA TO GROW CLIMATE ACTION IN TANZANIA RENEWABLE ENERGY (RE) SECTOR, The report '*Renewable Energy Baseline Data Assessment*' was developed in scope of a project funded by Bread for the World [Aligning II: ALIGNING CLIMATE RESILIENCE, RENEWABLE ENERGY EXPANSION AND SUSTAINABLE DEVELOPMENT IN TANZANIA (PHASE II)], CAN-Tanzania, May 2022

2.1.2 POPULATION DEVELOPMENT

Table 1: Overview— 9 Modelling regions of Tanzania

Scenario Region	Provinces	Regions	Population [2022]	Area [km²]	Population Density
1	Southern Zone	Lindi	864,652	69,087	12.5
		Mtwara	1,270,854	18,500	68.7
		Ruvuma	1,376,891	63,932	21.5
	Southern Zone		**3,512,397**	**151,519**	**23.2**
2	Southern Highlands Zone	Mbeya	1,708,548	37,558	45.5
		Njombe	702,097	23,213	30.2
		Songwe	998,862	26,215	38.1
	Southern Highlands Zone		**3,409,507**	**86,986**	**39.2**
3	South-Central Zone	Iringa	941,238	36,010	26.1
		Morogoro	2,218,492	72,396	30.6
	South-Central Zone		**3,159,730**	**108,407**	**29.1**
4	Coastal Zone	Dar es Salaam	4,364,541	1,211	3604.8
		Kaskazini Pemba	211,732	524	403.8
		Kaskazini Unguja	187,455	452	414.9
		Kusini Pemba	195,116	541	360.5
		Kusini Unguja	115,588	965	119.8
		Mjini Magharibi	593,678	232	2562.1
		Pwani	1,098,668	33,464	32.8
		Tanga	2,045,205	27,462	74.5
	Coastal Zone		**8,811,983**	**64,850**	**135.9**
5	Western Zone	Katavi	564,604	51,066	11.1
		Kigoma	2,127,930	46,834	45.4
		Rukwa	1,004,539	27,257	36.9
	Western Zone		**3,697,073**	**125,157**	**29.5**
6	West-Central Zone	Shinyanga	1,534,808	17,350	88.5
		Tabora	2,291,623	76,998	29.8
	West-Central Zone		**3,826,431**	**94,348**	**40.6**
7	Central/Capital	Dodoma	2,083,588	41,368	50.4
		Singida	1,370,637	49,567	27.7
	Central/Capital		**3,454,225**	**90,935**	**38.0**
8	Northern Highlands Zone	Arusha	1,694,310	41,776	40.6
		Kilimanjaro	1,640,087	14,487	113.2
		Manyara	1,425,131	42,773	33.3
	Northern Highlands Zone		**4,759,528**	**99,036**	**48.1**
9	Lake Zone	Geita	1,739,530	20,782	80.7
		Kagera	2,458,023	37,070	66.3
		Mara	1,743,830	30,087	58.0
		Mwanza	2,772,509	28,458	97.4
		Simiyu	1,584,157	22,886	69.2
	Lake Zone		**10,298,049**	**139,284**	**73.9**

Source: Population 2022 – Tanzania Census 2022 (The United Republic of Tanzania)[4]: Area (km²) – World Administration Divisions (ESRI)

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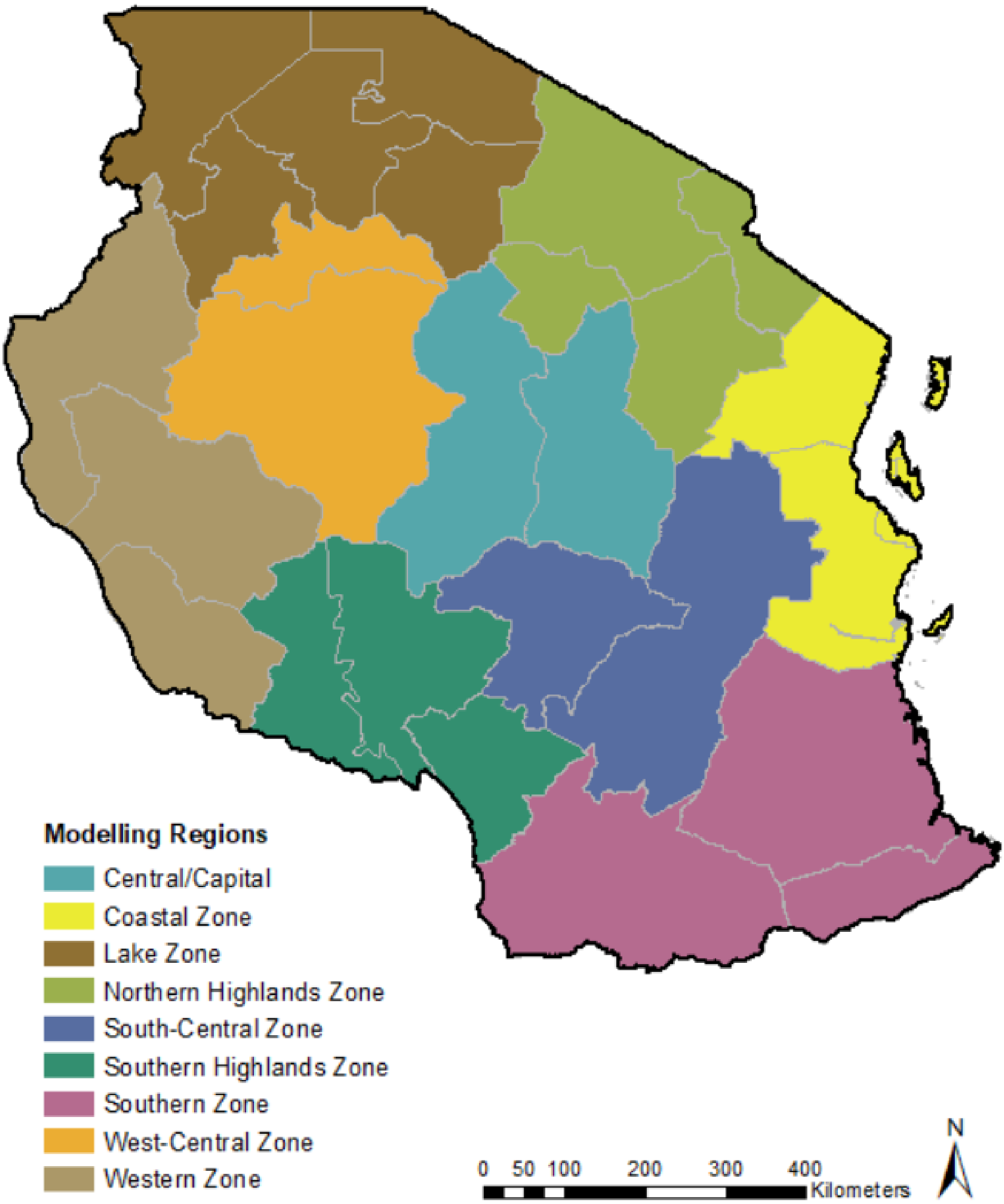
[4] Population 2022 – Tanzania Census 2022 (The United Republic of Tanzania): https://www.nbs.go.tz/nbs/takwimu/Census2022/



Source: UTS/ISF generated using World Administration Divisions (ESRI)

Figure 2: Tanzania—Modelling Regions

2.1.3 ECONOMIC CONTEXT

According to the World Bank, Tanzania has achieved respectable growth in the past, averaging 6.2% between 2009 and 2019. (World B 2022)[5]. However, Tanzania faces significant vulnerabilities in achieving inclusive and sustainable growth. The on-going 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 Tanzania's Government, which have been used for the NDC and the long-term energy plan.

Table 2: Tanzania's population and GDP projections until 2050

Tanzania	Units	2019	2025	2030	2035	2040	2045	2050
Population	[individuals]	58,005,461	69,147,027	79,270,600	90,116,099	101,606,261	113,544,743	125,782,639
Annual Population Growth	[%/a]	3.00%	2.80%	2.62%	2.47%	2.31%	2.15%	1.98%
GDP	[US$ billion]	60.32	80.98	114.00	159.89	222.16	306.96	420.17
Annual Economic Growth (data for 2030, 2040 and 2050 from LTLEDS)	[%/a]	5.8%	6.4%	7.3%	6.8%	6.8%	6.6%	6.4%
GDP/Person (calculated)	[US$/capita]	1040	1175	1439	1769	2165	2655	3247

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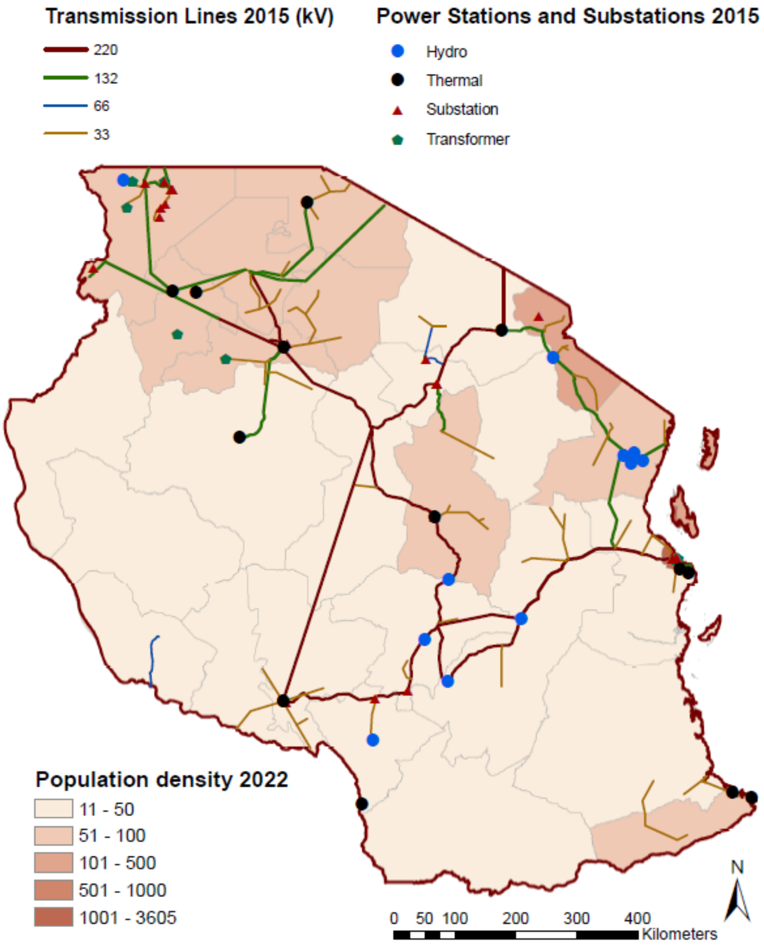
[5] World Bank 2022, Country Overview Tanzania, database from 2022.

2.2 ELECTRICITY INFRASTRUCTURE AND ENERGY ACCESS

For this analysis, Tanzania's power sector is divided into nice regions (Table 1). 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 & transmission network – World Bank Group (2014), substations - KTH Division of Energy Systems Analysis (2015))[6]

Figure 3: Distribution of population and the existing electricity infrastructure in Tanzania

Figure 3 also shows the population density of Tanzania. 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 Dar es Salaam and Coastal Zone (e.g. Zanzibar) of the country.

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 claim to be complete. The energy access rate of the rural population in mainland Tanzania is around 78%, although access to energy services does not necessarily mean that the supply is always available (see also section 2.1.1

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[6] Power stations & transmission network – World Bank Group (2014): https://energydata.info/dataset/tanzania-electricity-transmission-network-2014 , substations - KTH Division of Energy Systems Analysis (2015) https://energydata.info/dataset/tanzania---power-plants--2015-

2.3 ENERGY DEMAND—DEVELOPMENT SINCE 2005

It is necessary to analyse the development of the past energy demand to project that of the future. Therefore, the statistical data for Tanzania's energy demand between 2005 and 2019 have been analysed (IEA 2022)[7].

Figure 4 shows Tanzania's final energy demand development between 2005 and 2019. The overall energy demand grew constantly, despite years of reduced demand due to reduced economic activity. The gross final energy demand has grown by about 30% since 2005 to around 760 petajoules per annum (PJ/a). The main energy demand is required in the residential sector, whereas only 11% of the energy is for industry use and 12% for the transport sector.

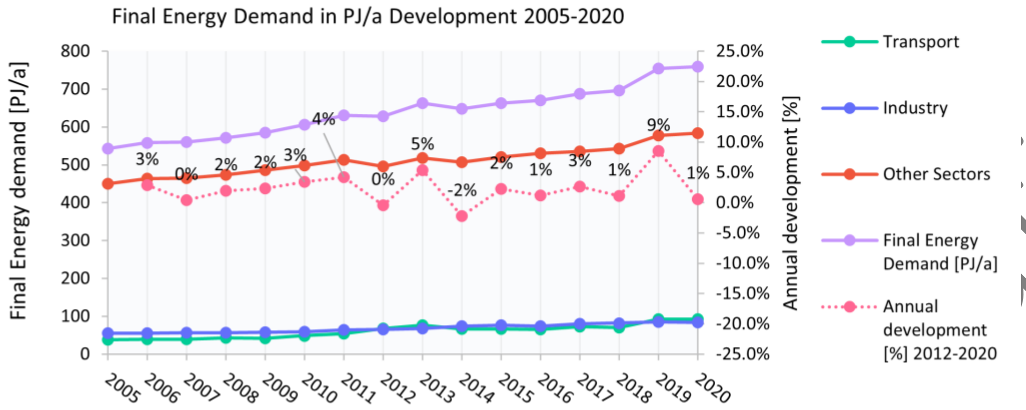

Figure 4: Final energy demand development in Tanzania from 2005 to 2019

The electricity demand has increased significantly faster than the final energy demand. By 2019, the annual electricity demand was around 7 billion kilowatt-hours (6.7 TWh/a), up from 2.6 TWh/a in 2005 (Figure 5), growing by a factor of 2.6. 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.

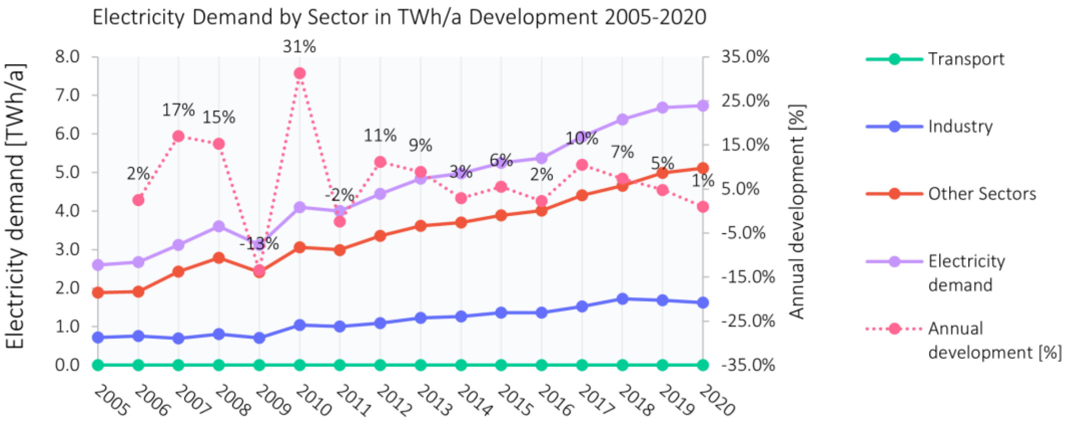

Figure 5: Electricity demand development in Tanzania from 2005 to 2020

However, Tanzania's electricity demand is currently 116 kWh per capita, one of the lowest in the world (IBN 2011)[8], with the global average consumption over 3000 kWh per annum (World Bank 2019)[9].

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[7] IEA 2022, Advanced World Energy Balances, Tanzania.

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

2.3.1 ENERGY SUPPLY

The primary energy supply is dominated by biomass (over 98% in 2020), used mainly for cooking and heating, whereas electricity is almost entirely supplied by fossil-fuel based gas (41%) and hydro energy (39%), as shown in Table 3. If the primary energy supply continues according to its development over the past 5 years (by 3% annually), the primary energy demand will double to 1937 PJ/a by 2050.

Table 3: Tanzania'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		3%	1%	4%	0%	4%	5%	1%	1%	1%	3%	2%	2%	2%	8%	0%	3%
Primary energy	[PJ/a]	662	683	689	702	719	745	779	785	809	811	834	845	864	878	948	951
Net Export (–) /Import (+)	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fossil fuels	[PJ/a]	73	78	77	79	76	89	104	125	144	128	136	134	144	149	179	170
Coal	[PJ/a]	1	0	1	0	0	0	2	2	2	6	7	7	14	16	18	18
Lignite	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oil	[PJ/a]	58	60	58	59	54	62	72	89	108	93	102	98	103	106	127	123
Gas	[PJ/a]	14	17	19	19	23	27	30	34	34	29	27	28	27	26	34	30
Nuclear	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conventional Renewables	[PJ/a]	588	604	611	622	641	655	673	658	665	681	696	709	717	727	767	778
Hydro	[PJ/a]	6	5	9	10	10	10	7	6	6	9	8	9	8	8	9	11
Wind	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solar		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass	[PJ/a]	582	599	602	612	632	645	666	652	659	671	688	701	709	719	758	767
Geothermal	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ocean energy	[PJ/a]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Conventional Renewables Share:	[%]	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
New Renewables Share	[%]	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

(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,[10] 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.'

2.4 DEVELOPMENT OF THE RESIDENTIAL ENERGY DEMAND

To develop a projection for the residential electricity demand in Tanzania over the coming 30 years to achieve the Tanzania 1.5 °C (T-1.5°C) scenario, a bottom-up electricity demand analysis was performed. The T-1.5°C aims to increase the access to energy—especially electricity—for all by 2050, while increasing the electrification and comfort standards to the levels of OECD countries. The growing economy requires a reliable power supply for small and medium businesses, industry, and the transport sector. It is assumed that households will use modern energy-efficient applications, 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.

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[10] 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.

2.4.1 HOUSEHOLD ELECTRICITY DEMAND

The current and future developments of the electricity demand for Tanzania'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 Tanzania's academia, civil society, and government. Table 4 shows the breakdown of Tanzania's households by size according to the latest census data[11]. The current average electricity demands of Tanzania's households are significantly lower than those of OECD countries.

Table 4: Population Distribution by Household and Average Household Size by Region, Tanzania; 2012 and 2022 PHCs

	2012 Census			2022 Census		
Region	Population	Households	Average Household Size	Population	Households	Average Household Size
Tanzania	**44,928,923**	**9,362,758**	**4.8**	**61,741,120**	**14,297,184**	**4.3**
Tanzania Mainland	**43,625,354**	**9,109,150**	**4.8**	**59,851,347**	**13,916,924**	**4.3**
Dodoma	2,083,588	453,844	4.6	3,085,625	757,821	4.1
Arusha	1,694,310	378,825	4.5	2,356,255	615,182	3.8
Kilimanjaro	1,640,087	384,867	4.3	1,861,934	497,850	3.7
Tanga	2,045,205	438,277	4.7	2,615,597	635,514	4.1
Morogoro	2,218,492	506,289	4.4	3,197,104	829,888	3.9
Pwani	1,098,668	257,511	4.3	2,024,947	542,919	3.7
Dar es Salaam	4,364,541	1,095,095	4	5,383,728	1,550,066	3.5
Lindi	864,652	225,972	3.8	1,194,028	347,235	3.4
Mtwara	1,270,854	344,834	3.7	1,634,947	493,094	3.3
Ruvuma	1,376,891	303,071	4.5	1,848,794	466,823	4
Iringa	941,238	223,028	4.2	1,192,728	321,889	3.7
Mbeya	1,708,548	400,755	4.3	2,343,754	630,102	3.7
Singida	1,370,637	258,280	5.3	2,008,058	395,855	5.1
Tabora	2,291,623	383,432	6	3,391,679	598,659	5.7
Rukwa	1,004,539	199,766	5	1,540,519	330,023	4.7
Kigoma	2,127,930	374,488	5.7	2,470,967	479,109	5.2
Shinyanga	1,534,808	261,732	5.9	2,241,299	423,373	5.3
Kagera	2,458,023	524,793	4.7	2,989,299	702,412	4.3
Mwanza	2,772,509	486,184	5.7	3,699,872	751,631	4.9
Mara	1,743,830	312,444	5.6	2,372,015	470,883	5
Manyara	1,425,131	273,284	5.2	1,892,502	403,468	4.7
Njombe	702,097	170,160	4.1	889,946	246,503	3.6
Katavi	564,604	101,224	5.6	1,152,958	215,981	5.3
Simiyu	1,584,157	229,946	6.9	2,140,497	317,963	6.7
Geita	1,739,530	286,757	6.1	2,977,608	561,942	5.3
Songwe	998,862	232,292	4.3	1,344,687	330,739	4.1
Tanzania Zanzibar	**1,303,569**	**253,608**	**5.1**	**1,889,773**	**380,260**	**5**
Kaskazini Unguja	187,455	38,651	4.8	257,290	54,810	4.7
Kusini Unguja	115,588	25,947	4.5	195,873	47,010	4.2
Mjini Magharibi	593,678	113,420	5.2	893,169	182,079	4.9
Kaskazini Pemba	211,732	39,706	5.3	272,091	48,575	5.6
Kusini Pemba	195,116	35,884	5.4	271,350	47,786	5.7

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[11] The United Republic of Tanzania (URT), Ministry of Finance and Planning, Tanzania National Bureau of Statistics and President's Office - Finance and Planning, Office of the Chief Government Statistician, Zanzibar. The 2022 Population and Housing Census: Administrative Units Population Distribution Report; Tanzania, December 2022

Table 5 shows the electricity demand and the electrical appliances used by households in Tanzania 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—especially young people—from leaving their home regions and moving to big cities. The phase-out of unsustainable biomass and liquefied pressurized gas (LPG) for cooking is particularly important in decarbonizing Tanzania'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

		Tanzania—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 Tanzania'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 Tanzania 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 Tanzania'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 Tanzania

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%

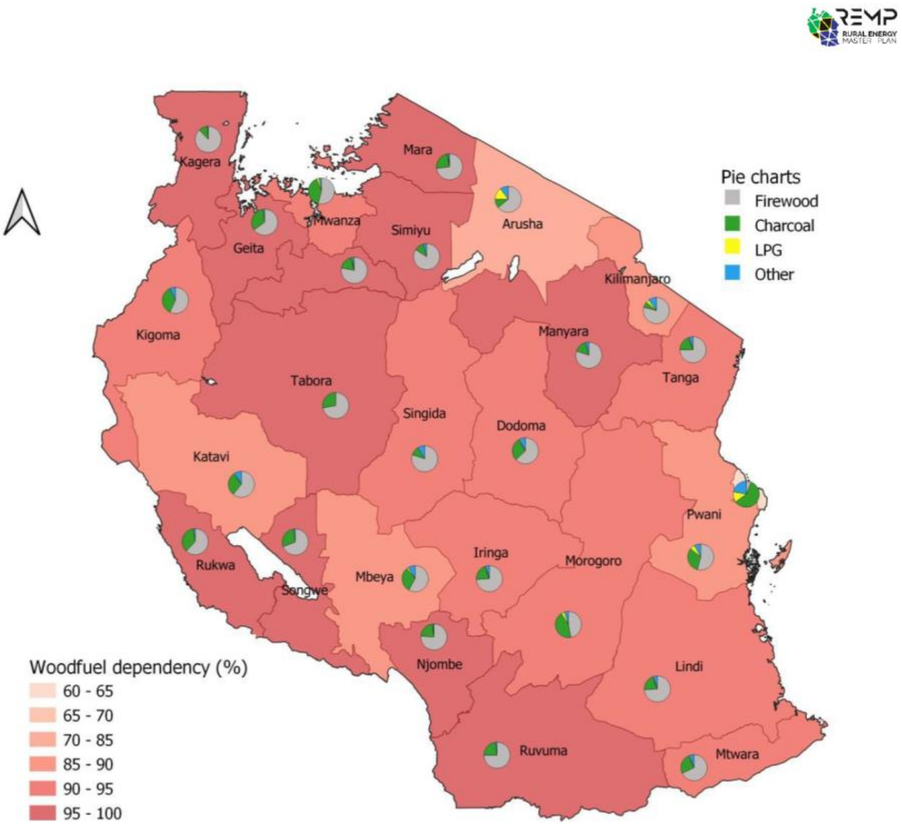
Source: CDP, REB, DESCO and UTS-ISF research

According to the most recent data in *The Energy Progress Report* published in June 2021 (EPR 2021)[12], over 43% of Tanzania's households have access to electricity. However, only 72% of households have access to reliable and uninterrupted electricity (World Bank 2017)[13]. 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 Tanzania's households is for cooking. Firewood and other solid biomass is the main energy source for households. According to the ***'Tanzania Cooking Energy Master Plan 2022'***[14] 87% of all rural households cooking with traditional biomass fuels, followed by 6% of the households using improved cookstoves with firewood and/or charcoal, 4% gas/LPG based cooking and 3% other fuels including electricity. Figure 6 shows that the level of wood fuel dependency for cooking in Tanzania is with well over 70% across all regions.

