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CAN
CLIMATE ACTION NETWORK
Tanzania

World Future Council

100% RENEWABLE ENERGY FOR TANZANIA

Access to renewable energy for all within generation

EXECUTIVE SUMMARY

UTS Institute for Sustainable Futures

Impressum

Tanzania has sufficient renewable energy resources to keep storage shares well below 20 per cent while securing supply with 100 per cent renewable energy.

ABOUT THE AUTHORS

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

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The energy scenario software for the long-term projections and economic parameters has been developed by 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.

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CHAPTER ONE

1.0 SETTING THE SCENE

Global energy markets are changing rapidly. Renewable energy technologies now constitute more than half of the new power plants built worldwide each year[1]. In 2014, growth rates for coal use stalled globally for the first time, including in China, and this trend continued throughout 2015 and 2016[2]. Oil and coal prices are now at record lows, halting the development of many new coal and oil mining projects.

While electric vehicles still have a negligible share of the global car transport market, this is likely to change as most international car manufacturers prepare for a massive shift toward electric vehicle technologies. It is very possible that the market for electric vehicles could follow the same exponential development path as the solar photovoltaic (PV) market, when rapid growth in solar technology between 2010 and 2015 delivered increasing market shares and significantly reduced investment costs. Today, solar photovoltaic at the household level is cheaper than retail electricity prices (tariffs) in most industrialised countries, making it cost-effective for many households to produce their own power. In addition, wind power has become the least expensive technology globally for new power plants, spurring a huge global market for wind that saw an additional capacity of 54,000 megawatts added during 2016 – equivalent to installing one new turbine every 20 minutes.

With renewable energy technologies now faster and more economical to build than fossil fuel-based power generation facilities, and subsequent reduction in dependency on imported fuels, these global developments support Tanzania's goal of providing access to energy for all.

Access to energy – 7th Sustainable development Goal

The growth of megacities and the slow process of providing access to energy services are closely related, and in many cases two sides of the same coin. Young people leave the rural areas for large cities due to the lack of professional opportunities, while access to energy is fundamental to sustain economic activities and alleviate poverty. For well over 1 billion people around the world, obtaining access to the energy required to meet very basic needs remains a daily struggle. In rural areas of many developing countries, as well as some urban slums and peri-urban areas, connection to central electric grids is economically prohibitive and may take decades to materialise, if at all (REN21-GSR 2016). Recent progress has been too slow to meet changing needs.

In 2013, the United Nations Development Programme (UNDP) launched the *Sustainable Energy for All* initiative to aid in accelerating the rate of increased energy access for the least developed countries. The first step in the process was to develop a database to centralise previously dispersed information available to decision makers. The UNDP – in cooperation with a number of other energy advocacy organisations such as the IEA and REN21 – published the *Global Tracking Framework*[3] report, providing a statistical overview of the progress of energy access between 1990 and 2010. Information from these reports combined with new data from the REN21 global status report provides a clear picture of progress in this area.

Between 1990 and 2010, an additional 1.7 billion people worldwide gained the benefit of electrification, while 1.6 billion people secured access to generally less-polluting non-solid fuels. Furthermore, the successful implementation of energy efficiency measures led to a significant reduction in energy intensity. As a result, economic growth and the growth of energy demand began to disconnect. This was a significant victory that avoided 2,300 exajoules of new energy supply over the past 20 years; in other words, without these measures, global energy demand would have been 25 per cent higher during that period. In addition, renewable energy supplied a cumulative global total of more than 1,000 exajoules between 1990 and 2010, comparable to the combined total energy consumption of China and France over the same period (UNDP 2013).

Unfortunately, the rapid demographic and economic growth over the last 20 years has to some extent diluted the impact of these advances. Between 1990 and 2010:

- the proportion of the world's population with access to electricity and non-solid fuels grew 1.2 per cent and 1.1 per cent respectively each year
- renewable energy supply grew by around 2 per cent per annum
- energy demand grew by 1.5 per cent per annum.

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[1] REN21 (2016) *Renewables 2016 Global Status Report*, Paris, REN21 Secretariat. Available at: www.ren21.net/status-of-renewables/global-status-report/

[2] Li Junfeng, Director General at the National Climate Change Strategy Research and International Cooperation Centre: *The Guardian Interview*, 20th January 2016. Available at: www.theguardian.com/environment/2016/jan/19/chinas-coal-burning-in-significant-decline-figures-show

[3] UNDP 2013: The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa, May 2013 http://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_energy/SEFA-resources/global-tracking-framework.html

As a result, the global renewable energy share increased from 16.6 per cent in 1990 to 18 per cent in 2010 (UNDP 2013) – an average of only 0.07 per cent per year. The majority of successful electrification in the past took place in urban areas, close to cities where the electrification rate was twice as high as in remote areas. Even with this significant expansion, however, electrification only just kept pace with rapid urbanisation in the same period, so that the overall urban electrification rate remained relatively stable, growing from 94 to 95 per cent (UNDP 2013).

Improvements to cooking devices are an important factor in increasing public health, particularly in developing nations. Globally, almost two million deaths each year from pneumonia, chronic lung disease and lung cancer are associated with exposure to indoor air pollution resulting from cooking with biomass and coal; 99 per cent of these deaths occur in developing countries. Almost half the global population (45 per cent) still relies on solid fuels for household use with dramatic impacts on health, particularly for children and women. Some 44 per cent of these deaths occur in children; of the adult deaths, 60 per cent occur in women in developing countries (UNDP 2013).

1.1 Status quo: Access to energy services

Currently, approximately 1.5 billion people in developing countries lack access to electricity and around 3 billion people rely on solid fuels for cooking. More than every second person without access to electricity lives in Sub-Saharan Africa. The entire African continent has a total installed capacity of approximately 150 gigawatts – equal to one-seventh of Europe's power plant capacity – and consumes about the same amount of electricity as Germany, while Africa's population is 12 times larger. In East Asia and the Pacific, less than 200 million people lack electricity access but almost 1.1 billion people rely on solid fuels for cooking (UNDP 2013). Figure 1 and Figure 2 provide an overview of the key statistics.

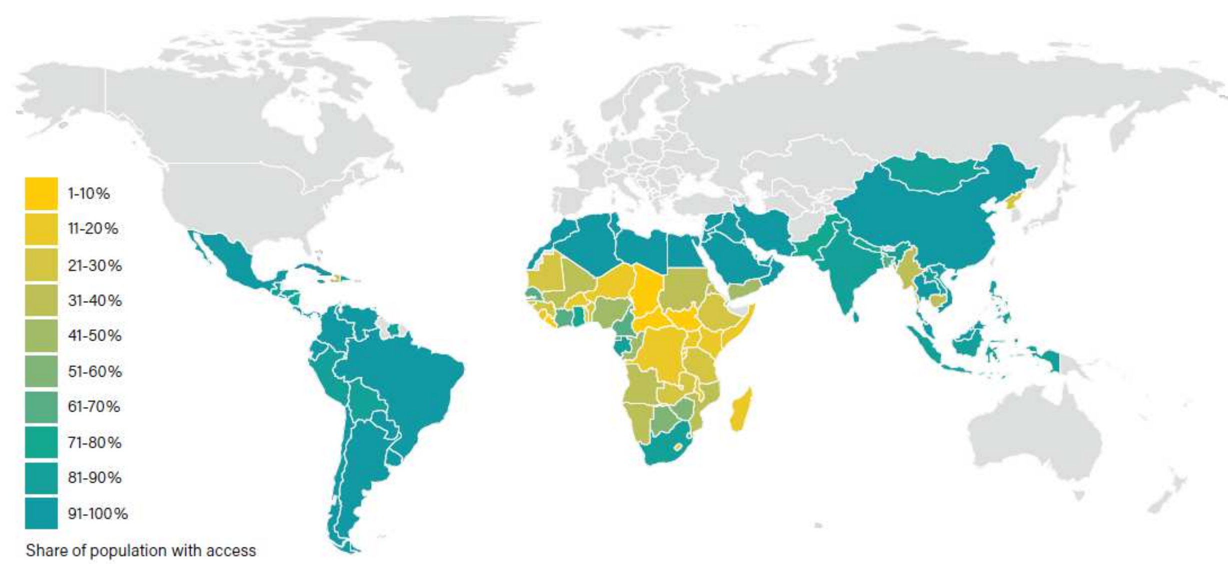

Figure 1: World electricity access in developing countries, 2014 (REN21-GSR 2017)

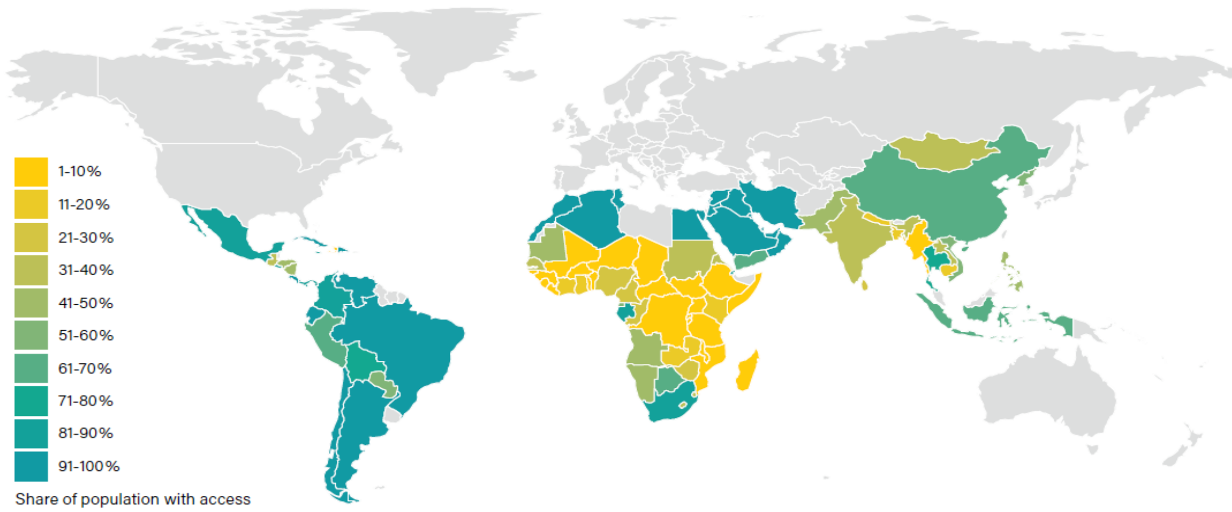

Figure 2: Access to clean cooking facilities in developing countries, 2014 (REN21-GSR 2017)

1.2 Status quo: Distributed renewable energy technologies for energy access

Distributed renewable energy (DRE) systems need to provide electricity for lighting, communication and small businesses, as well as energy for residential heating and process heat for applications such as in the agricultural sector and cooking. DRE systems can serve as a complement to centralised energy generation systems, or as a substitute (REN21-GSR 2016). These technologies and systems must operate reliably and with low maintenance requirements over many years, with multiple proven benefits including:

- improved health through the displacement of indoor air pollution
- reduced greenhouse gas emissions
- enabling of small business activities
- increased security, for example, via street lighting at night
- enhanced communications and facilitation of greater quality and availability of education through access to affordable lighting.

Table 1: Examples of distributed renewable energy use for productive energy services (REN21-GSR2016)

Energy service	Income Generating Value	Renewable Energy Technologies
Irrigation	Better crop yields, hihger-value crops, greater reliability of irrigation systems, enabling of crop growth during perieods when markey prices are higher	Wind, solar PV, biomass, miro-hydro
Illumination	Reading, extension of operating hours	Wind, solar PV, biomass, miro-hydro, geothermal
Grinding, Milling, Husking	Creation of value-added products from raw agricultural commodities	Wind, solarPV, Biomass, micro-hydro
Drying, Smocking (Preserving with process heat)	Creation of value aded products, preservation of products that enables sale in high-value markets	Biomass, solar heat, geothermal
Expelling	Production of refined oil from seeds	Biomass, solar heat, geothermal
Transport	Reaching new market	Biomass (biodisel)
TV, Radio, Computer, Internet, Telephone	Support of entertainment business, education, access to market news, co-ordination with suppliers and distributors	Wind, Solar PV, biomass, micro-hydro, geothermal

Battery charging	Wide range of services for end-users (e.g. phone charging business)	Wind, solar PV, biomass, miro-hydro, geothermal
Refrigiration	Selling cooled products, increasing the durability of products	Wind, solar PV, biomass, mirco-hydro

Energy access market development: Power

According to the most recently available data, an estimated 26 million households (or 100 million people) worldwide are served through DRE systems (REN21-GSR 2016).