Figure 6: Regional wood fuel dependency and primary fuel used for cooking



Source: REMP Volume 3, TANZANIA RURAL ENERGY MASTER PLAN, VOLUME 3: COOKING ENERGY MASTER PLAN, Page 226, August 2022, https://rea.go.tz/Articles/rural-energy-master-plan-remp

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[12] (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

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

[14] Tanzania Rural Energy Master Plan, Volume 3: Cooking Energy Master Plan, August 2022, https://rea.go.tz/Articles/rural-energy-master-plan-remp

Table 8 provides an overview of the most important cooking technologies and their key technical and economic parameters (WFC 2019).[15] 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)[16]. With slow cookers and pressure cookers enabling household cooking costs of 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 T-1.5°C scenario (Table 9). 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

Table 8: Basic data on technologies and energy use

Appliance	Cost range [EUR]	Median Cost [EUR]	Median Cost [TZS]	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	6,500	N/A	3.32–8.3 kg/day	54.78–136.95
Improved Cooking Stove (Wood)	5–65	35	91,000	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	13,000	N/A	1.6–4.01 kg/day	45.60–114.29
Improved Cooking Stove (Charcoal)	5–65	35	91,000	N/A	1.2–2.4 kg /day	34.20–68.40
Improved Cooking Stove (Wood-based Biomass Pellets)	16–80	48	124,800	N/A	1.76–3.96 kg/day	30.41–68.43
Improved Cooking Stove (Agro-waste Pellets)	16–80	48	124,800	N/A	2.42–5.44 kg/day	30.49–68.54
Single Burner Hot Plate	8–35	21.5	55,900	600–2000	1200–4000 Wh/day	4.32–14.40
Induction Hot Plate	45–95	67.5	175,500	1000–2300	2000–4600 Wh/day	7.20–16.56
Slow Cooker / Rice Cooker / Crock Pot	10–130	70	182,000	120–300	175–700 Wh/day	0.63–2.52
Electric Pressure Cooker	19–140	79.5	206,700	500–1000	160–340 Wh/day	0.58–1.22
Microwave Oven	50–100	75	195,000	600–1200	100–1200 Wh/day	0.36–4.32
Gas Stove (single burner)	20–60	40	104,000	N/A	0.3 kg/day	13.7
Gas Stove (double burner)	30–90	60	156,000	N/A	0.3 kg/day	13.7
Gas Stove (four burners)	40–100	70	182,000	N/A	0.3 kg/day	13.7

Source: (WFC 2019)

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

	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 cooking technologies groups are shown in Table 9. Based on these, a scenario for transitioning from fuel-based cooking to electricity-based cooking was developed (Table 10).

On average, 1% of all wood and bio energy fuel-based cooking applications will be gradually phased out and replaced with electric cooking appliances. The total phase-out of traditional bio energy-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

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[15] 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

[16] 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

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 therefore be emissions-free. This cooking scenario is in line with the Cooking Energy Action Plan (CEAP), developed by 'Sustainable Energy For All' (SE4ALL) published in the *'Tanzania Cooking Energy Master Plan 2022'* [17] which aims to achieve 75% access to modern cooking devices (improved cookstoves for firewood and charcoal and LPG) while tradition biomass use for cooking declines to 25% by 2030.

Table 10: Transition scenario from fuel-based to electricity-based cooking in Tanzania under the T-1.5°C pathway

Phase-out of Fossil Fuel-based Cooking 2020–2050											
	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	87%	[MJ/a HH]	2,540	3,048	3,811	15,242	3,811	3,811	3,811	5,081	7,621
2025	85%	[MJ/a HH]	2,482	2,978	3,723	14,892	3,723	3,723	3,723	4,964	7,446
2030	80%	[MJ/a HH]	2,336	2,803	3,504	14,016	3,504	3,504	3,504	4,672	7,008
2035	75%	[MJ/a HH]	2,190	2,628	3,285	13,140	3,285	3,285	3,285	4,380	6,570
2040	40%	[MJ/a HH]	1,168	1,402	1,752	7,008	1,752	1,752	1,752	2,336	3,504
2045	20%	[MJ/a HH]	584	701	876	3,504	876	876	876	1,168	1,752
2050	15%	[MJ/a HH]	438	526	657	2,628	657	657	657	876	1,314
	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	4%	[MJ/a HH]	17	20	25	100	25	25	25	33	50
2025	4%	[MJ/a HH]	17	20	25	100	25	25	25	33	50
2030	4%	[MJ/a HH]	1	1	1	4	1	1	1	1	2
2035	4%	[MJ/a HH]	17	20	25	100	25	25	25	33	50
2040	3%	[MJ/a HH]	13	15	19	75	19	19	19	25	38
2045	2%	[MJ/a HH]	8	10	13	50	13	13	13	17	25
2050	0%	[MJ/a HH]	0	0	0	0	0	0	0	0	0
	Phase-in of Electric Cooking 2020–2050										
	Share of Households with Electric Cooking		Rural—Phase 1	Rural—Phase 2	Rural—Phase 3	Semi-Urban 1	Semi-Urban 2	Urban Apartment 1	Urban Apartment 2	Urban House 1	Urban House 2
Average energy demand by HH (Based on World Future Council 2019)			**100**	**120**	**151**	**602**	**151**	**151**	**151**	**201**	**301**
2020	9%	[kWhelectric/a HH]	9	11	14	54	14	14	14	18	27
2025	11%	[kWhelectric/a HH]	11	13	17	66	17	17	17	22	33
2030	16%	[kWhelectric/a HH]	16	19	24	96	24	24	24	32	48
2035	21%	[kWhelectric/a HH]	21	25	32	126	32	32	32	42	63
2040	57%	[kWhelectric/a HH]	57	69	86	343	86	86	86	114	172
2045	78%	[kWhelectric/a HH]	78	94	117	470	117	117	117	157	235
2050	85%	[kWhelectric/a HH]	85	102	128	512	128	128	128	171	256

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.

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[17] Tanzania Rural Energy Master Plan, Volume 3: Cooking Energy Master Plan, August 2022, https://rea.go.tz/Articles/rural-energy-master-plan-remp

There are already numerous electric cooking devices on Tanzania'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 Tanzania 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 Tanzania's economic development is based on a breakdown of the fiscal year 2019 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 7 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) with 58%, whereas machinery and transport equipment activities contributed least. The contribution of the Industry (including construction) to the economic growth rate in that fiscal year (FY) was 29 %, and the contribution of agriculture, forestry and fishing was 25 %.

In addition, Figure 8 presents the annual GDP growth rate from 2005 to 2020.

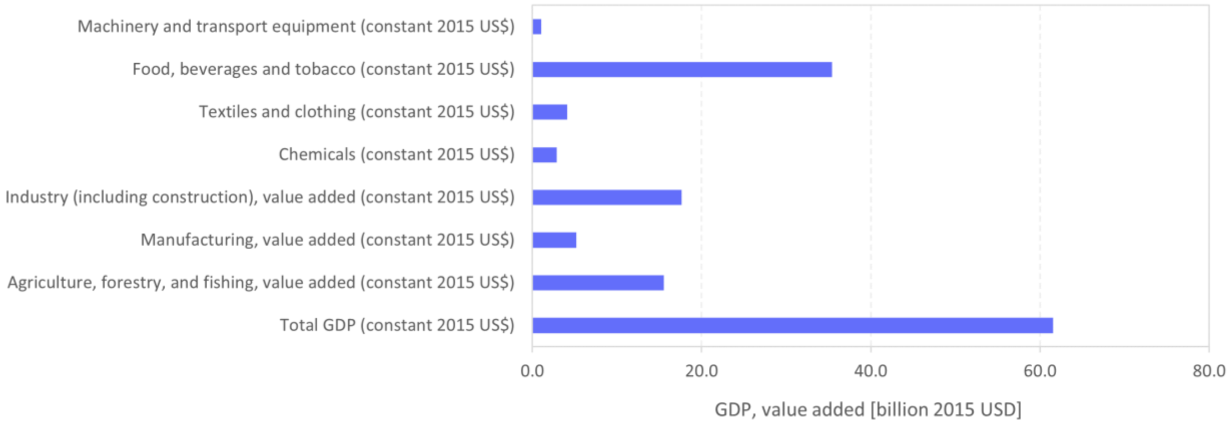

Figure 7: Contributions of sub-sectors to GDP growth

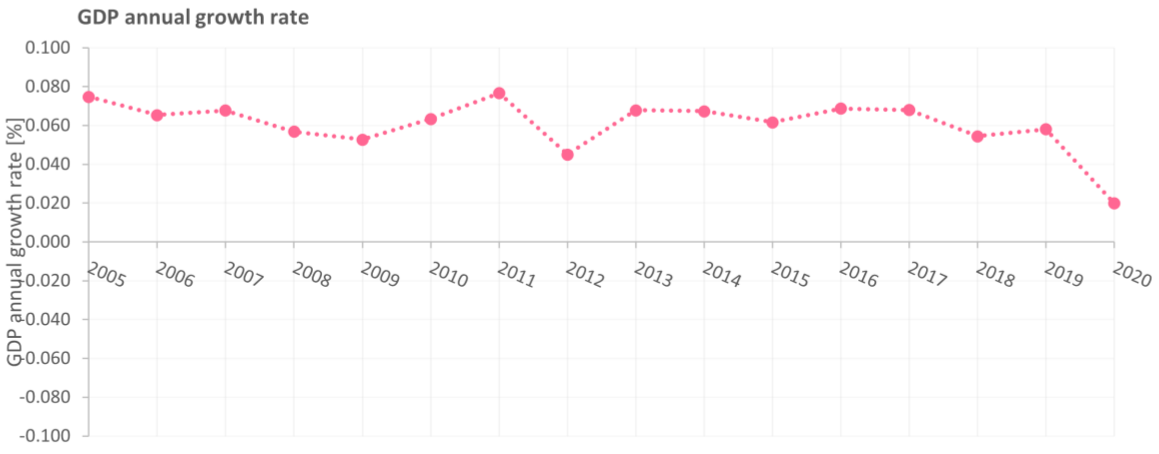

Figure 8: Gross domestic product (GDP) growth rate

2.6 TRANSPORT DEMAND

Tanzania’s transport sector is currently dominated by motorcycles, which account for 40% of all registered vehicles, whereas cars represent only around 40% of the vehicle fleet. Heavy goods transport (HGV) and large goods vehicles (LGV) accouns for 8% and 7% of all registered vehicles. The remaining 4 % includes construction and industry vehicles, such as tractors, cranes, and excavators.

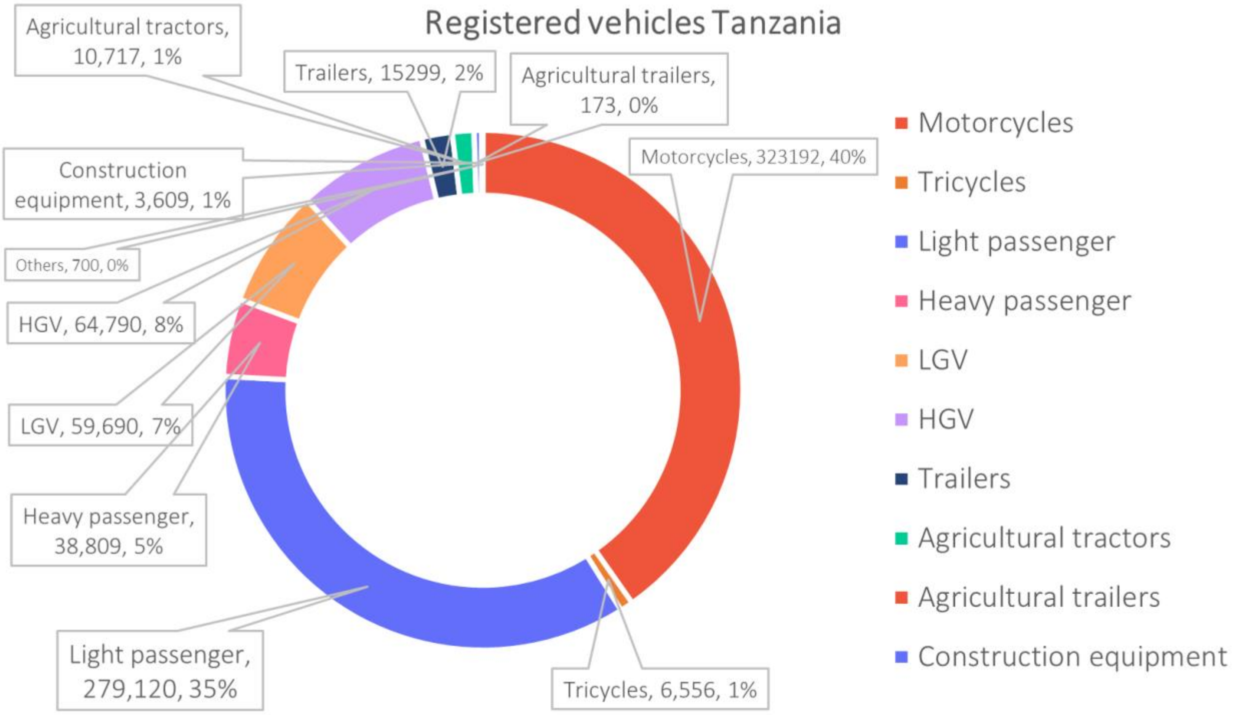

Figure 9: Categories of registered vehicles, with the percentages of the total number of registered vehicles (financial year 2010). Source: African development group[18]

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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[18] Tanzania, transport sector overview, https://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/Tanzania_-_Transport_Sector_Review.pdf

2.6.1 TECHNICAL PARAMETERS—INDIVIDUAL TRANSPORT

Passenger transport by road is the commonest and most important form of travel (TUMI 2021)[19]. 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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[19] 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)[20]. 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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[20] 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: Tanzania—projected passenger and freight transport demand under the T-1.5°C scenario

		2019	2020	2025	2030	2035	2040	2045	2050
Road: **Passenger** Transport Demand	[PJ/a]	1	1	0	0	0	0	0	0
Annual passenger kilometres	[million pkm]	3	3	2	2	2	2	2	2
Average energy intensity—passenger vehicles.	[MJ/pkm]	3.77	3.54	0.00	0.00	0.00	0.00	0.00	0.00
Annual demand variation:	[%/a]			-1.00%	-3.00%	-2.50%	-2.00%	-2.00%	-2.00%
kilometres per person per day	[km/person day]	0	0	0	0	0	0	0	0
Road: **Freight** Transport Demand	[PJ/a]	17,195	18,189	0	0	0	0	0	0
Annual freight kilometres	[million tkm]	2	2	1	1	1	1	1	1
Average energy intensity—freight vehicles	[MJ/tkm]	1.59	1.50	0.00	0.00	0.00	0.00	0.00	0.00
Annual demand Variations	[%/a]			8.00%	-1.00%	-1.00%	-1.00%	-3.00%	-3.00%

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 10 and Figure 11 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.

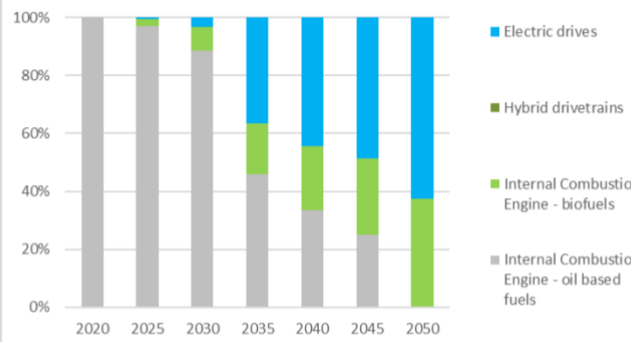

Figure 10: Passenger transport—drive trains by fuel

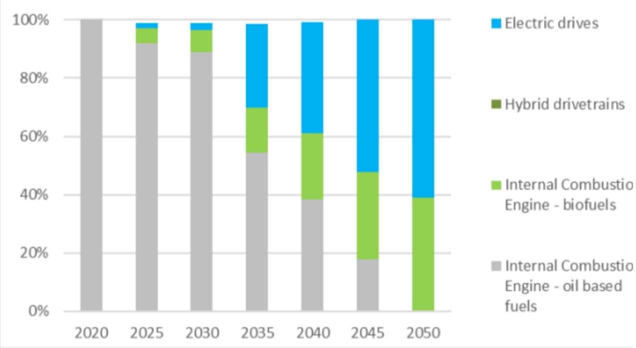

Figure 11: Freight transport—drive trains by fuel

The assumed trajectory for the transport sector (Figure 10 and Figure 11) is consistent with the National Determined Contribution (NDC) (NDC-Tanzania 2021)[21]of the Government of Tanzania published in July 2021, which identified the following three goals:

a) Promoting low emission transport systems through deployment of mass rapid transport system and investments in rail, maritime and road infrastructures, including high quality transport system and expansion/scaling up of BRT infrastructures.
b) Promoting the use of renewable (clean) energy in transportation systems.
c) Introduction and promotion of Non-Motorized Transport system and facilities and networks in both mega cities and metropolitan cities by2030.

Tanzania – NDC, July 2021

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.

Natural gas fuelled vehicles

While there are debates about the increased use of natural gas in the transport sector, this scenario does not assume an increase of natural gas vehicles beyond the current usage which is well below 1%. The reason is twofold:

1) The tailpipe emissions from natural gas fuelled vehicles are around 30% below those of petrol fuel vehicles. However, in case of methane emissions which can arise at gas extraction and transport, overall greenhouse gas emissions may be equal or even higher than petrol fuel vehicles. A full decarbonization is therefore not possible.
2) The introduction of gas-fuelled vehicle requires a new infrastructure for supply of natural gas including the transport to service stations as well as specific gas-fuel pumps. This requires an additional investment in infrastructure which needs to be phased out over time to fully decarbonize the transport sector. Thus, the investment might be stranded.
3) The implementation of vehicles is in line with global trends. Several governments have set target for the phase-out of internal combustion engines (ICE). Tanzania might therefore turn into a dumping ground for outdated vehicles and vehicles that cannot be sold in OECD countries. The access to latest vehicle technologies is therefore connected to access to charging infrastructure. The increased access to electricity and electricity services across the country can go hand in hand with the expansion of charging infrastructure. The integration of large proportions of cost-effective solar and wind power generation is made significantly easier by the high storage capacity of electric vehicles.

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 Tanzania'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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[21] The United Republic of Tanzania, Vice Presidents Office, Nationally Determined Contribution, July 2021, https://unfccc.int/sites/default/files/NDC/2022-06/TANZANIA_NDC_SUBMISSION_30%20JULY%202021.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)[22]. 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 12 shows the oil prices since 1997. After extremely high oil prices in 2012, we are currently in a low-price phase. Gas prices saw similar fluctuations (IEA 2017)[23]. Therefore, fossil fuel price projections have also seen considerable variations (IEA 2017[23]; IEA 2013[24]) and this has influenced the scenario results.