- 20 million households with solar home systems.
- 5 million households with renewables-based mini-grids (mainly micro-hydro).
- 0.8 million households supplied by small-scale wind turbines.

Markets for DRE systems continue to grow rapidly, with some countries already experiencing comparatively high market penetration.

1.3 Cooking with firewood, gas or electricity

A variety of technologies can provide cooking services in different capacities, with corresponding variances in performance and cost. Wood, charcoal and dung are still widely used around the world as fuels for cooking; dung is a major cooking fuel for about 185 million people. A number of substitutes currently exist, including improved and cost-efficient biomass cook stoves, biogas cook stoves and electric hot plates powered by SHS or mini-grids. While electric cooking has reduced the consumption of firewood and/or charcoal by between 10 and 40 per cent, biogas stoves – which are more widely used – offer a reduction in consumption levels of between 66 and 80 per cent (REN21-GSR 2017). Electric cooking costs are expected to decrease in line with reducing electricity generation costs for decentralised renewables, in particular solar photovoltaic.

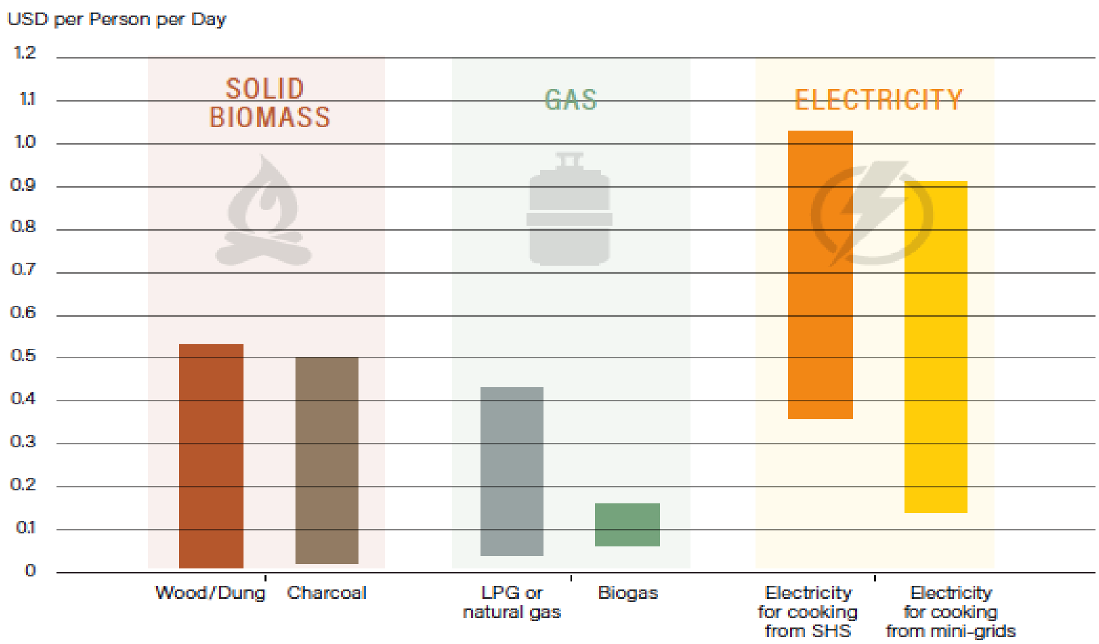

Figure 3: Costs of various cooking technologies (REN21 GSR 2017)

1.4 Population development

Tanzania is East Africa's largest country, with a population of 53,470,420 inhabitants – 45 per cent of whom are under the age of 15. Ranking 27th in the world in terms of its population[4], Tanzania has an average annual population growth rate (1960-2015) of 3.1 per cent and it is expected to reach 82.6 million people by 2030[5]. It has a population density of 60 per square kilometre [6] and is widely dispersed, with around 70 per cent of the population living in rural areas (Figure . In those rural areas there exists significant variation in population distribution; for instance, in the arid regions population density is as low as one person per square kilometre, while in the water-rich main highland that figure is closer to 53 people per square kilometre[7].

Projections for population and economic growth are important factors in energy scenario-building because they affect the size and composition of energy demand, both directly and through their impact on economic growth and development. World Bank projections detail expected population development (see Table 2).

Table 2: Tanzania's population and GDP projections

Economic + population development	Parameter	Unit	2015	2020	2025	2030	2035	2040	2045	2050
	GDP (direct input+linked)	[$/a]	46,400,000,000	93,326,973,500	187,713,878,937	316,056,673,674	422,585,748,426	499,405,181,975	578,947,480,035	671,158,803,986
	GDP/Person	[$/capita]	868	1,502	2,614	3,826	4,469	4,640	4,759	4,917
	(calculated) Population (calculated)	[persons]	53,470,420	62,137,471	71,817,765	82,603,769	94,557,831	107,632,136	121,657,019	136,505,977
Annual growth assumptions			2015	2015-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
Economic growth		[%/a]	7.0%	15.0	15.0	10.0	5.0	3.0	3.0	3.0
Population growth		[%/a]	3.2%	3.1	2.9	2.8	2.7	2.6	2.5	2.4

[4] World Population Review (2016) "Tanzania Population 2016" http://worldpopulationreview.com/countries/tanzania-population
[5] World Bank (2016) "Tanzania: Data" http://data.worldbank.org/country/tanzania
[6] World Bank (2016) "Tanzania: Population density (people per sq. km of land area)" http://data.worldbank.org/indicator/EN.POP.DNST
[7] World Population Review (2016) "Tanzania Population 2016)" http://worldpopulationreview.com/countries/tanzania-population