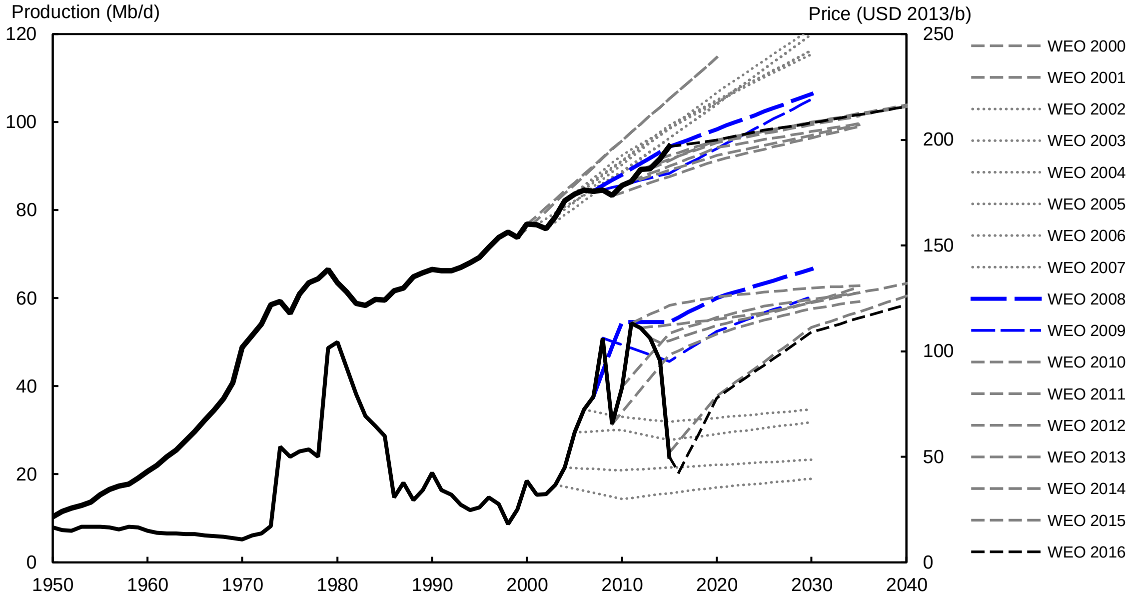

Figure 12: Historical development and projections of oil prices (bottom lines) and historical world oil production and projections (top lines) by the World Energy Outlook (WEO) published by the International Energy Agency (IEA), according to Wachtmeister et al. (2018)

Although oil-exporting countries have provided the best oil price projections in the past, institutional price projections have become increasingly accurate, with the IEA leading the way in 2018 (Roland Berger 2018)[25]. An evaluation of the oil price projections of the IEA since 2000 by Wachtmeister et al. (2018)[26] showed that price projections have varied significantly over time. Whereas the IEA's oil production projections seem comparatively accurate, oil price projections showed errors of 40%–60%, even when made only 10 years ahead. Between 2007 and 2017, the IEA price projections for 2030 varied from US$70 to US$140 per barrel, providing significant uncertainty regarding future costs in the scenarios.

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[22] 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.

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

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

[25] 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.

[26] 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

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 bio-energy has significant market shares in all sectors in many regions, a detailed assessment of future price projections is provided below.

Investment cost projections also pose challenges for scenario development. Available short-term projections of investment costs depend largely on the data available for existing and planned projects. Learning curves are most commonly used to assess the future development of investment costs as a function of their future installations and markets (McDonald and Schrattenholzer 2001[27]; Rubin et al. 2015[28]). 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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[27] 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

[28] 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)[29], 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)[30], 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)[31], 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 Tanzania. It is important to note that the cost reductions are, in reality, not a function of time but of cumulative capacity (production of units), so dynamic market development 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 T-1.5°C pathway (see below).

However, our approach is conservative when we compare the REFERENCE scenario with the more ambitious renewable energy scenarios under identical cost assumptions. Fossil-fuel power plants have limited potential for cost reductions because they are 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 (TZS/kW) by kW until 2050

Assumed Investment Costs for Power Generation Plants										
	2020		2025		2030		2040		2050	
Technology	[US$/kW]	[TZS/kW]	[US$/kW]	[TZS/kW]	[US$/kW]	[TZS/kW]	[US$/kW]	[TZS/kW]	[US$/kW]	[TZS/kW]
Coal power plants	2,018	5,044,434	2,018	5,044,434	2,018	5,044,434	2,018	5,044,434	2,018	5,044,434
Diesel generators	908	2,269,995	908	2,269,995	908	2,269,995	908	2,269,995	908	2,269,995
Gas power plants	504	1,261,109	504	1,261,109	504	1,261,109	504	1,261,109	676	1,689,886
Oil power plants	938	2,345,662	918	2,295,218	898	2,244,773	865	2,162,801	827	2,068,218
Conventional Renewables										
Hydropower plants*	2,674	6,683,876	2,674	6,683,876	2,674	6,683,876	2,674	6,683,876	2,674	6,683,876
New renewables										
PV power plants	989	2,471,773	744	1,860,925	736	1,841,219	565	1,412,442	474	1,185,442
Onshore Wind	1,594	3,985,103	1,559	3,896,826	1,523	3,808,548	1,463	3,657,215	1,412	3,531,104
Offshore Wind	3,723	9,306,981	3,097	7,743,207	2,472	6,179,432	2,295	5,738,044	2,119	5,296,656
Biomass power plants	2,371	5,927,210	2,346	5,864,155	2,320	5,801,100	2,220	5,548,878	2,129	5,321,878

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

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[29] 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.

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

[31] 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 Tanzania. 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$/kW]	[TZS/kW]	[US$/kW]	[TZS/kW]	[US$/kW]	[TZS/kW]	[US$/kW]	[TZS/kW]
Solar collectors	Industry	820	2,050,000	730	1,825,000	650	1,625,000	550	1,375,000
	In heat grids	970	2,425,000	970	2,425,000	970	2,425,000	970	2,425,000
	Residential	1,010	2,525,000	910	2,275,000	800	2,000,000	680	1,700,000
Geothermal		2,270	5,675,000	2,030	5,075,000	1,800	4,500,000	1,590	3,975,000
Heat pumps		1,740	4,350,000	1,640	4,100,000	1,540	3,850,000	1,450	3,625,000
Biomass heat plants		580	1,450,000	550	1,375,000	510	1,275,000	480	1,200,000
Commercial biomass heating systems	Commercial scale	810	2,025,000	760	1,900,000	720	1,800,000	680	1,700,000
Residential biomass heating stoves	Small scale / Rural	110	275,000	110	275,000	110	275,000	110	275,000

2.7.3 RENEWABLE ENERGY COSTS IN TANZANIA IN 2021

The following tables provide an overview of the assumed renewable energy costs in Tanzania. 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	[TZS]	[$]	[US$/kW$_{peak}$]
10 W	115,000	46	4,572
20 W	215,000	86	4,322
50 W	397,500	159	3,186
55 W	432,500	173	3,152
60 W	460,000	184	3,059
80 W	525,000	210	2,629
100 W	625,000	250	2,495
Institutional Solar Power Systems	[TZS]	[$]	[US$/kW$_{peak}$]
1000 W	5,692,500	2,277	2,277
2000 W	9,540,000	3,816	1,908

Table 18: Solar Dryer – estimated costs

Solar Dryers [1 sqft = 0.0929 m^2]	[TZS]	[$]	[US$/m^2]
3–6 sqft (household) [	645,000	258	617
10–15 sqft (household)	1,465,000	586	505
> 21 sqft (institutional)	2,265,000	906	464

Table 19: Solar Cooker – estimated costs

Solar Cookers	[TZS]	[$]
Parabolic—household	490,000	196
Parabolic—institutional	3,000,000	1,200

Table 20: Biomass stoves – estimated costs

Biomass Stoves	[TZS]	[$]
Institutional improved stove—type 1	972,500	389
Institutional improved stove—type 2	1,020,000	408
Institutional improved stove—type 3	1,212,500	485
Natural draft stove	87,500	35
Forced draft stove	177,500	71
Improved metallic stove	242,500	97

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 2050 on *World Energy Outlook 2023* (IEA 2017). Beyond 2040, we extrapolated the price developments for 2035 and 2040 and present them in Table 27. Although these price projections are highly speculative, they provide prices consistent with our investment assumptions. Fuel prices for nuclear energy are based on the values in the Energy [R]evolution report 2015 (Teske et al. 2015)[29], corrected by the cumulative inflation rate for the Eurozone between 2012 and 2015 of 1.82%.

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$/GJ]	[TZS/GJ]	[US$/GJ]	[TZS/GJ]	[US$/GJ]	[TZS/GJ]	[US$/GJ]	[TZS/GJ]	[US$/GJ]	[TZS/GJ]
Oil	8.5	21,250	12	30,000	11	27,500	10	25,000	10.5	26,250
Gas	9.8	24,500	20	50,000	10	25,000	11	27,500	12	30,000
Coal	3.2	8,000	3.5	8,750	4	10,000	3.8	9,500	3.5	8,750

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)[32] 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.[32] 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 Tanzania in 2021

Table 22: Biogas prices—small quantities—in Tanzania by region (estimation)

Biogas	2 m^3		4 m^3		6 m^3		8 m^3	
	[TZS]	[$]	[TZS]	[$]	[TZS]	[$]	[TZS]	[$]
Household— low cost assumption	1,027,500	411	1,467,500	587	1,690,000	676	1,890,000	756
Household— average cost	1,202,500	481	1,617,500	647	1,871,250	749	2,041,250	817
Household— high cost assumption	1,377,500	551	1,767,500	707	2,052,500	821	2,192,500	877

Source: UTS/ISF own research – March 2023

Table 23: Biogas prices—medium quantities—in Tanzania by region (estimation)

Biogas	12.5 m^3		40 m^3		60 m^3		100 m^3	
	[TZS]	[$]	[TZS]	[$]	[TZS]	[$]	[TZS]	[$]
Household— low cost assumption	5,427,500	2,171	15,637,500	6,255	20,760,000	8,304	30,280,000	12,112
Household— average cost	5,941,250	2,377	16,602,500	6,641	23,887,500	9,555	34,803,750	13,922
Household— high cost assumption	6,455,000	2,582	17,567,500	7,027	27,015,000	10,806	39,327,500	15,731

Source: UTS/ISF own research – March 2023

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[32] 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 Tanzania: Renewable Energy Potential

Tanzania'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

GIS mapping was used to ascertain Tanzania'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 onshore wind resources and for the demand projections for the nine modelling regions. Population density, access to electricity infrastructure, and economic development projections are key input parameters in a region-specific analysis of Tanzania'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: Tanzania—[R]E 24/7—GIS-mapping—data sources

Data	Assumptions	Source
Land cover	Land cover classes suitable for solar energy and onshore wind energy production were identified from Copernicus Global Land Cover 2019.	Copernicus Global Land Cover – 2019 [33]
Digital Elevation Model (DEM)	For both solar and offshore wind analyses, any land with a slope of > 30% was excluded from all scenarios.	SRTM Digital Elevation Data Version 4 [34]
Population and Population Density	A population census was conducted in 2022 by the Tanzania National Bureau of Statistics, and a preliminary report is available.	Population Census 2022 – National Bureau of Statistics[35]
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[36]
Power Plants, Transmission Lines, and Network	Solar and wind potential of areas ≤ 10 km from transmission lines was considered (Scenario 2).	Tanzania - Electricity Transmission Network (2014) • Electricity transmission network • Power stations Tanzania – Power Plants (2015) • Substations[37]
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 [38]
Wind Speeds	Wind speeds ≥ 5 m/s were considered at a height of 100 m.	Global Wind Atlas [39]

The [R]E Space mapping procedure is summarised in Figure 13. The land areas available for potential solar and onshore 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

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

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

[35] Population Census 2022 – National Bureau of Statistics: https://www.nbs.go.tz/nbs/takwimu/Census2022/

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

[37] Electricity transmission network & power stations: Tanzania - Electricity Transmission Network (2014): https://energydata.info/dataset/tanzania-electricity-transmission-network-2014, Substations - KTH Division of Energy Systems Analysis (2015): https://energydata.info/dataset/tanzania---power-plants--2015

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

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

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).

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 Tanzania, and the potential provided is a conservative estimate and may ultimately be larger.

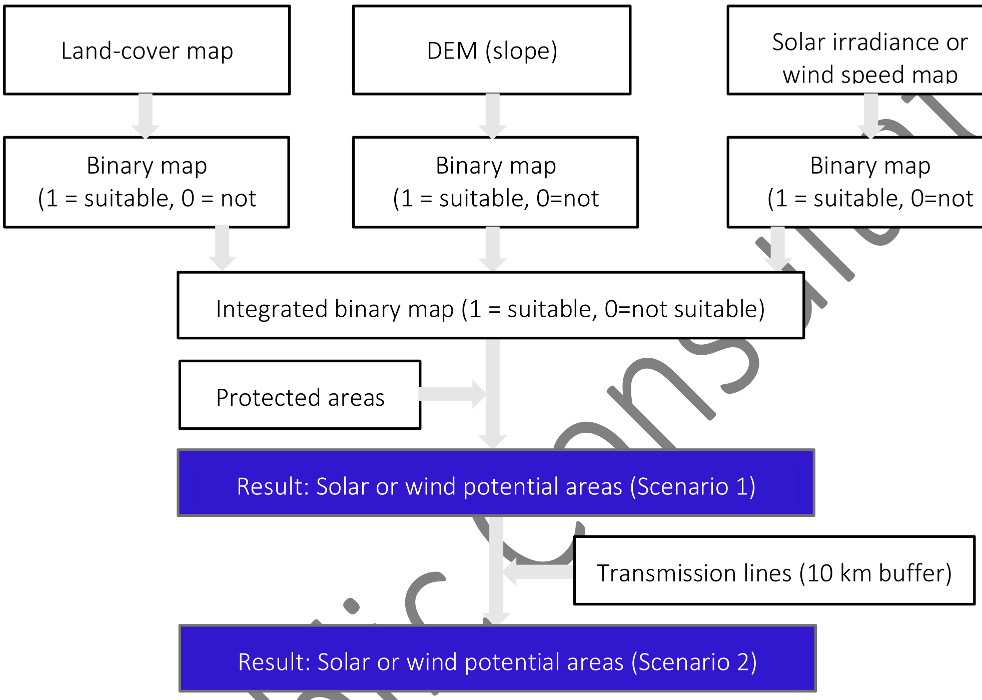

Figure 13: [R]E Space methodology—solar potential analysis and onshore wind potential analysis

3.2 MAPPING METHODOLOGY FOR OFFSHORE WIND

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

Table 25: Tanzania—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[40]
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[41]
Maritime boundaries		Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM) (version: 11)[42]
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 (GEBCO_2023) for 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 TANZANIA

Tanzania's power sector is currently mainly based on fossil fuelled resources – gas and some additional oil make up to 75% of total electricity generation. In 2020, solar PV produced 0.15 TWh, and wind produced almost zero, both playing minor roles in 2020 compared with hydropower (2.33 TWh) and bioenergy (0.10 TWh)[43]. Given Tanzania's renewable energy target (which includes additional hydro capacity such as the 2.1 GW Julius Nyerere Hydropower Station at the Stiegler's Gorge dam), and the recent growth in its renewable energy capacity there is reason to set more ambitious targets in short term. For example, Bloomberg NEF reports that "Tanzania's renewable installed capacity has nearly tripled from 61MW in 2018 to 177MW in 2021"[44] This section will look into potential of solar and wind energy using the spatial analysis.

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

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

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

[43] International Energy Agency: https://www.iea.org/data-and-statistics/charts/tanzania-electricity-generation-by-technology-in-the-stated-policies-scenario-2010-2040

[44] ClimateScope 2022, Power Transition Factbook. BloombergNEF

3.3.1 SOLAR POTENTIAL

The yearly totals of solar irradiation (DNI) level in Tanzania is 105– 2,429 kWh/m^2, and the higher end of that range is in the central regions of the country, including Central/Capital, West Central Zone[38]. Tanzania'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).

Table 26: Tanzania's potential for utility-scale solar photovoltaic

Scenarios	1. LU + PA + S30		2. LU + PA + S30 + PT10	
Scenario Regions	Solar Potential Area (km^2)	Solar Potential (GW)	Solar Potential Area (km^2)	Solar Potential (GW)
Southern Zone	64,873	1,622	4,718	118
Southern Highlands Zone	46,274	1,157	10,677	267
South-Central Zone	34,236	856	11,818	295
Coastal Zone	37,034	926	11,934	298
Western Zone	38,413	960	1,815	45
West-Central Zone	43,822	1,096	11,592	290
Central/Capital	60,932	1,523	15,035	376
Northern Highlands Zone	37,821	946	13,247	331
Lake Zone	71,711	1,793	28,454	711
TOTAL	**435,115**	**10,878**	**109,290**	**2,732**

Table 26 and Figure 14 show the results of a spatial analysis indicating the solar potential areas under Scenario 1 (LU + PA + S30). The scenario provides 435,115 km^2 of areas with solar potential and a total potential for solar PV capacity of 10,878 GW. Scenario 1 excludes all protected areas and areas with slopes >30%, because installing and maintaining solar panels in steep areas is unrealistic. Open forests, shrubs, herbaceous vegetation, bare/spare vegetation, agricultural land, and urban/built-up land-cover classes in the Copernicus Global Land Cover 2019 dataset are included. However, certain land-cover classes (e.g., closed forests, wetlands, water bodies, snow and ice) are excluded in the scenarios selected for the consideration of solar energy potential.

Figure 15 shows the solar potential areas for Scenario 2 (LU + PA + S30 + PT10). When the land area is restricted by its proximity to power lines (10 km), the potential solar areas decrease to 109,290 km^2. Under Scenario 2, utility-scale solar farms in Tanzania can potentially harvest 2,732 GW of solar PV.

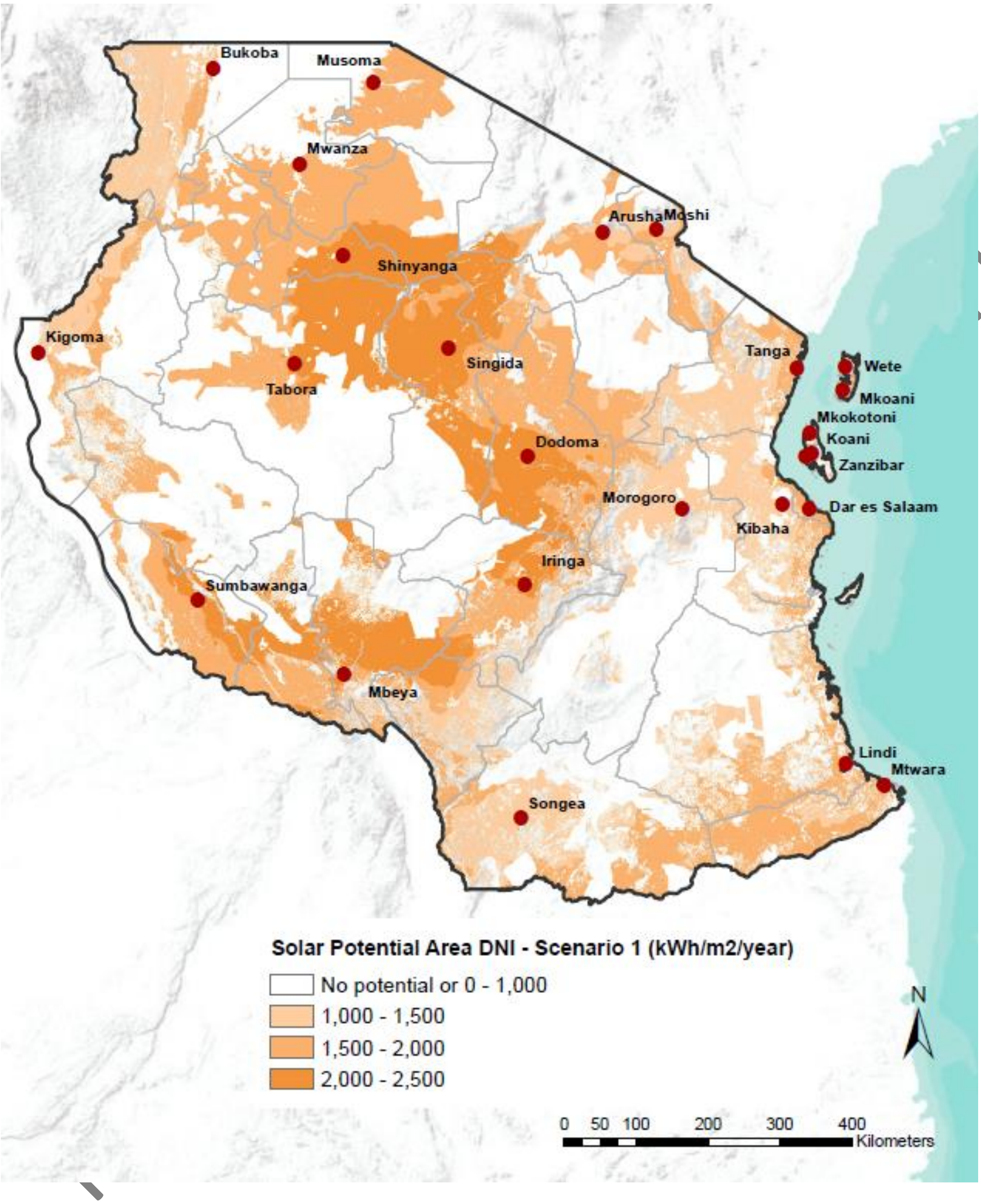

Figure 14: Tanzania—Solar Potential Areas (Scenario 1: LU + PA + S30)