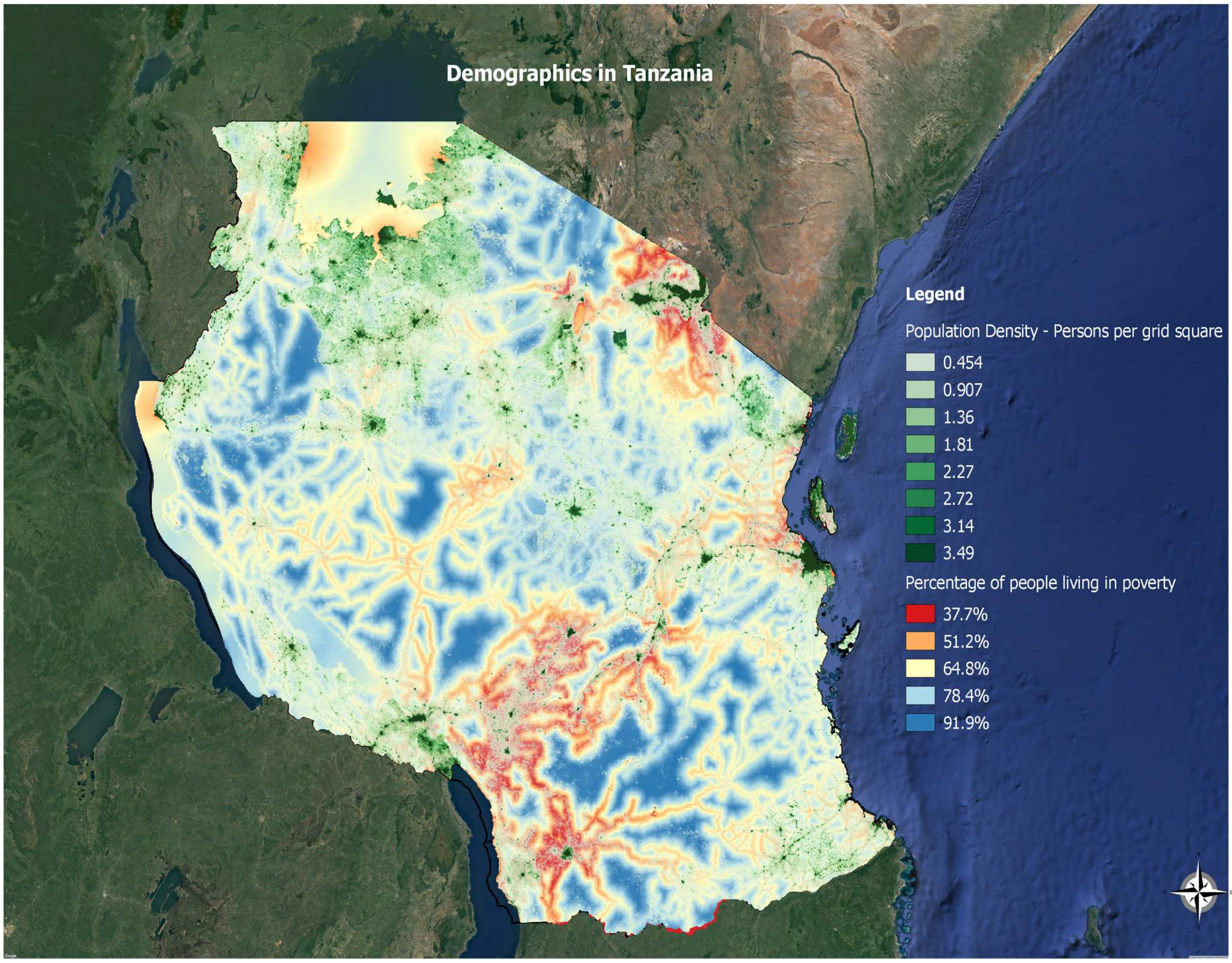

Figure 4: A map of Tanzania showing demographics

Source: ISF mapping, August 2017

1.5. Economic context

Tanzania is one of the world's poorest economies in terms of per capita income, averaging US$864.90 per year – equivalent to less than 9 per cent of the global average. Though its per capita income is slightly ahead of the average per capita income of low income countries (US$615.6o), it remains significantly below lower middle-income countries (US$1988.20) and even further from middle income countries (US$4736.70)[8]. Nonetheless, Tanzania has achieved high growth rates based on its vast natural resource wealth and tourism; GDP growth in 2009-15 was 6 to 7 per cent per annum[9], making it one of the 20 fastest growing economies in the world. Over the same period Tanzania's inflation has been reduced to 5.4 per cent as at March 2016 from the 2011 average of 12.6 per cent. The trade deficit also shrank in the last five years, falling from US$5 billion in 2010 to US$3 billion in 2015[10].

The economy relies largely on the agricultural sector, which accounts for more than one quarter of GDP, provides 85 per cent of exports and employs approximately 80 per cent of the work force[11]. Tourism is another key sector; with an average value of US$2 billion a year, in the past three years the tourism sector has delivered Tanzania the largest influx in foreign currency[12]. Construction, wholesale and retail trade, public administration and manufacturing contribute 12, 10, 7 and 6 per cent respectively to Tanzania's GDP[13].

Analysis of Tanzania's economic development is based on the 2015 GDP breakdown, and assumes that the overall structure of the economy does not change and that all sectors grow at equal rates to GDP. Agriculture and services and trade remain the backbone of Tanzania's economy, followed by construction, chemical and other industries such as mining.

[8] World Bank (2016) "GDP Per Capita (Current US$): Tanzania" http://data.worldbank.org/indicator/NY.GDP.PCAP.CD?name_desc=true
[9] US Central Intelligence Agency (2016) "Economy Overview: Tanzania" https://www.cia.gov/library/publications/the-world-factbook/fields/ print_2116.html
[10] Tanzania Invest (2016) "World Bank projects 7.1% GDP growth rate for Tanzania" http://tanzaniainvest.com/economy/world-bank-wb-tanzania-gdp- growth-2017-2018
[11] US Central Intelligence Agency (2016) "Economy Overview: Tanzania" https://www.cia.gov/library/publications/the-world-factbook/fields/ print_2116.html
[12] Deloitte (2016) "Tanzania Economic Outlook 2016" https://www2.deloitte.com/content/dam/Deloitte/tz/Documents/tax/ Economic%20Outlook%202016%20TZ.pdf
[13] US Central Intelligence Agency (2016) "Economy Overview: Tanzania" https://www.cia.gov/library/publications/the-world-factbook/fields/ print_2116.html