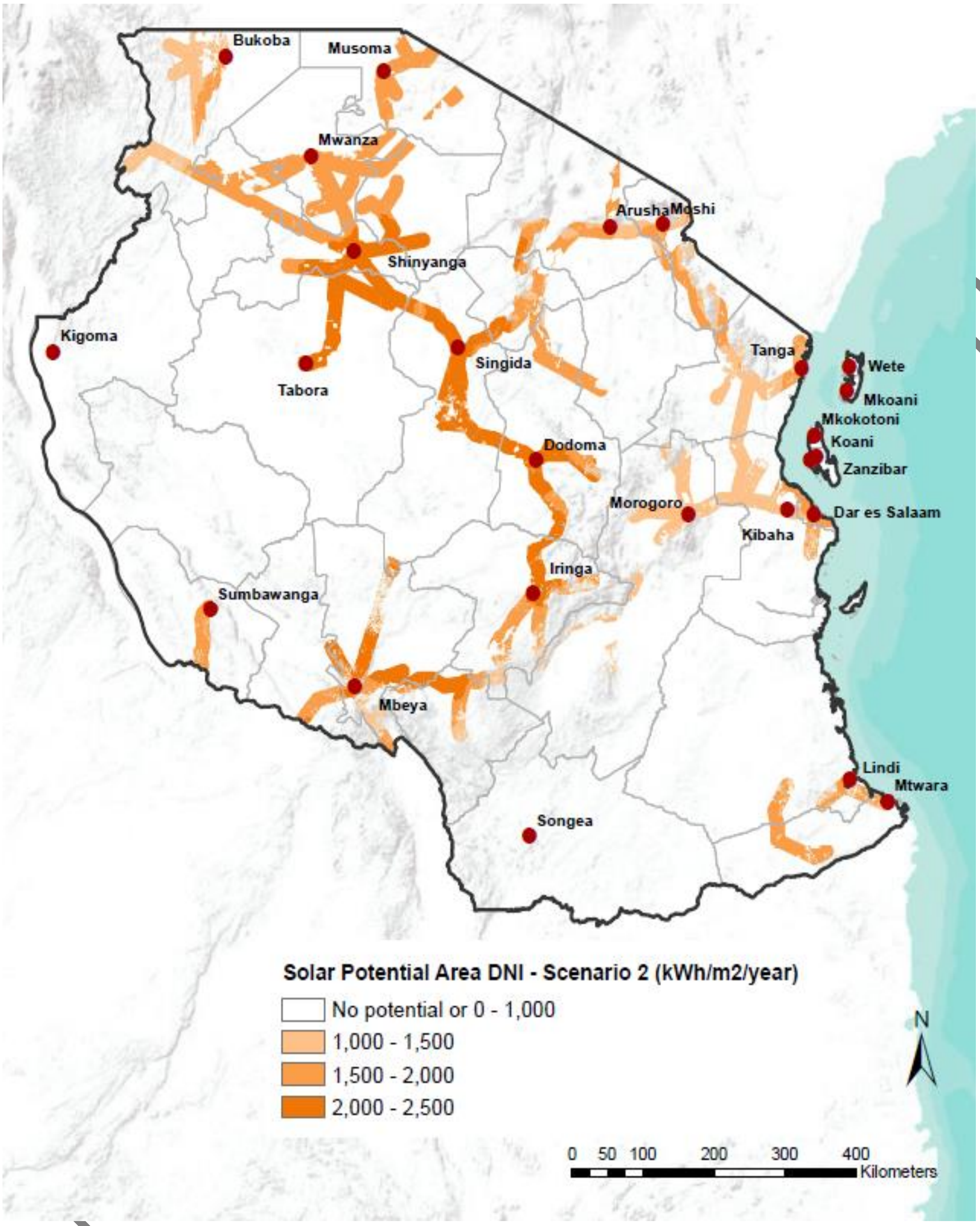

Figure 15: **Tanzania**—Solar Potential Areas (Scenario 2: LU + PA + S30 + PT10)

3.3.2 ONSHORE WIND POTENTIAL

The overall onshore wind resources are low in Tanzania compared with the solar potential. The wind speeds in Tanzania range from 0.7 to 19.8 m/s at 100 m height, and high-wind-speed areas are predominantly located in the central regions, including Central/Capital and Northern Highlands Zones (Global Wind Atlas). In this analysis, we have included only areas with an average annual wind speed of ≥ 5 m/s for onshore projects. Tanzania's wind potential has been mapped under two different scenarios. The current use of wind energy in Tanzania 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 Scenario 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 onshore wind potential under all restrictions is 789 GW for Scenario 1. Overall, the spatial analysis identified limited wind potential in Tanzania, especially under Scenario 2 (232 GW), 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: Tanzania's potential for utility-scale onshore wind power

Scenarios	1. LU + PA + S30		2. LU + PA + S30 + PT10	
Regions	Onshore Wind Potential Area (km²)	Onshore Wind Potential (GW)	Onshore Wind Potential Area (km²)	Onshore Wind Potential (GW)
Southern Zone	7,108	36	1,265	6
Southern Highlands Zone	21,711	109	6,532	33
South-Central Zone	12,830	64	4,369	22
Coastal Zone	39,672	198	2,127	11
Western Zone	10,659	53	1,629	8
West-Central Zone	23,446	117	7,664	38
Central/Capital	39,672	198	11,296	56
Northern Highlands Zone	20,276	101	6,036	30
Lake Zone	16,522	83	5,440	27
TOTAL	**157,778**	**789**	**46,358**	**232**

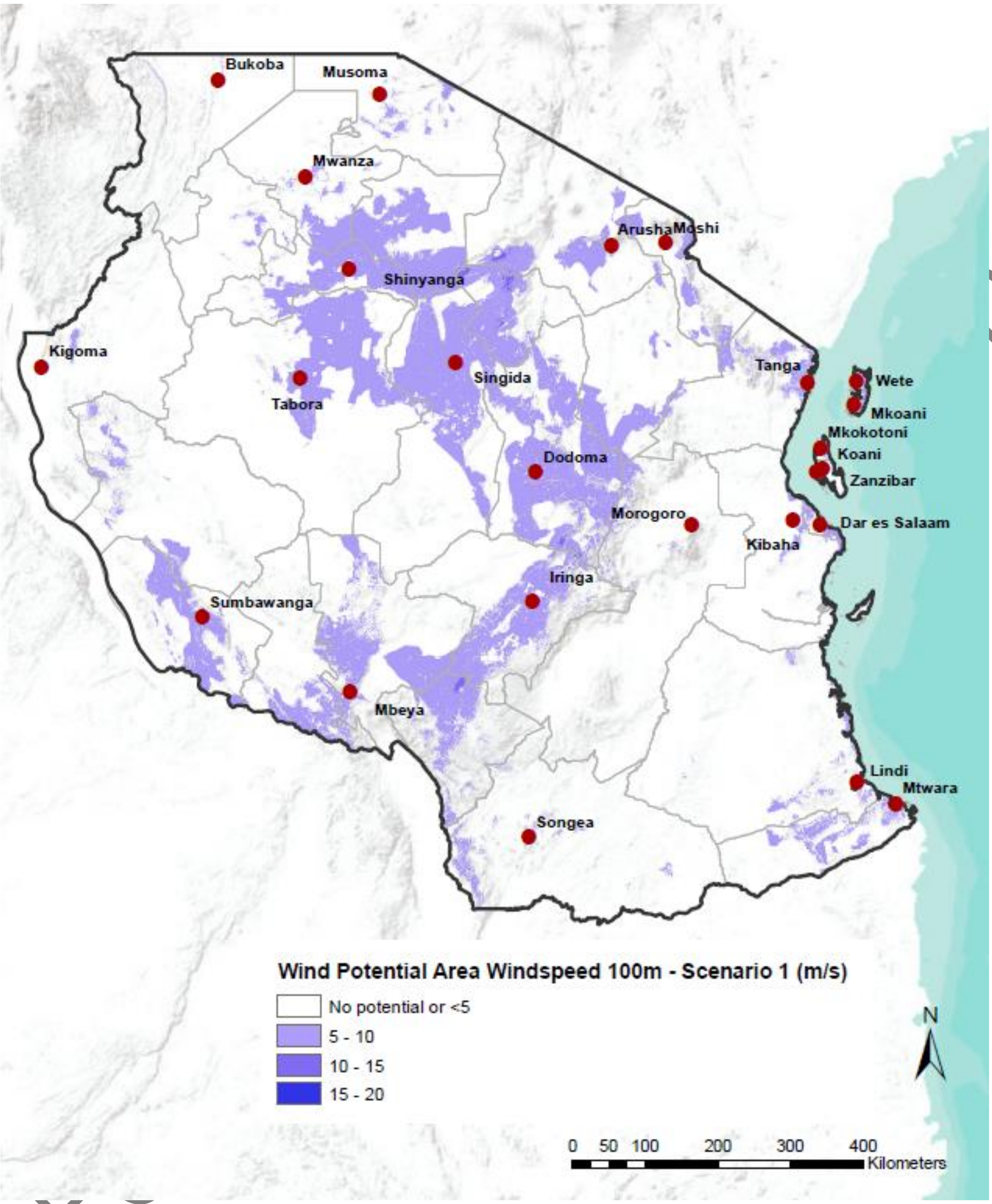

Figure 16: Tanzania—Onshore Wind Potential Areas (Scenario 1: LU + PA + S30)

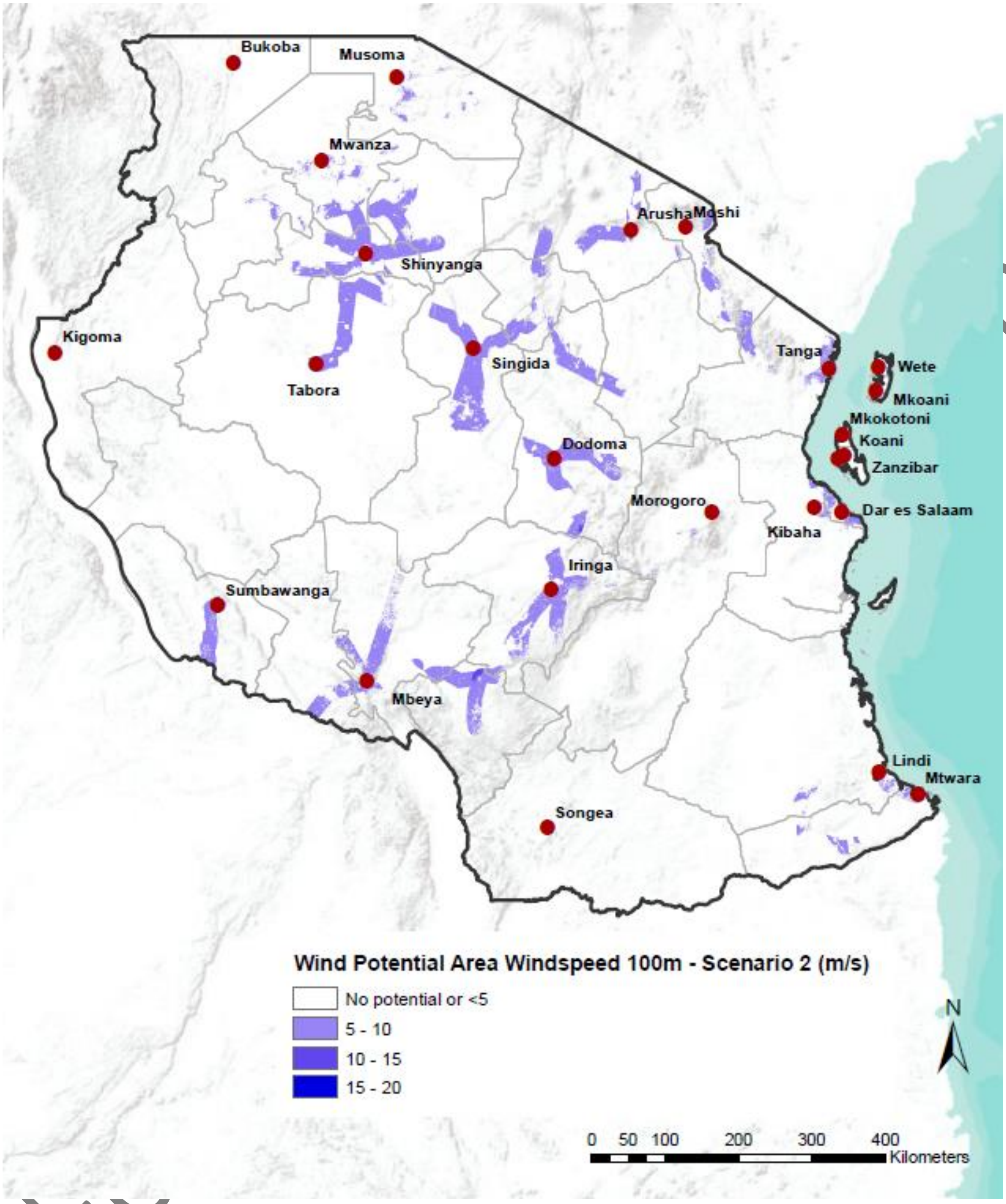

Figure 17: **Tanzania**—Onshore Wind Potential Areas (Scenario 2: LU + PA + S30 + PT10)

3.3.3 OFFSHORE WIND POTENTIAL

The wind speeds in the offshore areas in Tanzania range from 3.1 to 6.5 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 the onshore wind projects due to its economic viability. Tanzania'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 1,309 MW (1.3 GW) for Scenario 1 and 2,008 MW (2.0 GW) for Scenario 2 (232 GW).

Figure 18 and Figure 19 show the offshore wind potential areas for Scenario 1 and Scenario 2.

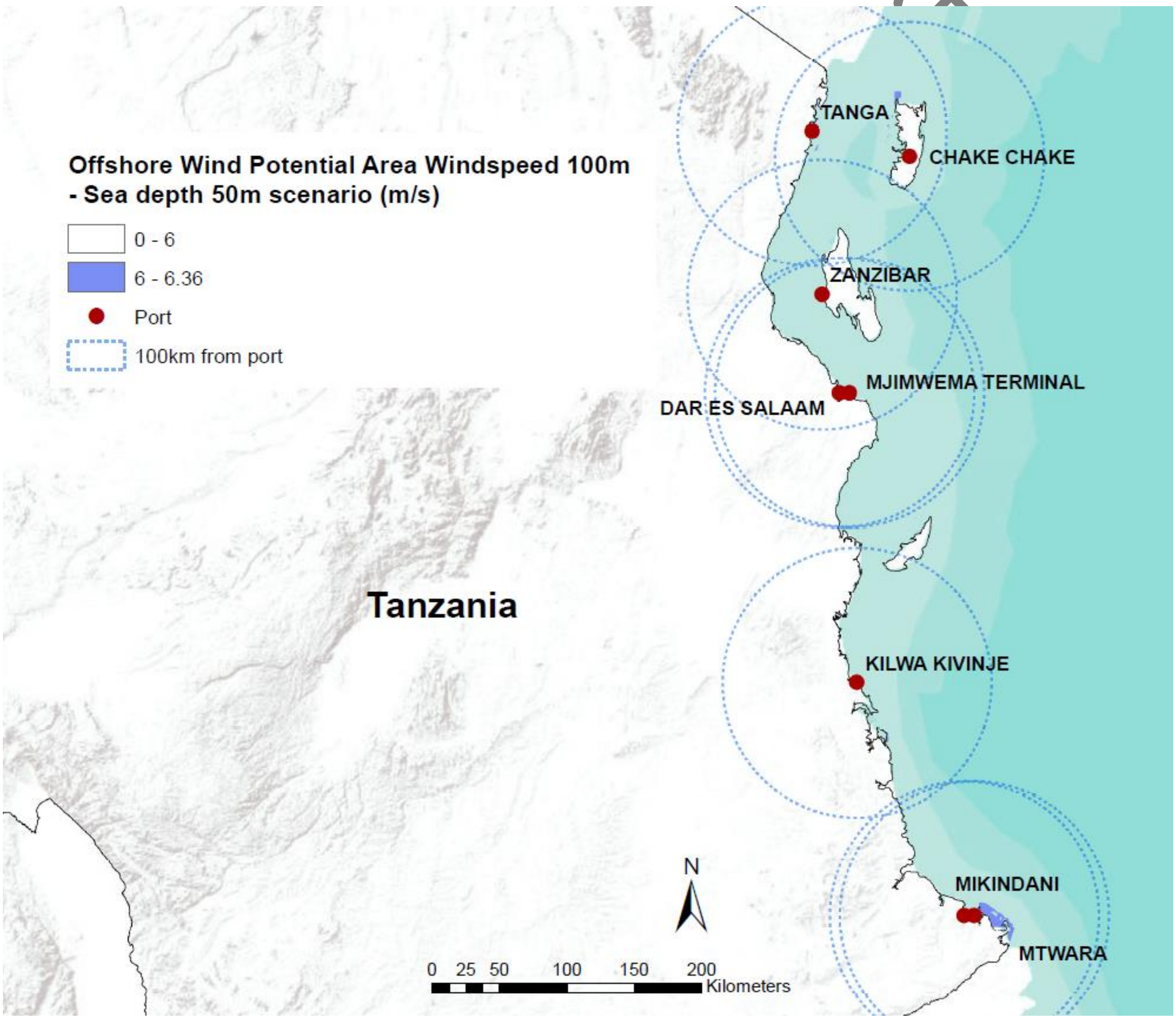

Figure 18: Tanzania's offshore wind potential – Scenario 1

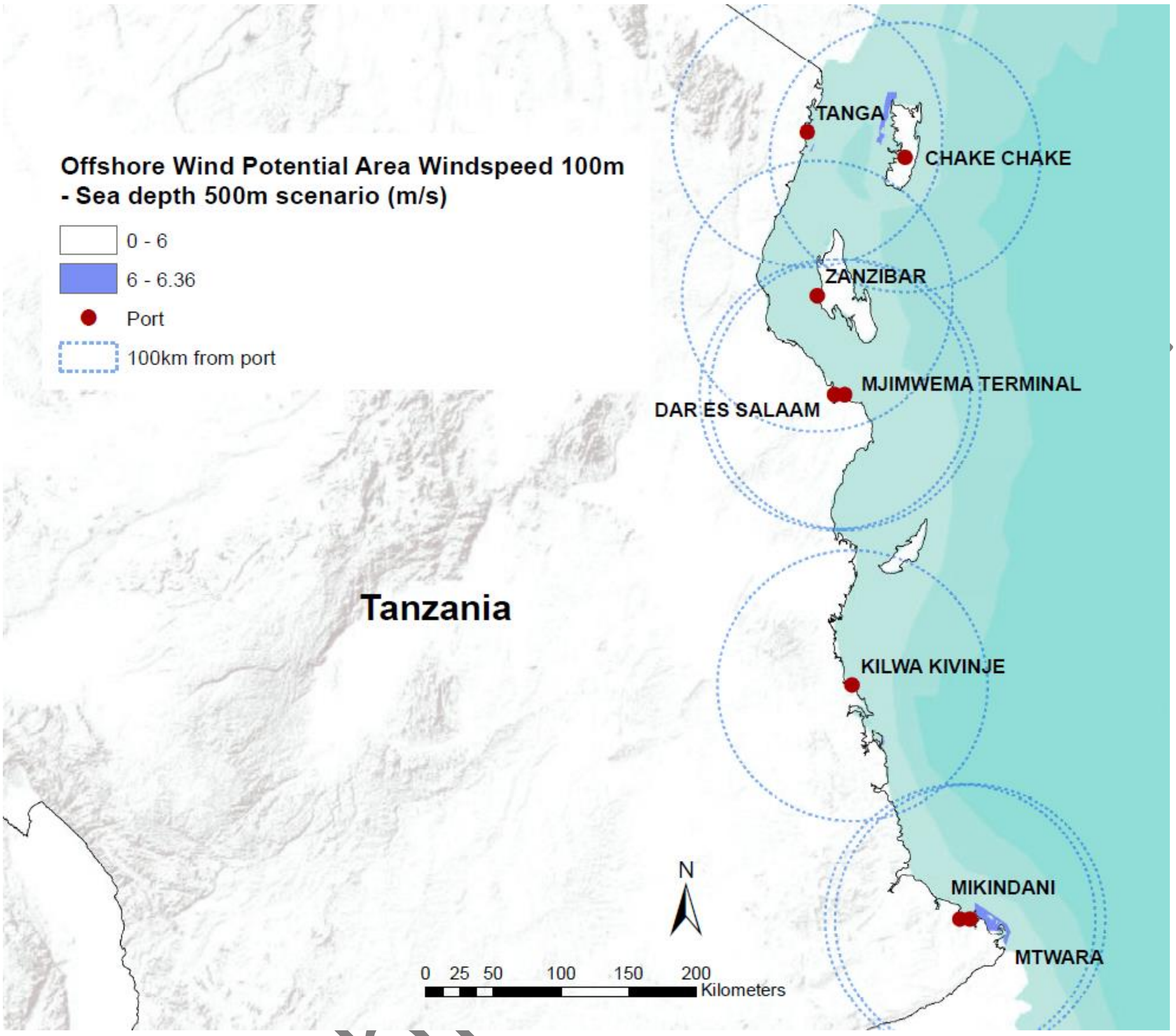

Figure 19: Tanzania's offshore wind potential – Scenario 2

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

To use Tanzania'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 Tanzania 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 Tanzania 1.5 °C (T-1.5°C) scenario, hydrogen and sustainable synthetic fuels will be introduced as a substitute for natural gas. Unsustainable biomass will only play a minor role and will be used almost exclusively by industry after 2030. Hydrogen is assumed to be produced by electrolysis, 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 T-1.5°C scenario introduces synthetic hydrocarbons from renewable hydrogen, electricity, and biogenic/atmospheric CO_2. These synthetic fuels will be introduced after 2030 and provide the remaining fossil fuel demand that cannot meet with biofuels because their potential is limited.

4 Areas of Forest Loss in Tanzania

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[45], the forest area in Tanzania in 2020 was 457,450 km^2 (including 451,920 km^2 of naturally regenerated forest), which is a 20.3 % decrease from 1990 and a 14.8% 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 Tanzania (FAO)

	Extent of Forest	
Year	Areas (km^2)	Change from 1990
1990	573,900	-
2000	536,700	-6.5%
2010	499,500	-14.9%
2020	457,450	-20.3%

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

Global Forest Change also reported that between 2001 to 2021 Tanzania has lost 28,604 km^2 of tree cover (equivalent to 11% decrease in tree cover since 2000) which generated 0.98 gigatonnes of CO_2e emissions[46]. This includes loss of 322 km^2 of humid primary forest between 2002 to 2021, and forest has been cleared mostly with the expansion of agricultural during that period[45]. The loss of forest areas in Tanzania were also visualized with ArcGIS. The spatial dataset by Hansen et al.[47]was used to highlight forest loss (2001–2021) (Figure 20). Areas of forest loss are found across the country, including coastal regions. Table 29 shows the areas of forest loss (km^2), which were also estimated from Hansen et al. (2013) together with the estimated CO_2e emissions since 2000 (the baseline year of this dataset) (Global Forest Watch, 2023).

Table 29: Tanzania—areas of forest loss (km^2) and estimated CO_2e emissions from the forest loss

Years	Area (km^2)	CO_2e emissions (kilotonnes)
2001–2005	4,098	135,027
2006–2010	6,531	211,472
2011–2015	7,839	264,355
2016–2021	10,135	367,666
TOTAL areas of forest loss (2001–2021)	28,604	978,520

Source: Global Forest Change

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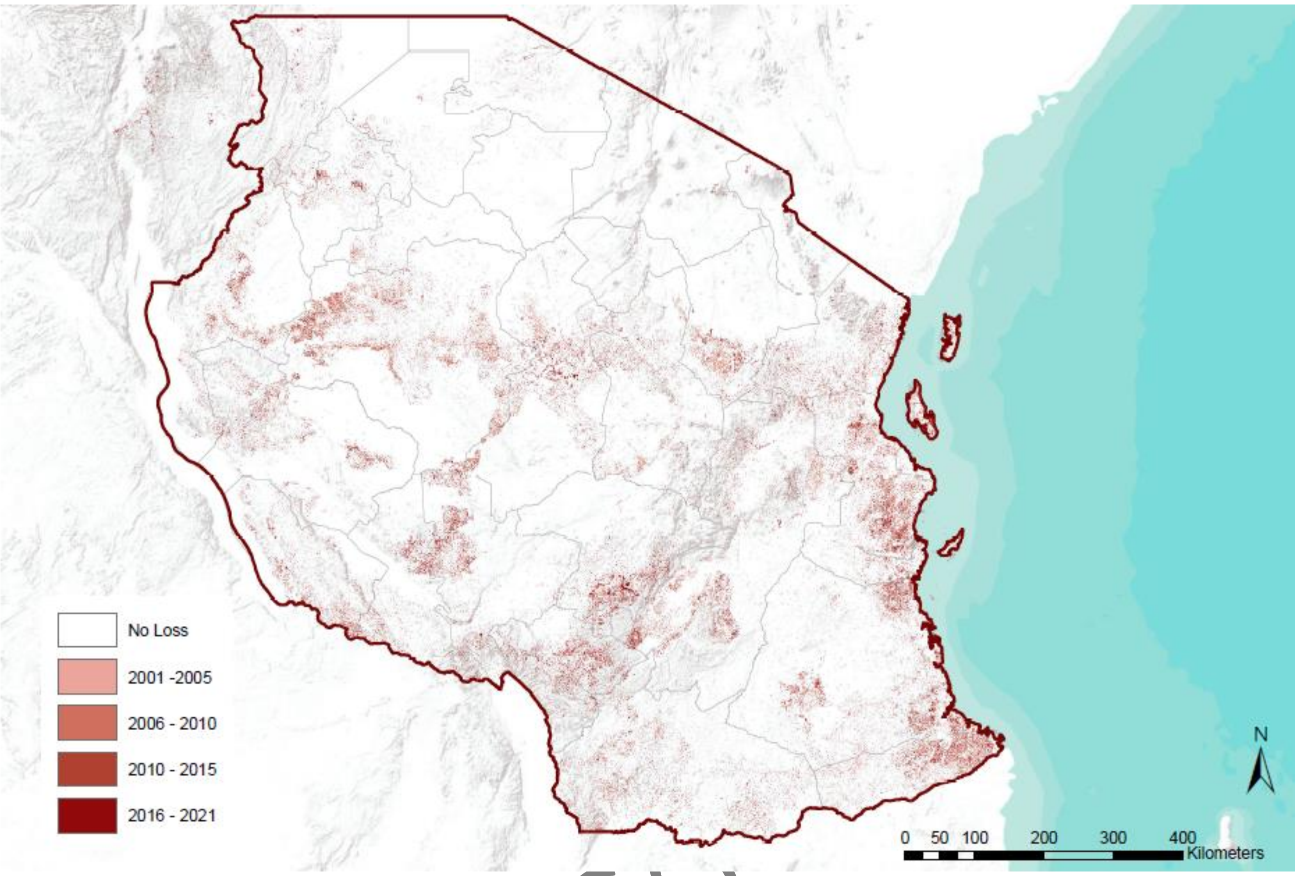
[45] FAO Global Forest Resources Assessment 2020 (Tanzania): https://www.fao.org/3/cb0085en/cb0085en.pdf

[46] Global Forest Change (Tanzania): https://www.globalforestwatch.org/dashboards/country/TZA/?map=eyJjYW5Cb3VuZCI6dHJ1ZX0%3D

[47] 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: Global Forest Change

Figure 20: Areas of forest loss in Tanzania 2001–2021

5 Key Results—Long-term Scenario

Tanzania 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[48]. Tanzania 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 Tanzania 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*[49].
- **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.”[50] 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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[48] REN21 – Global Status report 2021.
[49] World Bank, (2023), Reviewed on: https://data.worldbank.org/indicator/SP.POP.TOTL
[50] http://igrid.net.au/resources/downloads/project4/D-CODE_User_Manual.pdf

5.1 THE REFERENCE SCENARIO

There are a number of energy and / or electrification plans for Tanzania available. Most importunately the ***'Tanzania Rural Energy Master Plan, Volume 2: Rural Electricity Supply Plan'*** [51] published in August 2022. This plan developed a detailed electrification plan for Tanzania's rural region including grid expansion. However, the electrification of the metropolitan areas, the industry and the impact of the electrification of the transport sector to achieve the required decarbonization by 2050 according to the Paris Climate Agreement is not included.

Thus, the One Earth Climate Model builds on Tanzania's Rural Energy Plan and adds the transport and industry sector to this important work. Table 30 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 Tanzania, 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: Tanzania – literature review published energy scenarios and parameters

	Tanzania - 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	Tanzania: 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	14 The Five-Year Development Plan II (FYDPII) states as targets for "Proportion of energy derived from renewable green Energy" 50%by 2020/21 and 70% by 2025/26. However, under the plan this includes liquified petroleum gas
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	30-35% reduction of greenhouse gas emissions compared to BAU scenario by 2030
11.	Investment cost [billion $/a] until 2050	yes	No	
12.	Shares of cumulative investment in power generation 2020-2050	yes	Cumulative investment for 2019 – 2040, incl. fuels, heating, and networks	
13.	Cumulative investment heating technologies 2020-2050	yes	No	
14.	Installed PV capacities up to 2050	yes	No	

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[51] Tanzania Rural Energy Master Plan, Volume 2: Rural Electricity Supply Plan, August 2022, https://rea.go.tz/Articles/rural-energy-master-plan-remp

5.1.1 ASSUMPTIONS FOR THE TANZANIA 1.5 °C SCENARIO

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

- **Emissions reductions:** The main measures taken to meet the CO_2 emissions reductions in the T-1.5°C scenario include strong improvements in energy efficiency, which will double energy productivity over the next 10–15 years, and the dynamic expansion of renewable energy across all sectors.
- **Growth of renewables industry**: Dynamic growth in new capacities for renewable heat and power generation is assumed based on current knowledge of the 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 flat in Tanzania 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 bio-energy 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:** Tanzania's sustainable level of biomass use is assumed to be limited to 425 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 T-1.5°C scenario by state-of-the-art technologies, primarily highly efficient heat pumps and solar collectors.
- **Electrification of transport**: Efficiency savings in the transport sector will result from fleet penetration by new highly efficient vehicles, such as electric vehicles, but also from assumed changes in mobility patterns and the implementation of efficiency measures for combustion engines. The 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 Tanzania'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.

Tanzania's 1.5 °C scenario (T-1.5°C) takes an ambitious approach to transforming Tanzania's entire energy system to an accelerated new renewable energy supply. However, under the T-1.5°C 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 T-1.5°C.

Under the T-1.5°C scenario, the share of electric and fuel cell vehicles will increase. This scenario also relies on a greater production of synthetic fuels from renewable electricity, for use in the 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 Tanzania'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 Tanzania'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 T-1.5°C scenario also models a shift in the heating sector towards the increased direct use of electricity because of the enormous and diverse potential for renewable power and the limited availability of renewable fuels for high-temperature process heat in industry. Increased implementation of a district heating infrastructure (interconnections of buildings in central business districts), bio-energy-based heat generation, and solar collectors and heat pumps for office buildings and shopping centres in larger cities are assumed, leading to 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 TANZANIA REFERENCE SCENARIO

The REFERENCE case for Tanzania has been developed on the basis of the Tanzania 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 Tanzania'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 TANZANIA—ENERGY PATHWAY UNTIL 2050

The following section provides an overview of the key results of three different energy scenarios for Tanzania. 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 T-1.5°C 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 TANZANIA—FINAL ENERGY DEMAND

The projections for population development, GDP growth, and energy intensity are combined to project the future development pathways for Tanzania’s final energy demand. These are presented in Figure 21 for the REFERENCE and T-1.5°C scenarios. In the REFERENCE scenario, the total final energy demand will increase by 121% from 760 PJ/a to 1,682 PJ/a in 2050. The T-1.5°C scenario will reduce any additional costs by a higher proportion of electric cars.

As a result of the projected continued annual GDP growth of 5.6 % on average until 2025 and 6.8 % thereafter until 2050, the overall energy demand is expected to grow (Figure 21). The residential sector will remain dominant in Tanzania’s energy demand, but the energy demand of the industry sector will increase constantly. By 2050, industry will consume at least four times more energy than in 2020, making this sector the second highest consumer after transport in all three scenarios.

The energy demand of the transport sector will increase with 233% by 2050 under the REFERENCE scenario, whereas it will only increase with 54% to 142 PJ/a under the T-1.5°C 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 T-1.5°C pathway is attributable to the high electrification rates, mainly in the cooking and transport sectors, because combustion processes with high losses are significantly reduced.

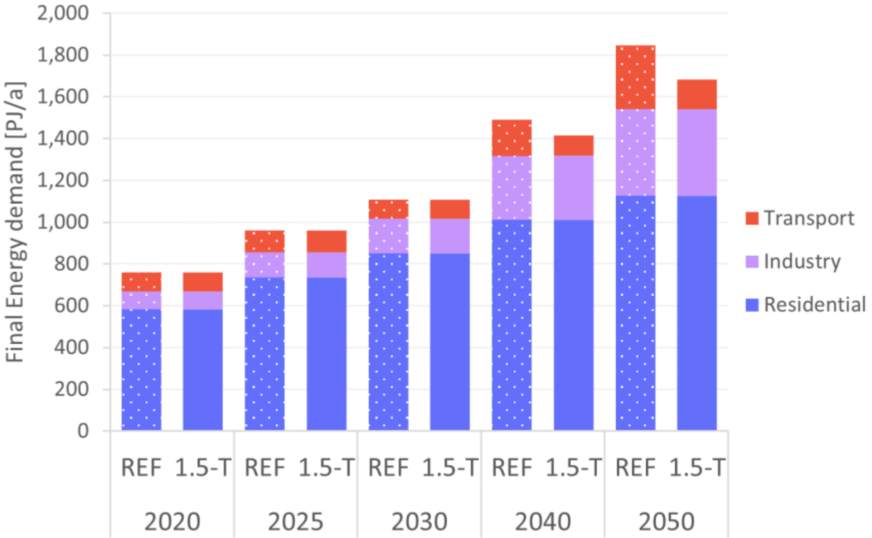

Figure 21: Projection of the total final energy demand by sector (excluding non-energy use and heat from CHP auto producers)

The increased projected electrification of the heating, cooking, and transport sectors, especially under the T-1.5°C scenario, will lead to a significantly increased electricity demand.

The T-1.5°C 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, Tanzania's electricity demand will increase to 292 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 T-1.5°C, around 24 TWh will be used for electric vehicles and rail transport in 2050.

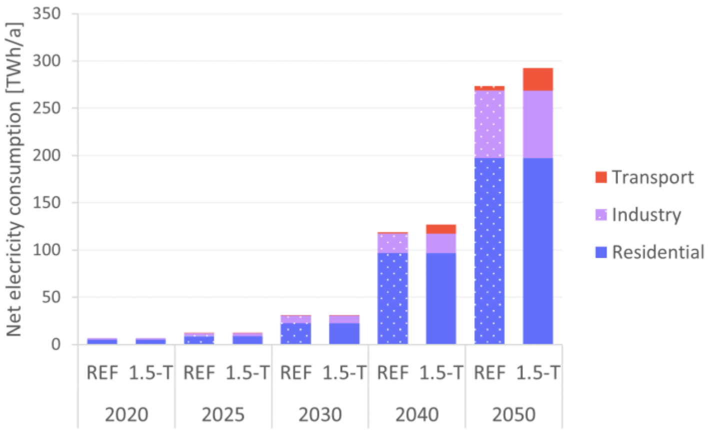

Figure 22: Development of electricity demand by sector two scenarios

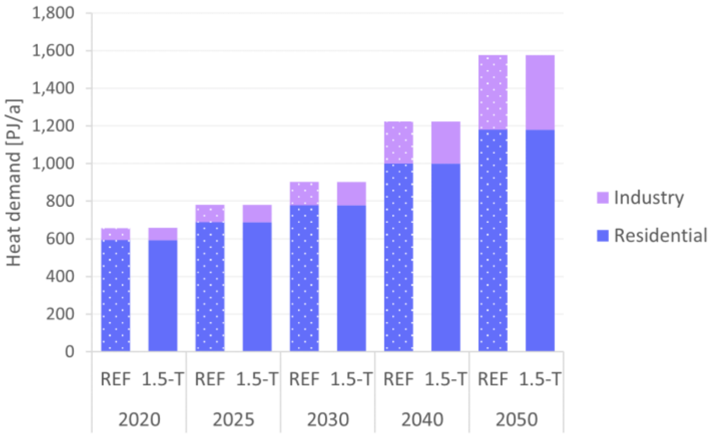

Figure 23: Development of final energy demand for heat by sector in two scenarios

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 Tanzania's GDP. The T-1.5°C pathways has an increased role of electrification in the heating supply (with heat pumps) and the implementation of electric cooking.

As a result, the T-1.5°C pathway will lead to an annual heat demand of around 1,576 PJ/a.

The projected development of the road transport sector (see Figure 24) is very similar between different pathways for Tanzania. More details of the assumptions made for the transport sector projections, broken down into freight and passenger transport, are documented in Section 2.6.

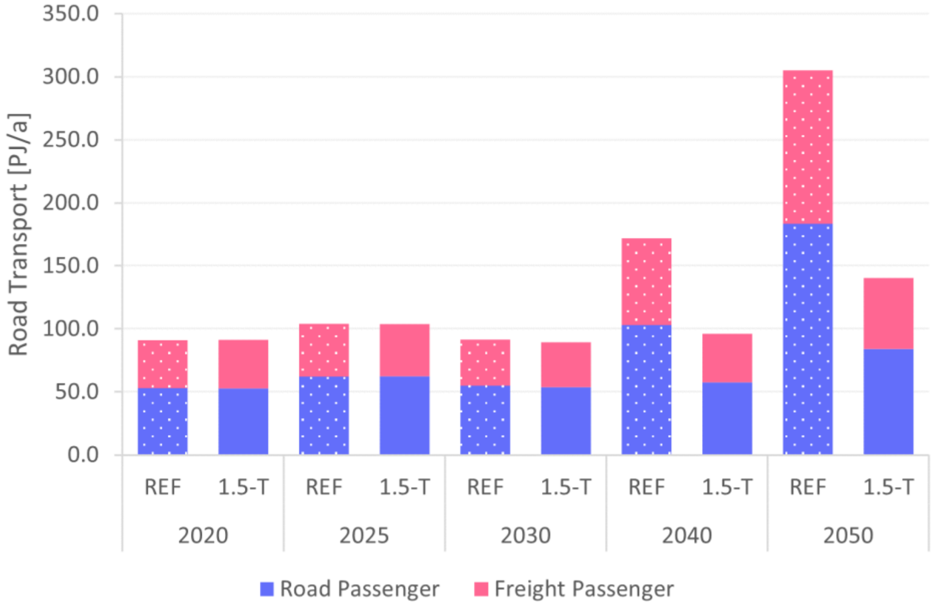

Figure 24: Development of the road transport energy demand for passengers and freight

5.2.2 ELECTRICITY GENERATION

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 T-1.5°C 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 74% and increase to 100% by 2050 under the T-1.5°C scenario. The installed capacity of new renewables will reach about 29 GW in 2030. The T-1.5°C scenarios will lead to higher capacities.

A 100% electricity supply from new renewable energy resources under the T-1.5°C scenario will lead to around 184 GW of installed generation capacity in 2050.

Table 34 shows the comparative evolution of Tanzania's power generation technologies over time. Solar PV will become the main power source. However, just after 2040, solar PV will overtake hydropower in installed capacity. After 2045, the continuing growth of solar PV and additional wind power capacities will lead to a total capacity of 177 GW, compared with 3 GW hydropower under the T-1.5°C scenario. It will lead to a high share of variable power generation and demand-side management, and the management of electric vehicle charging and other storage capacities, such as stationary batteries and pumped 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.

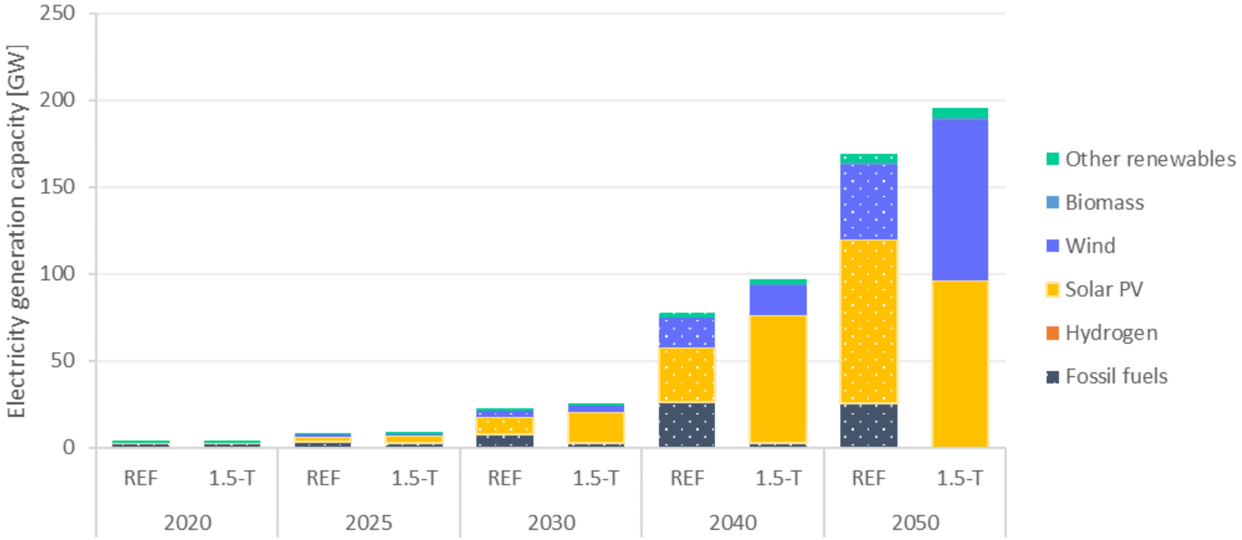

Figure 25: Breakdown of electricity generation by technology

Table 31: Projection of renewable electricity generation capacities

Generation Capacity [GW]		2020	2030	2035	2040	2050
Hydro	REF	1	1	1	2	3
	T-1.5°C	1	1	1	2	3
Biomass	REF	0.0	0.1	0.2	0.5	1.2
	T-1.5°C	0.0	0.1	0.3	0.5	1.3
Wind	REF	0	3	8	17	43
	T-1.5°C	0	3	8	18	96
PV	REF	0	10	22	32	94
	T-1.5°C	0	18	24	73	96
Total	REF	1	14	31	52	141
	T-1.5°C	1	22	33	94	196

5.2.3 ENERGY SUPPLY FOR COOKING AND INDUSTRIAL PROCESS HEAT

Today, bio-energy meets around 11% of Tanzania'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 T-1.5°C scenario, fuel-based cooking (mainly firewood and LPG) will be replaced by electric cooking stoves. The increased electricity used for e-cooking will increase the electricity demand but will replace a significant amount of bio-energy (firewood) because its efficiency is low. Under T-1.5°C, the use of heat pumps as one of the leading new heating supply technologies will accelerate, and direct electric heating, such as radiators, will be introduced, but only as an interim measure between 2025 and 2030. These will be exchanged for heat pumps at the end of their lifetimes.

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

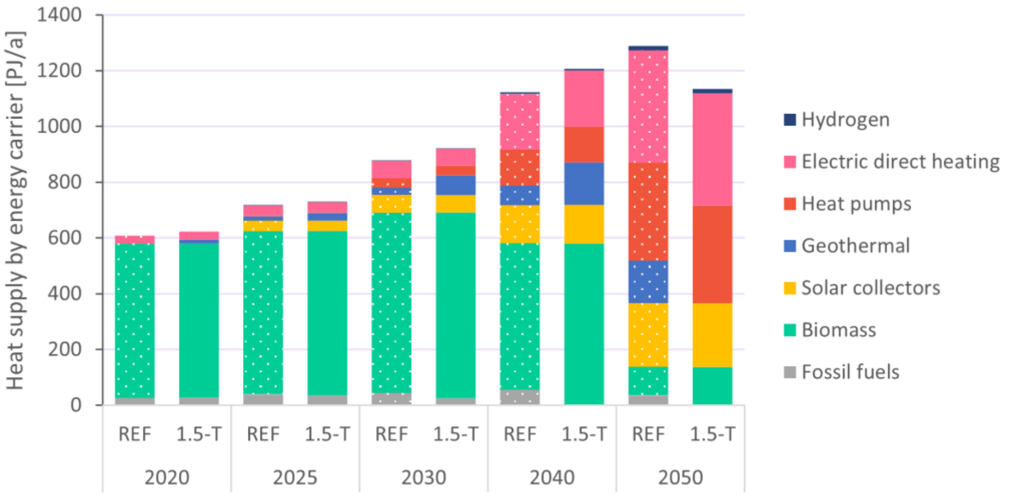

Figure 26: Projection of heat supply by energy carrier (T-1.5°C and REF scenario)

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

Supply (in PJ/a)		2019	2025	2030	2040	2050
Biomass	REF	553	585	647	524	102
	T-1.5°C	553	588	665	577	137
Solar Heating	REF	0	38	63	138	228
	T-1.5°C	0	38	63	138	228
Heat Pumps (electric)	REF	0	2	35	129	350
	T-1.5°C	0	2	35	129	350
Geothermal	REF	0	15	26	70	154
	T-1.5°C	0	15	26	70	154
Direct Electric Heating	REF	29	37	62	200	404
	T-1.5°C	29	37	62	200	404
Total	**REF**	**609**	**717**	**878**	**1123**	**1289**
	T-1.5°C	**609**	**717**	**878**	**1123**	**1289**

Table 32 shows the development of different renewable technologies for heating in Tanzania over time. Biomass will remain the main contributor, with increasing investments in highly efficient modern biomass technology. After 2030, a massive increase in solar collectors and growing proportions of geothermal and environmental heat, as well as electrical heat and some limited renewable hydrogen for industrial process heat, will compensate for the phase-out of fossil fuels. The T-1.5°C scenario includes many efficient heat pumps, which can also be used for demand-side management and load flexibility (see also Section **Error! Reference source not found.**.).