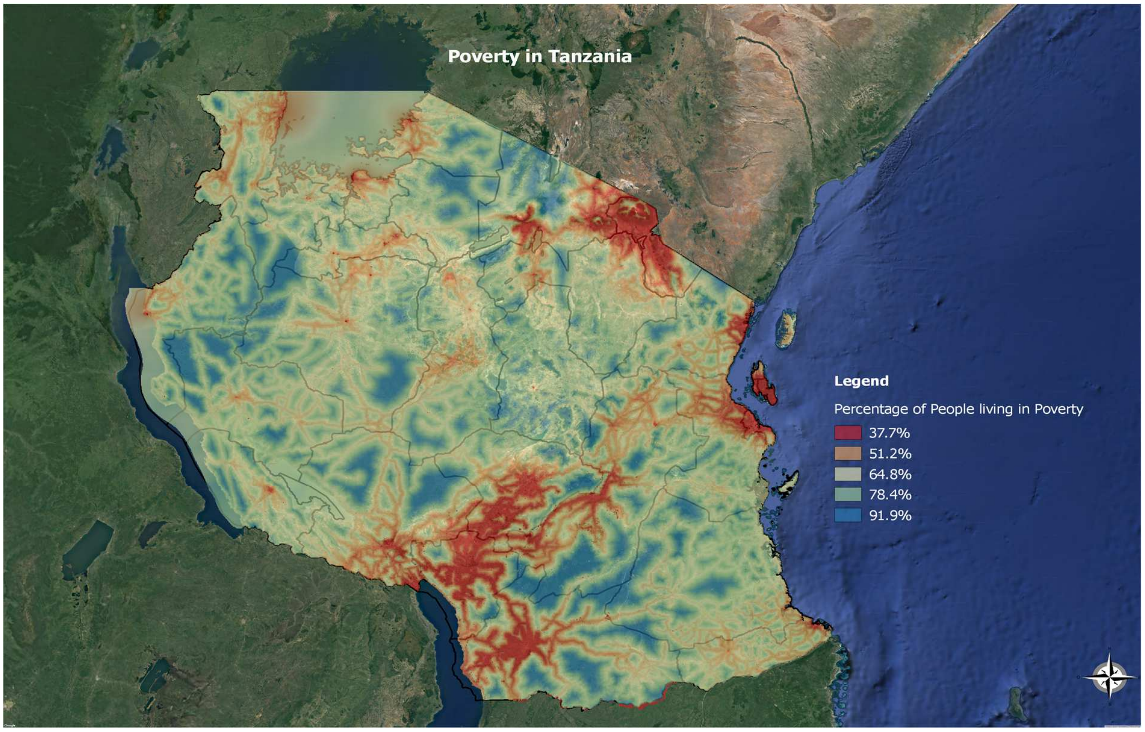

Figure 5: Poverty status distribution

***Source*:** ISF mapping, August 2017

Tanzania needs to build and expand its power generation system to be almost entirely new in order to increase the energy access rate to 100 per cent. Building new power plants – no matter the technology – will require new infrastructure such as power grids, spatial planning, a stable policy framework and access to finance.

With decreased prices for solar photovoltaic and onshore wind in recent years, renewables have become an economic alternative to building new gas power plants. As a result, renewables achieved a global market share of over 50 per cent of all new build power plants since 2014. Tanzania is blessed with vast solar and wind resources, and renewables generation costs are generally lower with increased solar radiation and wind speeds. However constantly shifting policy frameworks often lead to high investment risks, and therefore higher project development and installation costs, for solar and wind projects relative to countries with more stable policy.

The Ministry of Energy and Minerals of the United Republic of Tanzania published a comprehensive master plan for the country's power system. It stated that:

***The 2016 Power System Master Plan (PSMP*)** *reflects and accommodates recent development in the economy, including development in the gas sub sector as well as government policy guidelines. The policy guidelines include, among others the desire by the government to accelerate economic growth through the Vision 2025, MKUKUTA and the Five-Year Development Plan–II (2016/17-2020/21, FYDP-II). The government also aims to expedite economic growth by means of the revival and renovation of industries.*

Among the outcomes associated with the attainment of these objectives, FYDP 2016/17-2020/21 will raise annual real GDP growth to 10 percent by 2021 (from 7.0 percent in 2015), per capita income to US$ 1,500 (from US$ 1,043in 2014) and reduction of the poverty rate to 16.7 percent from 28.2 percent recorded in 2011/12. The Plan also envisages raising FDI flows from US$ 2.14 billion in 2014 to over US$ 9.0 billion by 2021; increase electricity generation from 1,501MW in 2015 to 4,915MW by 2020 and improving electricity connections to 60 percent of the population, up from 36 percent in 2015. On average, manufacturing sector will grow by over 10 percent per annum with its share in total exports increasing from 24 percent in 2014/15 to 30 percent in 2020. The government vision is to become a middle-income country by 2025 with electricity consumption of 490kWh/capita.

The fundamental objective is also to attain stable power supply in order to achieve Economic Growth, Energy Security and Environmental Protection. The government of Tanzania set the maximum target to reduce poverty by achieving high economic growth, which could be achieved through a stable and efficient power system.

The overall objective of the Plan is to re-assess short-term (2016 - 2020), mid-term (2021 - 2025) and long term (2026 - 2040), generation and transmission plans requirements and the need for connecting presently off-grid regions, options for power exchanges with neighbouring countries, and increased supply of reliable power. While the short-term plan requires immediate decision and actions, the mid - long term plans require coordinated planning and project development studies to ensure that future electricity supply utilizes the least cost projects in consistent with sound planning criteria in order to address national interests. This report has been prepared drawing inference on specific data items or detailed procedures in the previous PSMP 2008 and the subsequent 2009 and 2012 Update studies.

This master plan provided the basis for the reference case of the long-term scenario.

CHAPTER TWO

2.0 KEY RESULTS

2.1 Long-term and energy access scenario

The Institute for Sustainable Futures (ISF)/ at the University of Technology Sydney (UTS) calculated three long-term scenarios using a special energy model developed by the German Aerospace Center (DLR). Based on those results, an hourly simulation of the entire electricity market for Tanzania has been conducted, and the [R]E24/7 model used for the hourly calculation has been developed by UTS/ISF. The scenario was calculated as follows.