Table 33: Installed capacities for renewable heat generation

Capacities (in GW)		2020	2025	2030	2040	2050
Biomass	REF	98	103	113	86	16
	T-1.5°C	98	103	115	92	20
Geothermal	REF	0	3	5	12	26
	T-1.5°C	0	3	5	12	26
Solar heating	REF	0	12	20	43	71
	T-1.5°C	0	12	20	43	71
Heat pumps (electric and geothermal)	REF	0	3	18	60	138
	T-1.5°C	0	3	18	60	138
Total	REF	116	141	164	224	286
	T-1.5°C	116	141	164	224	286

5.2.4 TRANSPORT

A key target in Tanzania 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 roughly 1% of the transport under the T-1.5°C scenario. The T-1.5°C scenario will achieve the total decarbonization of the transport sector in Tanzania by 2050. More details about the assumptions made to calculate the transport demand and supply development are documented in Section 2.6.

Table 34: Projection of transport energy demands by mode

Transport mode		Unit	2020	2025	2030	2040	2050
Rail	REF	[PJ/a]	0	0	0	0	0
	T-1.5°C	[PJ/a]	0	0	0	0	0
Road	REF	[PJ/a]	91	104	91	172	305
	T-1.5°C	[PJ/a]	91	104	89	96	140
Domestic Aviation	REF	[PJ/a]	1	1	1	1	2
	T-1.5°C	[PJ/a]	1	1	1	1	2
Total	REF	[PJ/a]	92	105	93	173	307
	T-1.5°C	[PJ/a]	92	105	90	97	142

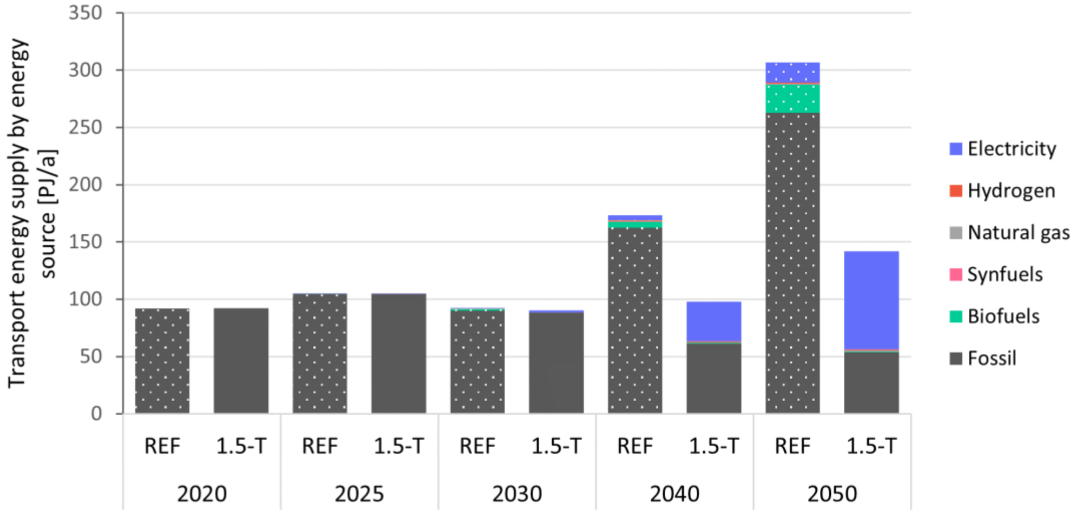

Figure 27: Final energy consumption by transport

5.2.5 PRIMARY ENERGY CONSUMPTION

Based on the assumptions discussed above, the resulting primary energy consumption from the T-1.5°C is shown in Figure 28. The T-1.5°C scenario will result in primary energy consumption of around 1,780 PJ in 2050.

The T-1.5°C scenario aims to phase-out oil in the transport sector and oil for industrial use as fast as is technically and economically possible, through the expansion of renewable energies. The fast introduction of very efficient vehicle concepts in the road transport sector will replace oil-based combustion engines. This will lead to an overall renewable primary energy share of more than 97% in 2050 under the T-1.5°C scenario (including non-energy consumption).

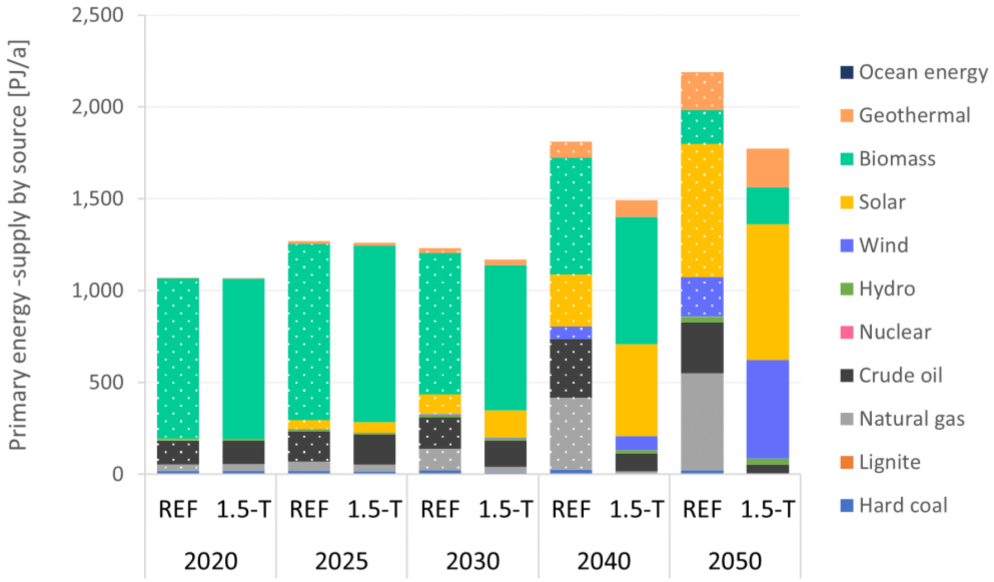

Figure 28: Projection of total primary energy demand by energy carrier (including electricity import balance)

5.2.6 CO_2 EMISSIONS TRAJECTORIES

The T-1.5°C scenario will reverse the trend of increasing energy-related CO_2 emissions after 2025, leading to a reduction of about 6% relative to 2020 by 2030 and of about 34% by 2040. In 2050, full decarbonization of Tanzania's energy sector will be achieved under the T-1.5°C scenario.

In the T-1.5°C scenarios, the cumulative emissions will sum to 283 Mt, compared to 449 Mt in the REF scenario.

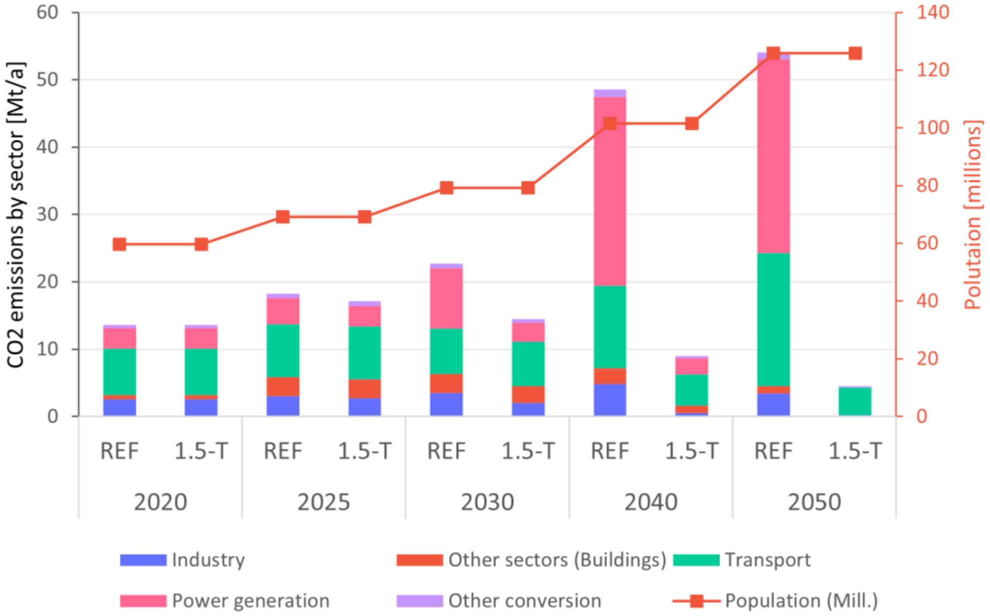

Figure 29: Development of CO_2 emissions by sector

5.2.7 COST ANALYSIS

5.2.7.1 Future costs of electricity generation

Figure 30 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 663 times in the T-1.5°C scenario from 2020 to 2050. The reason for high generation capacity is the far-reaching electrification strategy to replace fossil fuel with electricity for cooking, heating, and transport.

The T-1.5°C will have a cost advantage until 2035 compared to the REFERENCE case. Between 2035 and 2040, costs could be up to 10% higher than under the REFERENCE case if fossil fuel costs projections are correct. Cost advantages will be reached under the T-1.5°C case from 2050 onwards again due to accelerated investment in renewable electricity: full cost of generation is about 82 TZS/kWh (0.033 $/kWh) under the T-1.5°C scenario in 2030, when no consideration is given to the integration costs for storage or other load-balancing measures (see Figure 30).

However, the higher average generation costs under the T-1.5°C 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 T-1.5°C scenario will lead to average electricity generation costs of 103 TZS/kWh (0.023 US$ cent/kWh).

Tanzania’s total electricity supply costs will increase with the increasing electricity demand. The T-1.5°C pathway has similar total electricity costs in comparison to the REFERENCE case, but these will directly replace fuel costs for bioenergy and oil based power generation.

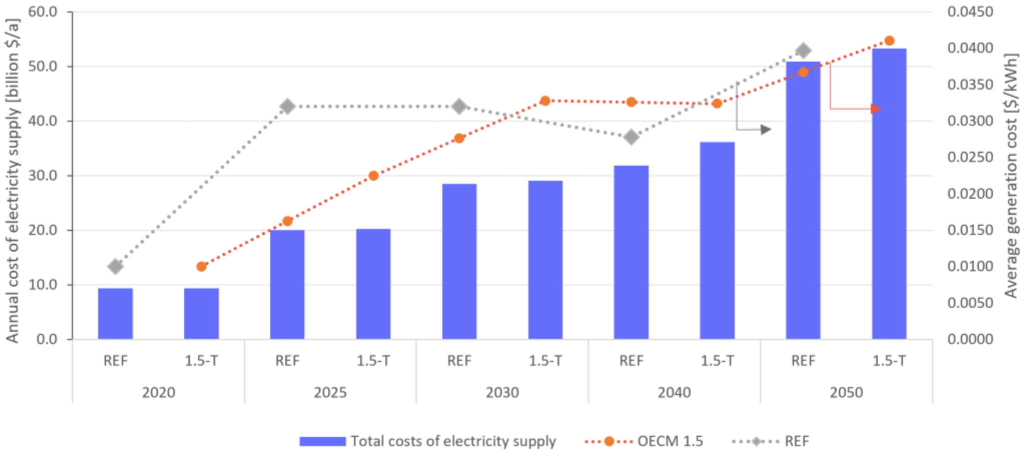

Figure 30: Development of total electricity supply costs and specific electricity generation costs

Investments in power generation

Tanzania will invest in new power generation—mainly solar PV. Here, the main difference between the T-1.5°C scenario and the other scenarios is the investment in other technologies—primarily solar PV. The onshore wind potential of Tanzania is 789 GW(Scenario 1) or 232 GW (Scenario 2) and the the annual average wind speeds ranges 6 m/s and 8m/s at 100 m height, but some very good sites with up to 10 m/s are documented as well. The electrification of remote villages under the T-1.5°C 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.

The additional investment in solar PV under the T-1.5°C scenario will amount to around 208 trillion TZS (US$83 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.

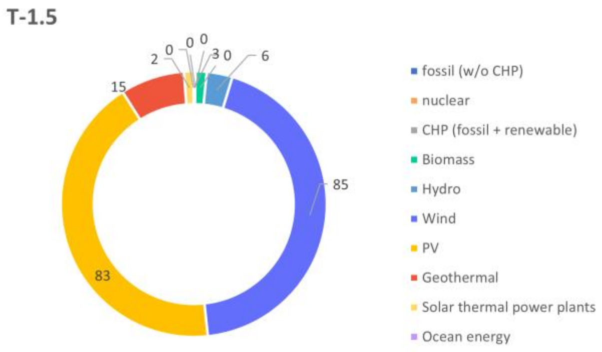

Figure 31: Shares of cumulative investment in power generation, T-1.5°C scenario, 2020 to 2050 [billion $]

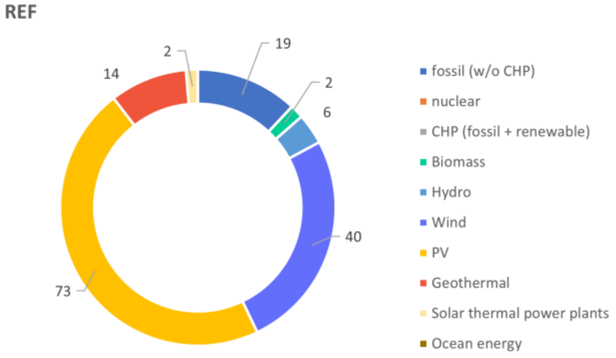

Figure 32: Shares of cumulative investment in power generation, REF scenario, 2020 to 2050 [billion $]

Table 35: Investment costs in new power generation in the T-1.5°C scenarios (exchange rate: 1 TZS= 0.00040 USD, 1st December 2023)

T-1.5°C	2020-–2050	
	[trillion TZS]	[billion US$]
Hydro	15	6
Biomass	7	3
PV	208	83
Wind	212	85
Fossil & other	45	18
Total	**487**	**195**
REFERENCE	2020-–2050	
	[trillion TZS]	[billion US$]
Hydro	14	6
Biomass	6	2
PV	182	73
Wind	100	40
Fossil & other	88	35
Total	390	156

5.2.7.2 Future investments in the heating sector

The main difference between the T-1.5°C pathway and other pathways is the significant variety in bio-energy use and the diversification of heating technologies. Electrical heat pumps, geothermal heat pumps, and solar thermal applications for space and water heating and drying will lead to a considerable reduction in the use of biogas and solid biomass, and therefore reduce the fuel costs. Figure 33 shows the shares of cumulative investments in the heating sector between 2020 and 2050.

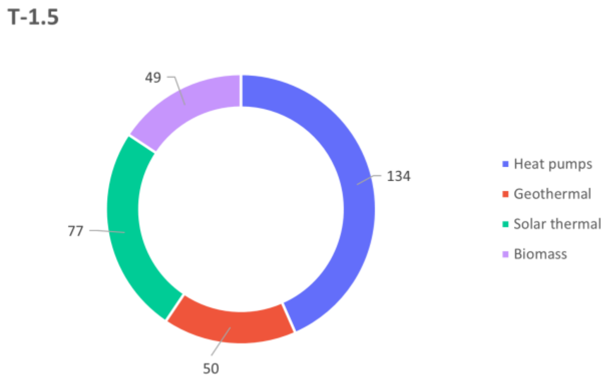

Figure 33: Cumulative investment in the heating technologies (generation) under the T-1.5°C scenario

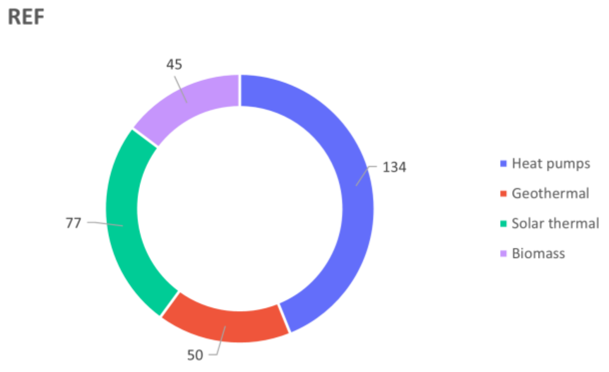

Figure 34: Cumulative investment in the heating technologies (generation) under the T-1.5°C scenario

Table 36 shows the cumulative investment and fuel costs in the heating sector. The overall heat sector costs—investment and fuel costs—over the entire scenario period until 2050 will be 38,022 trillion TZS.

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

T-1.5°C scenario, cost 2020-2050	[trillion TZS]	[billion US$]
Cumulative heating investment	774	309
Cumulative fuel cost	36,762	14,705
Cumulative electricity cost	487	195
Total	**38,022**	**15,209**
REFERENCE scenario	[trillion TZS]	[billion US$]
Cumulative heating investment: 2020–2050	765	306
Cumulative fuel cost	43,265	17,306
Cumulative electricity cost	390	156
Total	**44,420**	**17,768**

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 Tanzania. Under the most ambitious electrification strategy of the T-1.5°C pathway, total investment will be 44,420 trillion TZS (US$ 17,306 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 and 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 T-1.5°C scenario will be 6398 trillion TZS (US$ 2559 billion), more than 13 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 T-1.5°C scenarios in billion USD and TZS

REFERENCE		2021–2030		2031–2040		2041–2050		2021–2050		2020–2050 average per year	
		Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD
Power	Total	43	17	126	50	221	89	390	156	13	5
Heat	Total	193	77	190	76	382	153	765	306	26	10
Transport	Total	33,250	13,300	0	0	0	0	43,265	17,306	1442	577
Summed Fuel Costs		33,486	13,394	0	0	604	0	44,420	17,768	1,481	577
T-1.5°C		2021–2030		2031–2040		2041–2050		2021–2050		2020–2050 average per year	
		Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD	Trillion TZS	Billion USD
Power	Total	56	22	175	70	256	102	487	195	16	6
Heat	Total	197	79	195	78	381	153	774	309	26	10
Transport	Total	26,747	10,699	0	0	0	0	36,762	14,705	1,122	449
Summed Fuel Costs		27,000	10,800	370	148	638	255	38,022	15,209	1,164	490

6 Tanzania: 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 T-1.5°C scenario, and the consequent increased demand on the power grid transmission capacities, possible new inter-provincial connections, and/or expanded energy storage facilities.

6.1 POWER SECTOR ANALYSIS—METHODOLOGY

After the socio-economic (Section 2) and geographic analyses (Section 3) and the development of the long-term energy pathways for Tanzania (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.

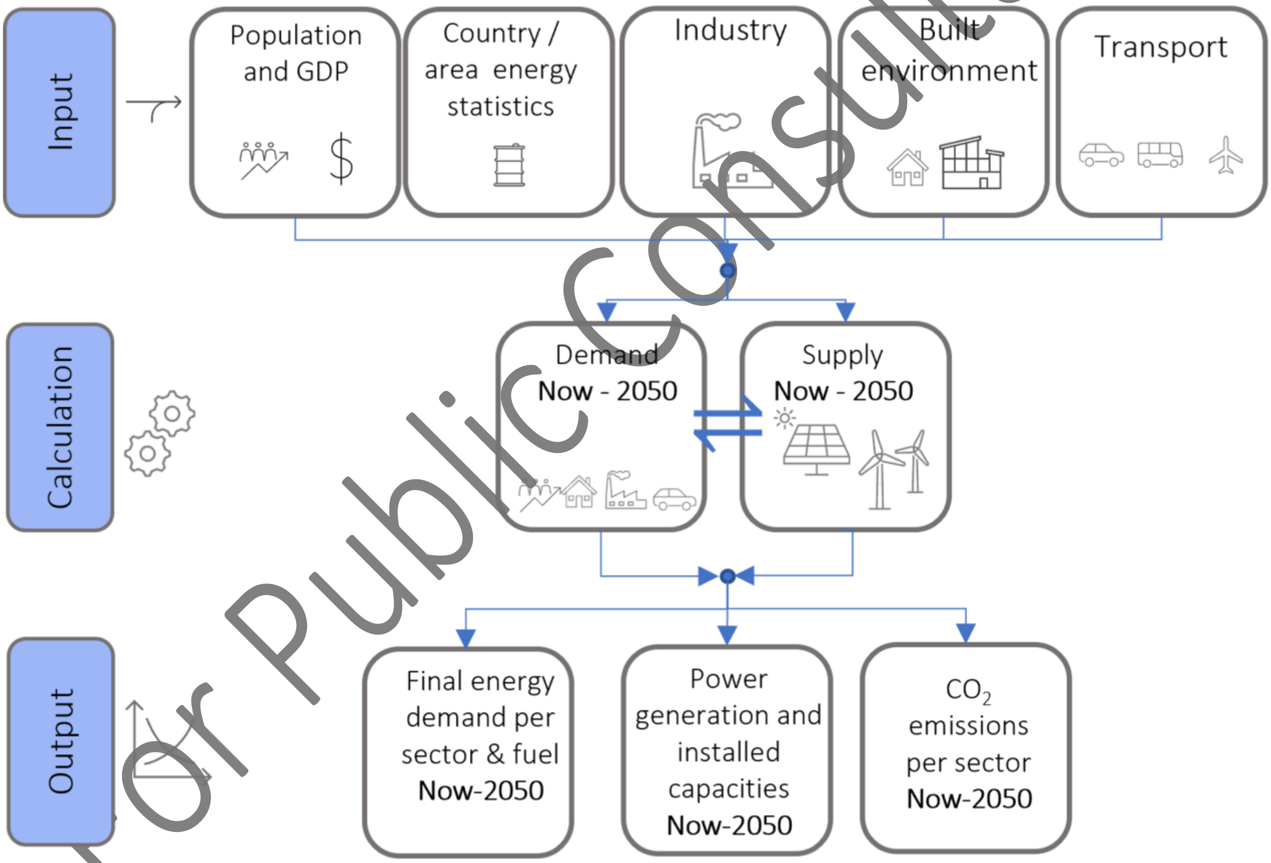

Figure 35: Overview—Energy demand and load curve calculation module

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)[52], 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 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)[53], and is based on weather data from global re-analysis models and satellite observations (Rienecker and Suarez 2011[54]; Müller and Pfeifroth, 2015[55]).