- The **REFERENCE scenario (REF)** reflects a continuation of current policies and is based on the Tanzanian Government forecasts in *Tanzania Power System Masterplan 2016*.
- The **RENEWABLES scenario (RE)** is designed to meet Tanzania's energy-related targets to achieve 100 per cent renewable energy for electricity, buildings and industry as soon as possible. The renewable energy trajectories for the initial years are taken from the joint publication of Bread for the World, World Future Council and Climate Action Network Tanzania entitles *Policy Roadmap for 100% Renewable Energy and Poverty Eradication in Tanzania,* published in May 2017 (WFC (2017))[14].
  The **ADVANCED Renewables Scenario (ADV RE)** takes a more ambitious approach to transforming Tanzania's entire energy system towards 100 per cent renewable energy supply. The consumption pathways remain almost the same as in the **Renewables scenario**, however under this scenario a much faster introduction of new technologies leads to a complete decarbonisation of energy for stationary energy (electricity), heating (including process heat for industry) and transportation. The latter requires a strong role for storage technologies such as batteries, synthetic fuels and hydrogen.
- The **ENERGY ACCESS SCENARIO (EAS)** simulated the results of the RENEWABLES scenario (RE) and calculates hourly supply and demand curves along with storage demand requirements.

All scenarios presented in this analysis include assumptions on policy stability, the role of future energy utilities, centralised fossil fuel-based power generation, population and GDP, firm capacity and future costs.

- **Policy stability:** This research assumes that Tanzania will establish a secure and stable framework for the deployment of renewable power generation. In essence, 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.
- **Strengthened energy efficiency policies:** Existing policy settings, namely energy efficiency standards for electrical applications, buildings and vehicles, will need to be strengthened in order to maximise cost-efficient use of renewable energy and achieve a 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 take up the challenge of increased local generation and develop new business models which focus on energy services, rather than only selling kilowatt-hours.
- **Population and GDP:** The three scenarios are based on the same population and GDP assumptions. Projections of population growth are taken from the *World Population Review* while the GDP projection assumes long-term average growth of around 2 per cent per year over the scenario period.

2.2 Key results of the long-term energy pathway for Tanzania

100 per cent renewable energy for all Tanzanians is technically and economically possible, and a realistic pathway for Tanzania to align with the Paris Agreement and Sustainable Development Goals.

- **Final energy demand:** Combining the projections on population development, GDP growth and energy intensity results in future development pathways for Tanzania's final energy demand. Under the Reference scenario, total final energy demand increases by 40 per cent from the current 1000 PJ/a to 1400 PJ/a in 2050. Under both RE scenarios, due to economic growth, increasing living standards and electrification of the transport sector, overall electricity demand is expected to increase despite efficiency gains in all sectors.

[14] WFC (2017) Bread for the World, World Future Council and Climate Action Network Tanzania *"Policy Roadmap for 100% Renewable Energy and Poverty Eradication in Tanzania"*, May 2017

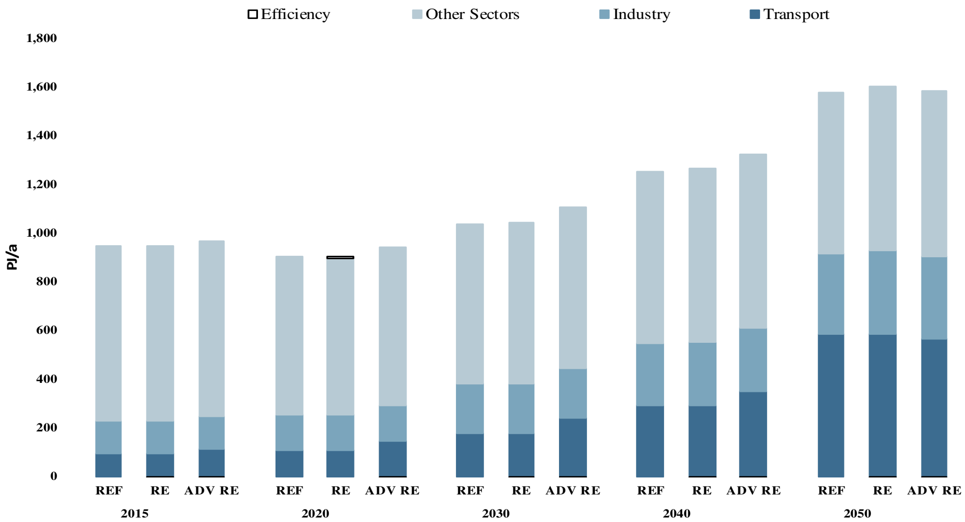

Figure 6: Projection of total final energy demand by sector

- **Electricity demand:** This will rise from around 5 TWh/a to 110 TWh/a by 2050 in the basic RE scenario. For the heating sector, it is assumed that renewable heating technologies for residential and commercial buildings – mainly geothermal heat pumps and solar collectors – will significantly influence building construction standards.
- **Electricity generation, capacity and breakdown by technology**: The renewable energy market grows dynamically, and renewable electricity's share in the required electricity supply is increasing. By 2020 wind and solar photovoltaic will overtake hydro, currently the largest contributor to the growing renewable market. After 2020, growth shares from solar thermal, bio- and geothermal energy will complete the variety of new technologies and by 2050, 100 per cent of the electricity produced in Tanzania will come from renewable energy sources under the basic RENEWABLES scenario. 'New' renewables – mainly wind, PV, ocean and geothermal energy – will contribute 75 per cent to the total electricity generation. By 2020, the share of renewable electricity production will already be 53 per cent, and 75 per cent by 2030; the installed capacity of renewables will reach about 20GW in 2030 and 60 GW by 2050. New gas power plants will operate within around 20 years, while the financial write-off time is calculated with 10 years, therefore avoiding stranded investments.

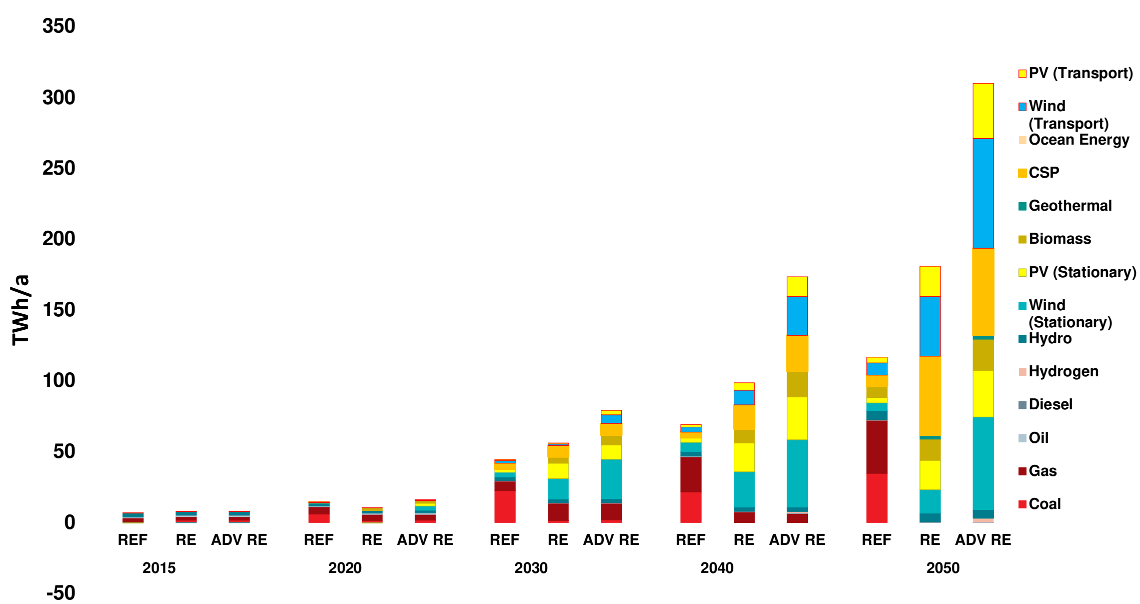

Figure 7: Breakdown of electricity generation by technology

- **Energy supply for heating:** In 2015, renewables meet around 90 per cent of Tanzania's energy demand, primarily through traditional use of biomass for cooking. Dedicated support instruments are required to ensure dynamic development, in particular for renewable technologies for cooking, buildings and renewable process heat production for increased industrial process heat requirements. In the basic RENEWABLES scenario, renewables already provide 90 per cent of Tanzania's total heat demand in 2030 and 100 per cent in 2050. Energy efficiency measures help to reduce the currently growing energy demand for wood fuel for cooking stoves and shifts 100 per cent to modern sustainable biomass, solar and geothermal heating, as well as electric cooking and heating, by 2050.

- **Transport: :** Due to population increase, GDP growth and higher living standards, energy demand arising from the transport sector is expected to increase in all scenarios by around 601 per cent to 590 PJ/a in 2050. Additional modal shifts and technology switches lead to energy savings in the ADVANCED scenario of 4 per cent (20 PJ/a) in 2050 compared to the REFERENCE scenario. Highly efficient propulsion technology with hybrid, plug-in hybrid and battery-electric power trains will deliver large efficiency gains. By 2030, electricity will provide 4 per cent of the transport sector's total energy demand in the RENEWABLES scenario, while in 2050 the share will be 40 per cent (and 75 per cent in the ADVANCED scenario). These changes are achieved by introducing incentives for people to keep public transport as the preferred transport mode and to significantly increase its convenience. Individual transport should rely to a large extend on smaller and more efficient vehicle concepts. In addition, it is vital to shift transport use to efficient modes like rail, light rail and buses, especially in the large and expanding metropolitan areas.

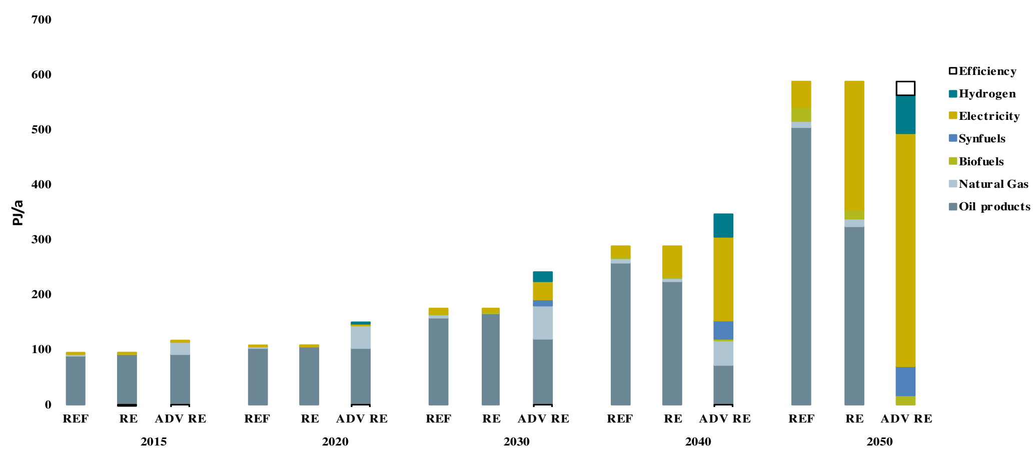

Figure 8: Final energy consumption transport under the scenarios

Primary energy consumption: Under the basic RENEWABLES scenario, primary energy demand will increase by 82 per cent from today's 1100 PJ/a toe around 2000 PJ/a. Compared to the REFERENCE scenario, overall primary energy demand will be reduced by 2 per cent in 2050 under the RE scenario (REF: around 2000 PJ/a in 2050), while the ADVANCED scenario results in additional conversion losses in primary energy consumption of around 2200 PJ/a in 2050. The overall renewable primary energy share of the basic RENEWABLES case will be 72 per cent in 2030 and 82 per cent in 2050, with the remaining 18 per cent comprised of fossil fuels used in the transport sector. In the ADVANCED scenario, all fossil fuels are phased out by 2050 and 100 per cent of renewable energy is achieved across all sectors. Furthermore, the phasing out of traditional inefficient use of biomass for cooking and the introduction of modern, efficient bio energy applications keeps overall bioenergy demand stable, while unstainable biomass like fuel wood is replaced with sustainable biomass such as agricultural waste.