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.

<u>Limitations:</u> 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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[52] 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/

[53] 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

[54] 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

[55] 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.

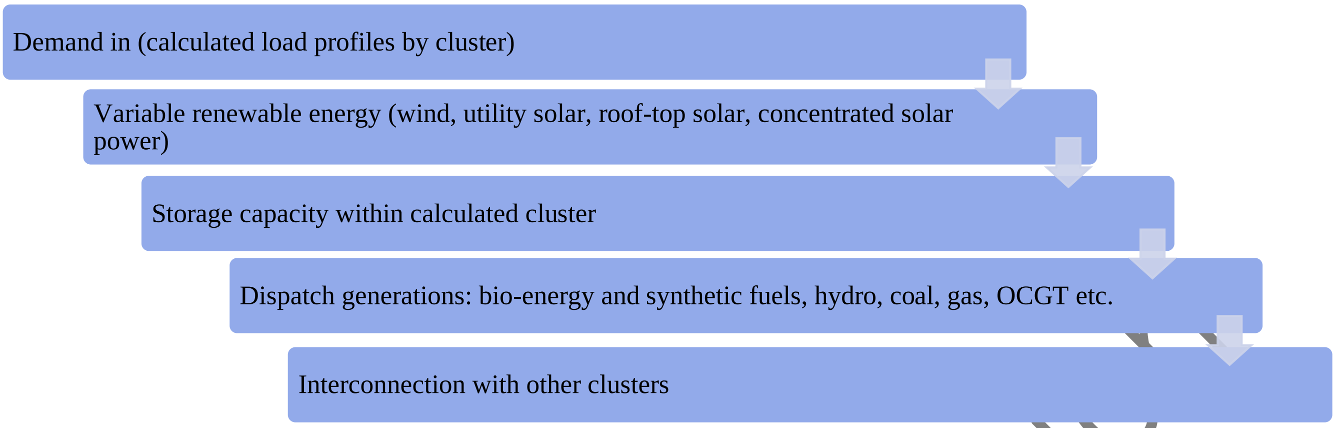
The key objective of the modelling is to calculate the load development by region, modifying the residual load (load minus generation), theoretical storage, and interconnection requirements for each cluster and for the whole survey region. The theoretical storage requirement is provided as the “storage 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 36 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 on the basis of meteorological data (in the cases of solar and wind power) or dispatch requirements.

Figure 36: Dispatch order within one cluster



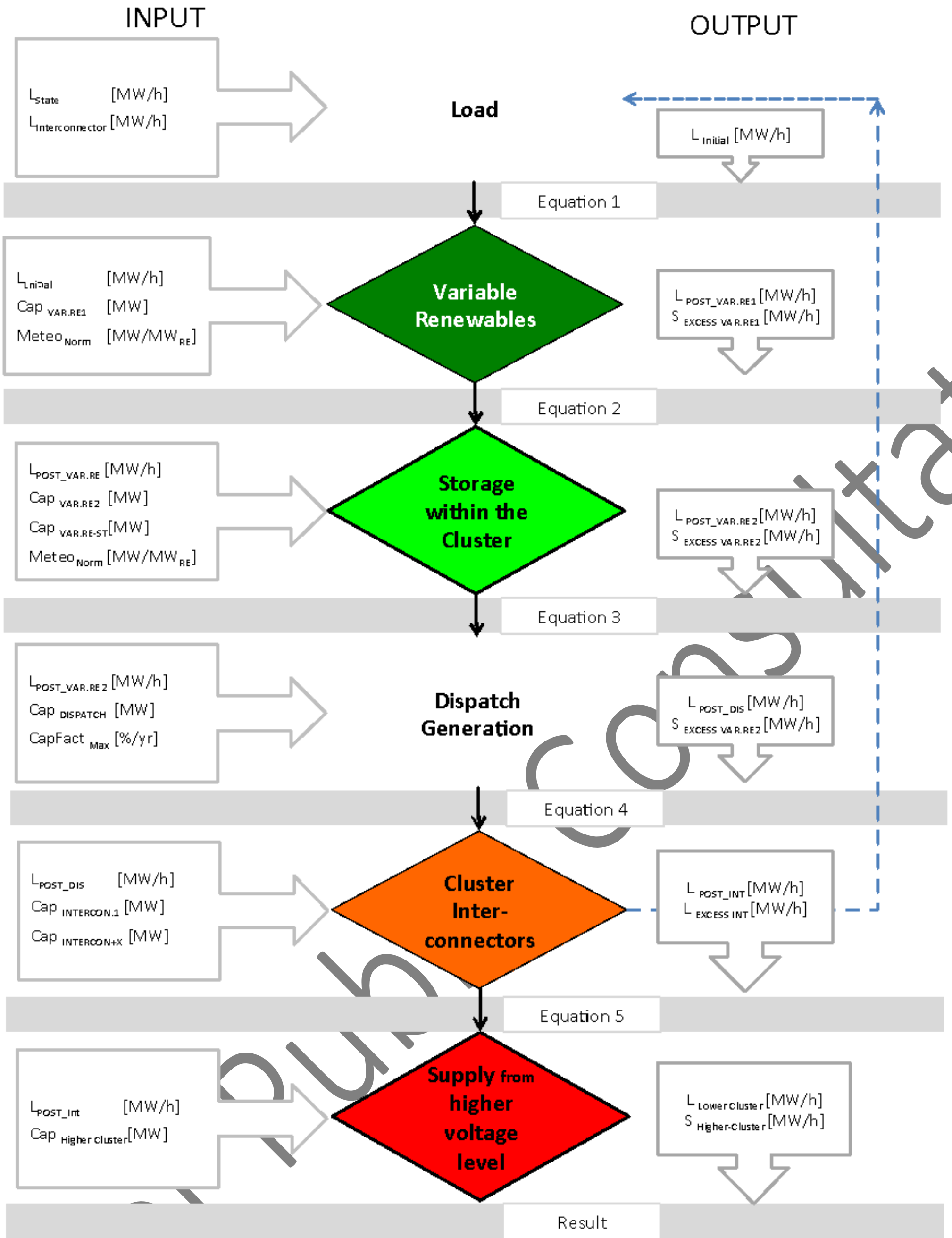
Overview: input and output— OECM 24/7 energy dispatch model

Figure 37 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 with regard to 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 37: Overview—Input, output, and dispatch order



6.2 TANZANIA: DEVELOPMENT OF POWER PLANT CAPACITIES

Tanzania has substantial untapped renewable energy potential, as described in Section 3. Natural gas and hydropower plants provide the bulk of the grid-connected electricity generation, followed by diesel generators which provide the majority 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, and biomass energy-based generators—can play in the future.

In terms of Tanzania's renewable electricity potential, most of the future generation will be solar PV and onshore wind. Due to offshore wind resources, Tanzania can start a new offshore wind industry and increase this generation capacity after 2030 significantly. 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 Tanzania over the next decade. However, it is a viable future option. The potential for geothermal heating systems (heat pumps) for low-temperature heating is significant as well, which can be used for demand side management.

The capacity for solar PV installations will increase substantially under the T-1.5°C pathway. The solar photovoltaic market will increase to around 2,800 MW per year between 2021 and 2030 and increase to around 5,500 MW per year between 2031 and 2040. Tanzania's wind power market is projected to increase its annual market volume to around 800 MW by 2030 and 1,800 MW between 2035 and 2040, increasing further to 10,000 by 2050: making it an important local industry. Tanzania's hydropower plant capacity will grow slowly by a factor of 3 from around 900 MW in 2021 to 2,800 MW in 2050. Finally, the offshore wind capacity will increase from a first installation around 2030 to 2,000 MW by 2050.

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

Table 38:Tanzania—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	0	0	0	200	0	0	0	33
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
natural gas	0	0	0	0	0	-200	0	-33
oil	0	0	-200	200	-400	0	-67	-67
diesel	0	0	0	0	0	0	0	0
hydro	0	0	0	100	100	200	0	67
wind onshore	250	200	800	1,800	4,000	10,600	417	2,942
wind offshore	0	200	200	200	200	200	133	167
PV	1,000	2,800	5,800	5,200	3,400	1,200	3,200	3,233
geothermal	0	0	0	100	100	200	0	67
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 Tanzania's solar market will provide electricity for households and electric mobility. By 2030, solar PV will generate around 26 TWh— about three times Tanzania's current electricity demand. By 2030, wind power and solar PV will provide over 75 % of the country's electricity demand, which is projected to increase 5 -fold relative to 2021.

6.3 TANZANIA: UTILIZATION OF POWER GENERATION CAPACITIES

Table 39 and Table 40 show the installed capacities for roof-top and utility -scale solar PV under the T-1.5°C 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: Tanzania T-1.5°C pathway—Installed photovoltaic capacities by region (2030)

T-1.5C pathway 2030	Southern Zone	Southern Highlands Zone	South-Central Zone	Coastal Zone	Western Zone	West-Central Zone	Central Capital	Northern Highlands Zone	Lake Zone
	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]
Photovoltaic (roof-top)	1,080	945	945	2,565	1,080	1,215	1,080	1,350	3,105
Photovoltaic (utility-scale)	360	315	315	855	360	405	360	450	1,035

Table 40: Tanzania T-1.5°C pathway—installed photovoltaic capacities by region (2050)

T-1.5C pathway 2050	Southern Zone	Southern Highlands Zone	South-Central Zone	Coastal Zone	Western Zone	West-Central Zone	Central Capital	Northern Highlands Zone	Lake Zone
	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]	[MW]
Photovoltaic (roof-top)	5,760	5,040	5,040	13,680	5,760	6,480	5,760	7,200	16,560
Photovoltaic (utility-scale)	1,920	1,680	1,680	4,560	1,920	2,160	1,920	2,400	5,520

The T-1.5°C 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. The vast solar potential is accompanied by a growing wind generation - mainly onshore but also offshore - to compensate for differences in seasonal generation.

To diversify the generation, mix to reduce the seasonal storage requirements, Tanzania wind resources should be used to the highest possible degree.

The coastal regions and the southern part of Tanzania host only minor parts of the country's generation capacities, mainly hydro power, and gas power plants. Due to a low utilization of gird connected solar photovoltaic and wind power, The share of variable generation in 2020 is under 5% accept in the West-Central Zone. Most of the hydro power plants are in the central and northern regions of Tanzania, which is shown has high shares of dispatchable renewables in Table 41. Fossil fuel power plants – mainly oil and gas – are located close to the industrial areas in the more densely populated parts of Tanzania.

The projections for 2030 and 2050 show an increase of variable renewables in regions with higher dispatchable capacities, while dispatchable decreases in all regions. On average, Tanzania will have around 75% variable renewables with the rest of dispatchable power plants by 2035.

Table 41: Tanzania—power system shares by technology group

Power Generation Structure in Percentage of Annual Supply [%/a]		T-1.5C		
		Variable Renewable	Dispatch Renewable	Dispatch Fossil
Southern Zone	2020	5%	42%	53%
	2030	84%	13%	3%
	2050	85%	15%	0%
Southern Highlands Zone	2020	4%	96%	0%
	2030	81%	19%	0%
	2050	88%	12%	0%
South-Central Zone	2020	1%	99%	0%
	2030	63%	37%	0%
	2050	80%	20%	0%
Coastal Zone	2020	1%	2%	97%
	2030	70%	5%	25%
	2050	89%	11%	0%
Western Zone	2020	5%	0%	95%
	2030	84%	10%	6%
	2050	89%	11%	0%
West-Central Zone	2020	11%	0%	89%
	2030	88%	9%	3%
	2050	93%	7%	0%
Central/Capital	2020	2%	0%	98%
	2030	78%	11%	12%
	2050	92%	8%	0%
Northern Highlands Zone	2020	2%	1%	97%
	2030	78%	8%	14%
	2050	91%	9%	0%
Lake Zone	2020	4%	0%	96%
	2030	85%	8%	8%
	2050	91%	9%	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 TANZANIA: 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 T-1.5°C pathway projections. To validate the data, we compared our results with the real-time data published by the local grid operator.

The statistical data for each province for 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 Tanzania'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: Tanzania—calculated load, generation, and residual load in 2020/21

Real Load (rounded)—measured by grid operators in 2018	Electricity Generation	Maximum Load (Domestic)	Maximum Generation	Minimum Load	Average Load
	[TWh/a]	[MW]	[MW]	[MW]	[MW]
Southern Zone	595	0.12	0.12	0.04	0.07
Southern Highlands Zone	669	0.13	0.13	0.05	0.08
South-Central Zone	520	0.11	0.11	0.03	0.06
Coastal Zone	1,784	0.32	0.32	0.11	0.17
Western Zone	446	0.12	0.12	0.03	0.06
West-Central Zone	669	0.11	0.09	0.04	0.07
Central/Capital	372	0.11	0.11	0.03	0.06
Northern Highlands Zone	892	0.16	0.16	0.05	0.09
Lake Zone	1,561	0.16	0.16	0.05	0.09
Tanzania total	7,508	1.18	1.16	0.38	0.66

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 Tanzania will increase from around 1 GW in 2020 to just under 40GW in 2050. In relation to Tanzania‘s population, 40 GW load is still lower than OECD countries with equal population.

The increase in load is attributable to the growth of the commercial and industrial sectors of Tanzania 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 Tanzania’s power distribution and transmission grid, both within Tanzania and as interconnections with neighbouring countries—especially Kenya.

Furthermore, increased electricity demand in the residential sector is a consequence of electrification of cooking, heating, and cooling, which constitutes an increase of the living standards of all Tanzania’s households as they acquire more residential appliances.

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: Tanzania—projection of load, generation, and residual load until 2050

Tanzania Development of Load and Generation		K-1.5C			
		Maximum Load	Maximum Generation	Maximum Residual Load	Peak Load Increase
		[MW]	[MW]	[MW]	[%]
Southern Zone	2020	0.12	0.12	0.00	100%
	2030	0.44	0.75	-0.31	367%
	2050	3.90	10.2	-6.3	3250%
Southern Highlands Zone	2020	0.13	0.13	0	100%
	2030	0.47	0.95	-0.48	362%
	2050	4.20	13.3	-9.1	3231%
South-Central Zone	2020	0.11	0.11	0	100%
	2030	0.39	0.85	-0.46	355%
	2050	3.50	6.8	-3.3	3182%
Coastal Zone	2020	0.32	0.32	0	100%
	2030	1.24	1.46	-0.22	388%
	2050	11.00	12.9	-1.9	3438%
Western Zone	2020	0.12	0.12	0	100%
	2030	0.36	0.73	-0.37	300%
	2050	3.20	6.7	-3.5	2667%
West-Central Zone	2020	0.11	0.09	0.02	100%
	2030	0.44	0.96	-0.52	400%
	2050	4.00	10.7	-6.7	3636%
Central/Capital	2020	0.11	0.11	0	100%
	2030	0.34	1.04	-0.7	309%
	2050	3.10	17.6	-14.5	2818%
Northern Highlands Zone	2020	0.16	0.16	0	100%
	2030	0.61	0.8	-0.19	381%
	2050	5.40	8.4	-3	3375%
Lake Zone	2020	0.16	0.16	0	100%
	2030	0.00	0	0	0%
	2050	0.00	0	0	0%
Tanzania	2020	1.18	1.16	0.02	89%
	2030	4.29	7.54	-3.25	318%
	2050	38.30	86.60	-48.30	2844%

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 **Error! Reference source not found.**).

6.5 TANZANIA: 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 nine analysed regions (Figure 38). 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. Tanzania's significant potential for additional onshore and offshore wind power projects 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 Tanzania'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.

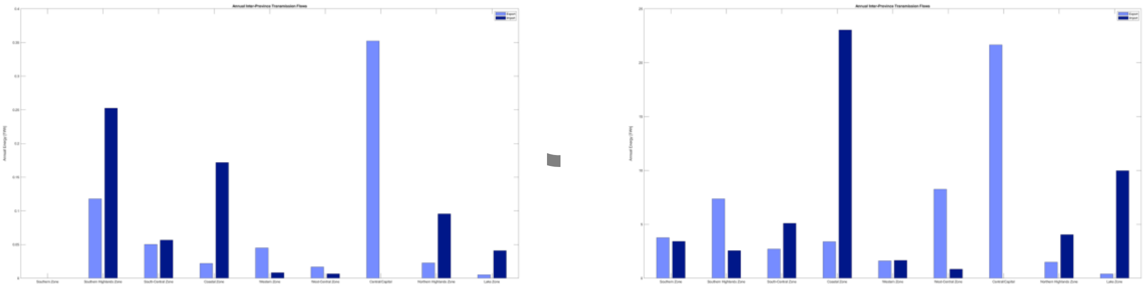

2030
2050

Figure 38: Tanzania—maximum inter-regional exchange capacities, additional to the required grid capacity expansion in response to load increase, under the T-1.5°C scenario

The T-1.5°C 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 **Error! Reference source not found.**)—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 38 shows the calculated exchange capacities between the nine defined sub-regions of Tanzania in 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 and north of the country. The Coastal Zone, the Northern Highlands and Lake regions will increase the required electricity import 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 Tanzania'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[56] 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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[56] 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 T-1.5°C 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 **Error! Reference source not found.**). To determine the annual distribution -of Tanzania's solar and wind power generation, generation and expected load are simulated in a one -hourly resolution (8760 h/a).

Error! Reference source not found. 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 storage and hydrogen/synthetic fuel production later used for e.g. industrial processes heat or feedstock for the chemical industry.

Figure 39 shows the weekly values of inter-province transmission requirements under the T-1.5°C scenario by 2050, which is a function of the import and export requirements on the national level.

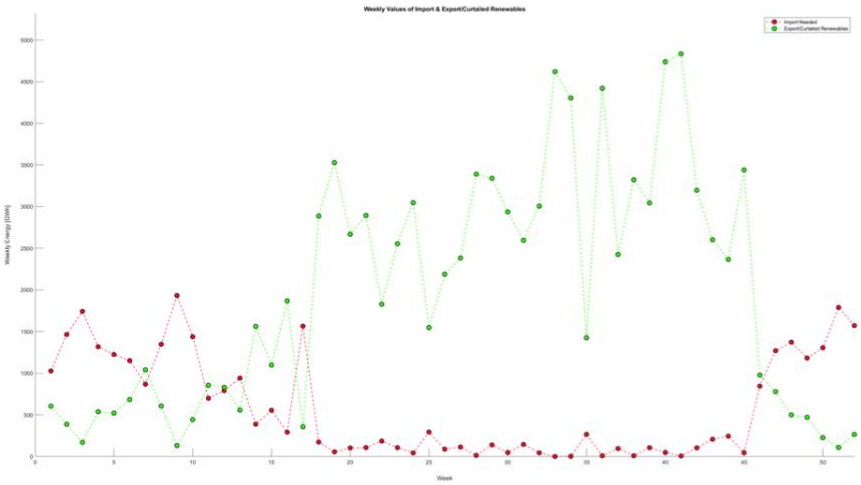

Figure 39: Tanzania: Weekly values of electricity import & export – 2050

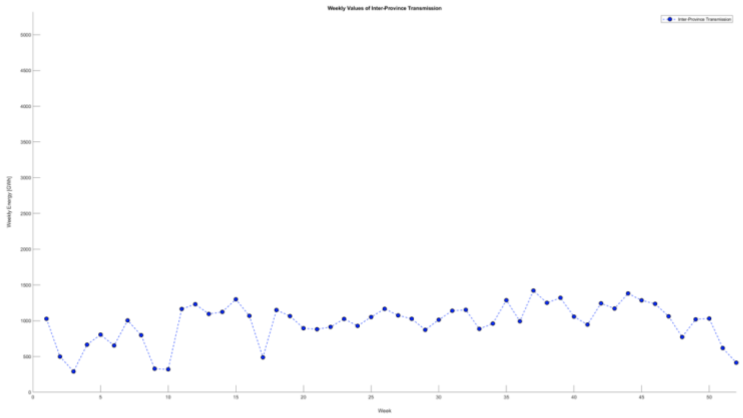

Figure 40: Tanzania: Weekly values of Interprovince Transmission – analysis for 2050

The analysis shows that during late February and early March (24. February -hour 1,340; 3. March – hour 1,520) – 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 Tanzania's start of the rainy season. The other extreme – a period with very high-power generation rates – has been determined around August, the dry season with clear skies. The purple area (Figure 41 and Figure 42) 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.

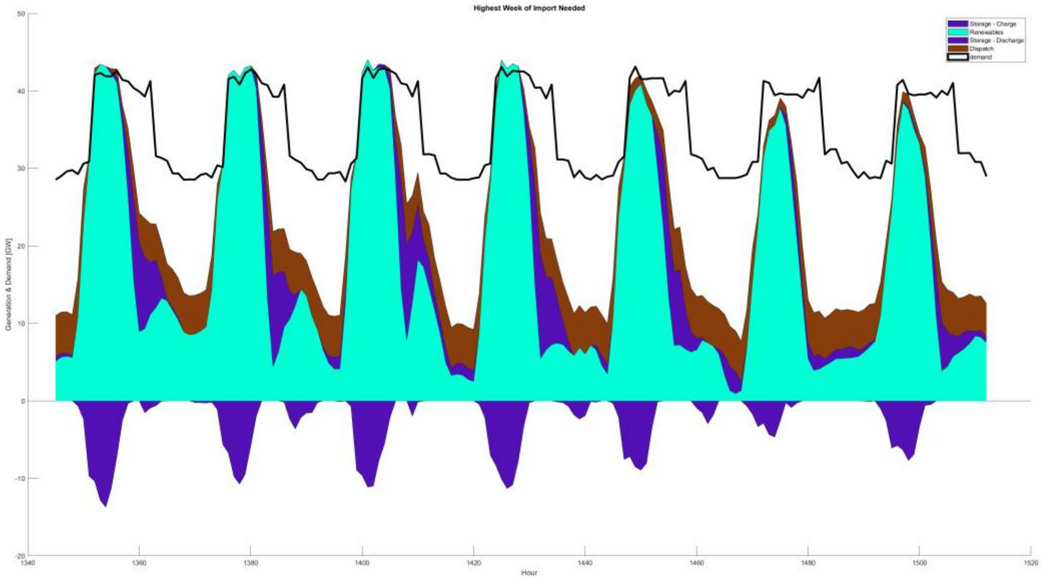

Figure 41: Tanzania - lowest renewable electricity production under the T-1.5°C scenario in 2050

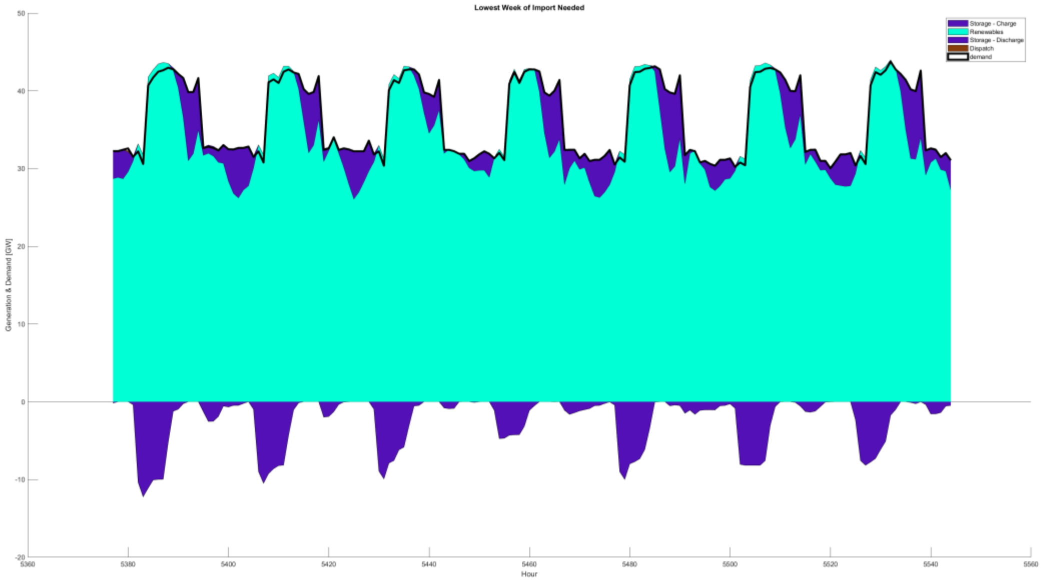

Figure 42: Tanzania - highest renewable electricity production under the T-1.5°C scenario in 2050

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)[57]. 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)[58] 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)[59]. The California Independent System Operator (CISO)[60] 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

Tanzania 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)[61], Tanzania 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 Tanzania 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 used to balance inflexible nuclear power plants, which must operate in base-load mode, and to hedge against price fluctuations on power markets.

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[57] 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.

[58] 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

[59] 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

[60] Impacts of renewable energy on grid operations, factsheet, https://www.caiso.com/Documents/CurtailmentFastFacts.pdf

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

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 T-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 Tanzania. 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)[62], 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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[62] 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 Tanzania under the T-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 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: Tanzania - 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)[63]. 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 (TZS 1.6 million) in 2013 to US$137 (TZS 0.34 million) 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 (TZS 145,000) 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 T-1.5°C scenario based on the specific situation of Tanzania—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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[63] IEA-BAT (2020) IEA Energy Storage – website viewed October 2022, https://www.iea.org/reports/grid-scale-storage

7 Tanzania: Data Annex

Tanzania 1.5˚C

Electricity generation [TWh/a]	2020	2025	2030	2035	2040	2045	2050
Power plants	8	15	41	93	155	229	345
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	3	3	3	2	2	2	0
of which from H2	0	0	0	0	0	0	0
- Oil	1	1	1	1	2	0	0
- Diesel	0	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	1	2	4	6
- Hydro	3	3	3	3	5	6	9
- Wind	0	2	6	15	33	71	167
of which wind offshore	0	1	2	4	6	8	9
- PV	0	6	26	66	105	135	145
- Geothermal	0	0	0	3	6	10	16
- Solar thermal power plants	0	0	0	0	1	1	2
- Ocean energy	0	0	0	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
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	8	15	41	93	155	229	345
- Fossil	4	5	4	4	4	2	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	3.104	3.258	3.040	2.430	2.066	2.004	0.000
- Oil	1.378	1.434	1.351	1.215	1.549	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	0.000	0.000	0.000	0.000	0.000	0.000
- of which renewable H2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
- Renewables (w/o renewable hydrogen)	3	11	37	89	152	227	345
- Hydro	2.782	2.607	3.040	3.240	5.454	6.167	9.414
- Wind	0.004	1.788	6.433	14.854	32.574	70.718	166.863
- PV	0.188	5.961	25.922	66.380	104.635	135.265	144.682
- Biomass (& renewable waste)	0.068	0.136	0.406	1.121	2.191	3.761	5.799
- Geothermal	0.000	0.130	0.676	3.240	6.060	10.279	15.848
- Solar thermal power plants	0.000	0.033	0.101	0.292	0.595	1.066	1.972
- Ocean energy	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Distribution losses	1	1	2	4	7	10	15
Own consumption electricity	0	0	1	2	4	6	9
Electricity for hydrogen production	0	2	7	12	17	24	28
Electricity for synfuel production	0	0	0	0	0	0	0
Final energy consumption (electricity)	6	12	32	76	129	193	297
Variable RES (PV, Wind, Ocean)	0	8	32	81	137	206	312
Share of variable RES	3%	50%	79%	88%	88%	90%	90%
RES share (domestic generation)	40%	69%	89%	96%	98%	99%	100%

Transport - Final Energy [PJ/a]	2020	2025	2030	2035	2040	2045	2050
road	91	104	89	79	96	117	140
- fossil fuels	91	104	87	59	61	56	54
- biofuels	0	0	0	0	0	0	0
- synfuels	0	0	0	0	0	0	0
- natural gas	0	0	0	0	0	0	0
- hydrogen	0	0	0	1	1	1	1
- electricity	0	0	2	20	34	60	85
rail	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
- electricity	0	0	0	0	0	0	0
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	1	1	1	1	1	1	2
- fossil fuels	1	1	1	1	1	0	0
- biofuels	0	0	0	0	1	1	1
- synfuels	0	0	0	0	0	0	1
total (incl. pipelines)	92	105	90	80	97	118	142
- fossil fuels	92	105	88	59	61	56	54
- biofuels (incl. biogas)	0	0	0	0	1	1	1
- synfuels	0	0	0	0	0	0	1
- natural gas	0	0	0	0	0	0	0
- hydrogen	0	0	0	1	1	1	1
- electricity	0	0	2	20	34	60	85
total RES	0	0	2	20	35	61	88
RES share	0%	0%	2%	25%	36%	52%	62%

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	614	717	878	991	1,123	1,242	1,289
- Fossil fuels	29	36	26	18	3	0	0
- Biomass	556	588	665	628	577	483	137
- Solar collectors	0	38	63	101	138	168	228
- Geothermal	0	15	26	41	70	103	154
- Heat pumps 2)	0	2	35	77	129	186	350
- Electric direct heating	29	33	42	87	144	206	277
- Hydrogen	0	0	1	2	6	12	16
Total heat supply3)	614	717	878	991	1,123	1,242	1,289
- Fossil fuels	29	36	26	18	3	0	0
- Biomass	556	588	665	628	577	483	137
- Solar collectors	0	38	63	101	138	168	228
- Geothermal	0	15	26	41	70	103	154
- Heat pumps 2)	0	2	35	77	129	186	350
- Electric direct heating (incl. process heat)	29	37	62	124	200	289	404
- Hydrogen	0	0	1	2	6	12	16
RES share (including RES electricity)	92%	93%	96%	97%	99%	100%	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	4	9	29	69	112	152	196
- Fossil	2	2	2	2	2	1	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)	1	1	1	1	1	1	0
- Oil & Diesel	1	1	1	1	1	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	0	0	0
- Renewables	1	7	27	67	110	152	196
- Hydro	1.001	0.853	0.978	1.024	1.694	1.883	2.874
- Wind	0	1	2	5	11	24	58
of which wind offshore	0	0	1	1	1	2	2
- PV	0	5	24	60	95	123	132
- Biomass (& renewable waste)	0.016	0.031	0.093	0.256	0.500	0.9	1.3
- Geothermal	0	0	0	0	1	1	2
- Solar thermal power plants	0	0	0	0	0	0	1
- Ocean energy	0	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	6	26	65	106	147	189
Share of variable RES	6%	65%	88%	95%	95%	97%	96%
RES share (domestic generation)	35%	74%	92%	97%	98%	100%	100%

Final Energy Demand [PJ/a]	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-Energy use)	843	963	1,109	1,234	1,418	1,601	1,687
Total Energy use 1)	841	960	1,107	1,231	1,415	1,597	1,682
Transport	98	105	90	80	97	118	142
- Oil products	98	105	88	59	61	56	54
- Natural gas	0	0	0	0	0	0	0
- Biofuels	0	0	0	0	1	1	1
- Synfuels	0	0	0	0	0	0	1
- Electricity	0	0	2	20	34	60	85
RES electricity	0	0	2	19	34	59	85
- Hydrogen	0	0	0	1	1	1	1
RES share Transport	0%	0%	2%	25%	36%	52%	62%
Industry	95	121	166	226	307	414	416
- Electricity	6	11	30	50	74	107	257
RES electricity	2	8	27	48	72	106	257
- Public district heat	0	0	0	0	0	0	0
RES district heat	0	0	0	0	0	0	0
- Hard coal & lignite	20	16	11	7	0	0	0
- Oil products	1	1	2	2	0	0	0
- Gas	6	8	5	2	0	0	0
- Solar	0	4	9	13	18	27	40
- Biomass	61	80	106	143	194	240	64
- Geothermal	0	1	3	6	10	16	24
- Hydrogen	0	0	1	4	12	24	32
RES share Industry	67%	77%	88%	94%	99%	100%	100%
Other Sectors	649	735	850	925	1,010	1,065	1,125
- Electricity	17	32	81	199	349	515	710
RES electricity	7	22	72	191	341	511	710
- 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	8	18	13	10	3	0	0
- Gas	0	0	0	0	0	0	0
- Solar	0	34	54	88	120	141	189
- Biomass	623	636	679	592	478	321	96
- Geothermal	0	14	23	35	60	87	130
- Hydrogen	0	0	0	0	0	0	0
RES share Other Sectors	97%	96%	97%	98%	99%	100%	100%
Total RES	694	799	976	1,141	1,339	1,534	1,628
RES share	82%	83%	88%	93%	95%	96%	97%
Non energy use	2	2	3	3	4	4	5
- Oil	2	2	3	3	4	4	5
- 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	3	3	3	2	2	1	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	2	2	1	1	1	1	0
- Oil + Diesel	1	2	1	1	2	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	3	3	3	2	2	1	0
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	2	2	1	1	1	1	0
- Oil + Diesel	1	2	1	1	2	0	0
CO2 intensity (g/kWh)	0	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0	0
- CO2 intensity fossil electr. generation	684	657	633	625	657	404	0
- CO2 intensity total electr. generation	407	201	68	25	15	4	0
CO2 emissions by sector	14	16	14	10	9	5	4
0	0%	0%	0%	0%	0%	0%	0%
- Industry 1)	3	3	2	1	1	0	0
- Other sectors 1)	1	3	2	2	1	0	0
- Transport	7	8	7	4	5	4	4
- Power generation 2)	3	3	3	2	2	1	0
- Other conversion 3) - part of industry & tr	0	1	1	0	0	0	0
Population (Mill.)	60	69	79	90	102	114	126
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)	1,070	1,265	1,171	1,306	1,496	1,667	1,780
- Fossil (excluding on-energy use)	183	217	184	137	114	72	54
- Hard coal	20	16	11	7	0	0	0
- Lignite	0	0	0	0	0	0	0
- Natural gas	35	37	31	21	16	15	0
- Crude oil	128	165	143	108	98	57	54
- Nuclear	0	0	0	0	0	0	0
- Renewables	884	1,045	985	1,166	1,379	1,590	1,721
- Hydro	10	9	11	12	20	22	34
- Wind	0	1	6	26	76	198	535
- Solar	1	57	149	329	500	639	738
- Biomass	873	962	790	747	692	592	203
- Geothermal	0	16	29	53	91	140	211
- Ocean energy	0	0	0	0	0	0	0
Total RES	884	1,045	983	1,162	1,371	1,579	1,703
RES share	83%	83%	84%	89%	92%	96%	97%

Tanzania REFERENCE

Electricity generation [TWh/a]	2020	2025	2030	2035	2040	2045	2050
Power plants	8	15	41	87	146	214	324
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	3	5	13	29	49	57	74
of which from H2	0	0	0	0	0	0	0
- Oil	1	1	3	6	8	6	0
- Diesel	0	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0	0
- Biomass (& renewable waste)	0	0	0	1	2	3	5
- Hydro	3	3	3	3	5	6	9
- Wind	0	2	6	14	31	50	78
of which wind offshore	0	1	2	4	6	8	9
- PV	0	4	14	31	45	82	142
- Geothermal	0	0	0	3	6	10	15
- Solar thermal power plants	0	0	0	0	1	1	2
- Ocean energy	0	0	0	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
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	8	15	41	87	146	214	324
- Fossil	4	6	16	35	57	63	74
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	3	5	13	29	49	57	74
- Oil	1	1	3	6	8	6	0
- Diesel	0	0	0	0	0	0	0
- Nuclear	0	0	0	0	0	0	0
- Hydrogen	0	0	0	0	0	0	0
- of which renewable H2	0	0	0	0	0	0	0
- Renewables (w/o renewable hydrogen)	3	9	25	53	89	151	250
- Hydro	3	3	3	3	5	6	9
- Wind	0	2	6	14	31	50	78
- PV	0	4	14	31	45	82	142
- Biomass (& renewable waste)	0	0	0	1	2	3	5
- Geothermal	0	0	1	3	6	10	15
- Solar thermal power plants	0	0	0	0	1	1	2
- Ocean energy	0	0	0	0	0	0	0
Distribution losses	1	1	2	4	6	9	14
Own consumption electricity	0	0	1	2	4	6	9
Electricity for hydrogen production	0	2	7	12	17	24	28
Electricity for synfuel production	0	0	0	0	0	0	0
Final energy consumption (electricity)	6	12	31	71	121	179	278
Variable RES (PV, Wind, Ocean)	0	6	21	45	76	132	219
Share of variable RES	3%	39%	51%	52%	52%	61%	68%
RES share (domestic generation)	40%	58%	61%	60%	61%	71%	77%

Transport - Final Energy [PJ/a]	2020	2025	2030	2035	2040	2045	2050
road	91	104	91	123	172	244	305
- fossil fuels	91	104	89	117	162	224	263
- biofuels	0	0	1	3	5	9	24
- synfuels	0	0	0	0	0	0	0
- natural gas	0	0	0	0	0	0	0
- hydrogen	0	0	0	1	1	1	1
- electricity	0	0	1	2	4	10	18
rail	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
- electricity	0	0	0	0	0	0	0
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	1	1	1	1	1	1	2
- fossil fuels	1	1	1	1	1	0	0
- biofuels	0	0	0	0	1	1	1
- synfuels	0	0	0	0	0	0	1
total (incl. pipelines)	92	105	93	124	173	245	307
- fossil fuels	92	104	90	118	162	224	263
- biofuels (incl. biogas)	0	0	2	3	6	10	25
- synfuels	0	0	0	0	0	0	1
- natural gas	0	0	0	0	0	0	0
- hydrogen	0	0	0	1	1	1	1
- electricity	0	0	1	2	4	10	18
total RES	0	0	2	5	9	18	40
RES share	0%	0%	2%	4%	5%	7%	13%

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	614	717	878	991	1,123	1,242	1,289
- Fossil fuels	29	39	44	51	56	42	36
- Biomass	556	585	647	594	524	441	102
- Solar collectors	0	38	63	101	138	168	228
- Geothermal	0	15	26	41	70	103	154
- Heat pumps 2)	0	2	35	77	129	186	350
- Electric direct heating	29	33	42	87	144	206	277
- Hydrogen	0	0	1	2	6	12	16
Total heat supply3)	614	717	878	991	1,123	1,242	1,289
- Fossil fuels	29	39	44	51	56	42	36
- Biomass	556	585	647	594	524	441	102
- Solar collectors	0	38	63	101	138	168	228
- Geothermal	0	15	26	41	70	103	154
- Heat pumps 2)	0	2	35	77	129	186	350
- Electric direct heating (incl. process heat)	29	37	62	124	200	289	404
- Hydrogen	0	0	1	2	6	12	16
RES share (including RES electricity)	92%	92%	91%	87%	84%	85%	84%
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	4	8	23	50	78	120	187
- Fossil	2	3	7	15	24	25	26
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas (w/o H2)	1	2	4	10	17	20	26
- Oil & Diesel	1	1	3	5	7	5	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	0	0	0
- Renewables	1	5	16	35	55	95	162
- Hydro	1	1	1	1	2	2	3
- Wind	0	1	2	5	11	17	26
of which wind offshore	0	0	1	1	1	2	2
- PV	0	4	13	28	41	74	129
- Biomass (& renewable waste)	0.016	0.031	0.092	0.239	0.467	0.8	1.2
- Geothermal	0	0	0	0	1	1	2
- Solar thermal power plants	0	0	0	0	0	0	1
- Ocean energy	0	0	0	0	0	0	0
Variable RES (PV, Wind, Ocean)	0	4	15	33	51	91	155
Share of variable RES	6%	54%	65%	66%	66%	76%	83%
RES share (domestic generation)	35%	64%	70%	69%	70%	79%	86%

Final Energy Demand [PJ/a]	2020	2025	2030	2035	2040	2045	2050
Total (incl. non-Energy use)	843	962	1,111	1,277	1,493	1,727	1,852
Total Energy use 1)	841	960	1,108	1,274	1,489	1,722	1,847
Transport	98	105	93	124	173	245	307
- Oil products	98	104	90	118	162	224	263
- Natural gas	0	0	0	0	0	0	0
- Biofuels	0	0	2	3	6	10	25
- Synfuels	0	0	0	0	0	0	1
- Electricity	0	0	1	2	4	10	18
RES electricity	0	0	0	1	3	7	14
- Hydrogen	0	0	0	1	1	1	1
RES share Transport	0%	0%	2%	4%	5%	7%	13%
Industry	95	121	166	225	305	412	415
- Electricity	6	11	30	50	74	107	257
RES electricity	2	6	18	30	45	76	198
- Public district heat	0	0	0	0	0	0	0
RES district heat	0	0	0	0	0	0	0
- Hard coal & lignite	20	19	23	24	27	26	23
- Oil products	1	1	2	2	3	0	0
- Gas	6	8	10	13	15	10	4
- Solar	0	4	9	13	18	27	40
- Biomass	61	76	89	113	148	203	35
- Geothermal	0	1	3	6	10	16	24
- Hydrogen	0	0	1	4	12	24	32
RES share Industry	67%	73%	72%	74%	76%	84%	79%
Other Sectors	649	735	850	925	1,010	1,065	1,125
- Electricity	17	32	81	199	349	515	710
RES electricity	7	19	49	120	214	364	548
- 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	8	18	18	20	20	13	14
- Gas	0	0	0	0	0	0	0
- Solar	0	34	54	88	120	141	189
- Biomass	623	636	674	582	461	309	83
- Geothermal	0	14	23	35	60	87	130
- Hydrogen	0	0	0	0	0	0	0
RES share Other Sectors	97%	96%	94%	89%	85%	85%	84%
Total RES	694	791	923	996	1,097	1,264	1,317
RES share	82%	82%	83%	78%	74%	73%	71%
Non energy use	2	2	3	3	4	4	5
- Oil	2	2	3	3	4	4	5
- 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	3	4	9	19	28	28	29
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	2	2	6	13	21	23	29
- Oil + Diesel	1	2	3	6	7	5	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	3	4	9	19	28	28	29
- Hard coal (& non-renewable waste)	0	0	0	0	0	0	0
- Lignite	0	0	0	0	0	0	0
- Gas	2	2	6	13	21	23	29
- Oil + Diesel	1	2	3	6	7	5	0
CO2 intensity (g/kWh)	0	0	0	0	0	0	0
without credit for CHP heat	0	0	0	0	0	0	0
- CO2 intensity fossil electr. generation	684	610	568	537	496	453	388
- CO2 intensity total electr. generation	407	254	220	214	192	133	89
CO2 emissions by sector	14	18	22	35	47	51	53
0	0%	0%	0%	0%	0%	0%	0%
- Industry 1)	3	3	4	4	5	4	3
- Other sectors 1)	1	3	3	3	2	1	1
- Transport	7	8	7	9	12	17	20
- Power generation 2)	3	4	9	19	28	28	29
- Other conversion 3) - part of industry & tr	0	1	1	1	1	1	1
Population (Mill.)	60	69	79	90	102	114	126
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)	1,070	1,273	1,235	1,510	1,816	2,045	2,194
- Fossil (excluding on-energy use)	183	235	311	510	715	766	828
- Hard coal	20	19	23	24	27	26	23
- Lignite	0	0	0	0	0	0	0
- Natural gas	35	51	117	244	390	430	528
- Crude oil	128	164	171	242	299	310	277
- Nuclear	0	0	0	0	0	0	0
- Renewables	884	1,036	922	997	1,097	1,275	1,360
- Hydro	10	9	11	11	18	21	32
- Wind	0	1	6	24	71	123	214
- Solar	1	51	107	201	285	445	726
- Biomass	873	959	769	709	633	549	182
- Geothermal	0	16	29	52	90	137	207
- Ocean energy	0	0	0	0	0	0	0
Total RES	884	1,035	921	994	1,092	1,267	1,347
RES share	83%	81%	75%	66%	60%	62%	62%

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