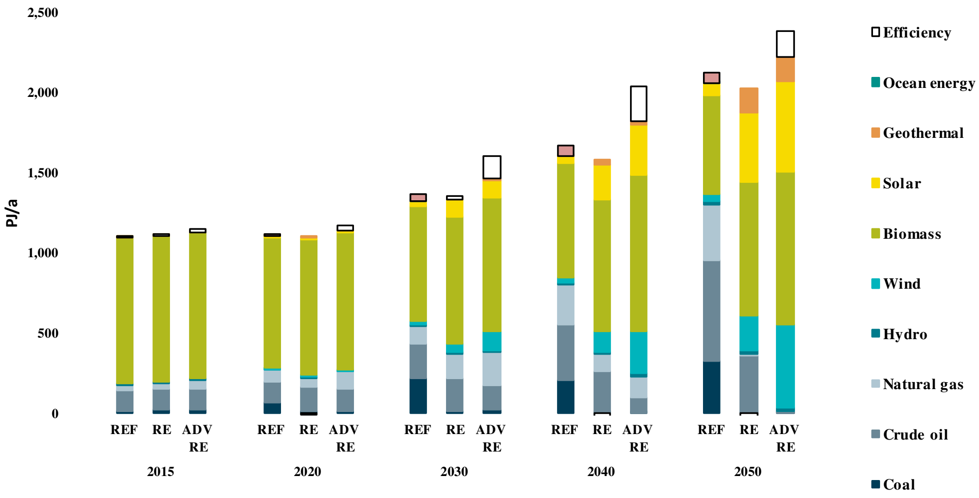

Figure 9: Projection of total primary energy demand by energy carrier (incl. electricity import balance)

- **CO_2 emissions trajectories:** Whilst Tanzania's CO_2emissions will increase by a factor of 7, from 12 million tonnes to over 90 million tonnes, between 2015 and 2050 under the REFERENCE scenario, the RENEWABLES scenario will result in a moderate increase to 24.5 million tonnes with a population increase from 53 to 137 million people in the same period. As such, annual per capita emissions will remain at 0.2 tonnes. In spite of increasing power demand, CO_2 emissions will decrease in the electricity sector. In the long run, efficiency gains and the increased use of renewable electricity in vehicles will also dramatically reduce emissions in the transport sector. With a 98 per cent share of CO_2, the transport sector will be the largest source of emissions in 2050 in the basic RE scenario. By 2050, Tanzania's CO_2 emissions will increase by 15 million tons on 2015 levels in the RENEWABLES scenario, while energy consumption is fully decarbonised in the ADVANCED case.

- **Future costs of electricity generation:** The introduction of renewable technologies under both RENEWABLES scenarios may increase the cost of electricity generation in the future compared to the REFERENCE scenario for a short period – around 2025 or 2030, depending on the assumed coal and gas price. However, this difference in the full cost of generation will be less than 1.7 cents/kWh in the basic RE and about 1.4 cents/kWh in the ADVANCED scenario. Electricity generation costs will fall under the REFERENCE case by around 2030 under the RENEWABLES scenarios. By 2050, the cost will be 4.5 cents/kWh, below those in the REFERENCE case. Thus, the RENEWABLES energy pathways are the low cost option compared to the REFERENCE case when taking into account the entire lifetime of the power plants.
- **Future investments in the power sector**: An approximate investment of US$160 billion is required for the RENEWABLES scenario to become reality, including investments for replacement after the economic lifetime of the plants, totalling around US$5 billion per year. The total investment required for the ADVANCED scenario to 2050 is US$310 billion, averaging US$9 billion per year. Under the REFERENCE scenario, the levels of investment in conventional power plants add up to almost 25 per cent, while approximately 75 per cent would be invested in renewable energies and cogeneration until 2050. Under the RENEWABLES scenarios, however, Tanzania would shift almost 99 per cent of the entire investment towards renewables and cogeneration. By 2030, the fossil fuel share of power sector investment would be focused mainly on gas power plants.

  Because renewable energy incurs no fuel costs, the fuel cost savings for the electricity sector (excluding road transport) in the basic RENEWABLES scenario total of US$80 billion up to 2050, or US$2.3 billion per year. These savings would therefore cover 70 per cent of the total additional investments compared to the REFERENCE scenario. Fuel cost savings in the ADVANCED scenario are even higher, equalling US$85 billion, or US$2.4 billion per year. Renewable energy sources would then go on to produce electricity without any further fuel costs beyond 2050, whereas costs for coal and gas will continue to be a burden on national economies. In addition, fuel costs savings in the transport sector from modular shifts and increased electrification would increase average annual savings to US$5.3 billion in the basic RENEWABLES case and US$8.1 billion in the ADVANCED case. Most savings, however, would occur after 2030.

2.3 Tanzania Energy Access Scenario – detailed assessment of the RENEWABLES scenario

Tanzania has sufficient renewable energy resources to keep storage shares well below 20 per cent while securing supply of 100 per cent renewable energy. The ENERGY ACCESS SCENARIO (EAS) aims to provide universal access to energy – particularly electricity – for all by 2050, while increasing the electrification and comfort standard to the level of industrialised countries.

The growing economy requires a reliable power supply for small and medium businesses (SME's), industry and the transport sector. It is assumed that households will use modern and energy-efficient applications according to the highest efficiency standards in order to slow down the power demand growth, and to allow the parallel expansion of energy infrastructure and the construction of renewable power plants. The electrification will be organised from the 'bottom up' in a new and innovative approach developed by UTS/ISF:

- **3-Step—Solar-Swarm Grid (3SG) expansion** – from pico-grid via micro grid to transmission grids. Currently over 70,000 households in Tanzania get access to electricity via startup companies such as Mobisol and bboxx. Those companies supply small solar systems in varying sizes from 80 to 200 Wp to match the various energy needs of differing households. Solar home systems (SHS) provide enough electricity to power bright efficient LED lights, radios, mobile phones, TVs, DC fridges and a variety of other household and consumer appliances. However, this development is not currently coordinated with the national grid expansion plans of the Tanzanian government. The project aims to develop a technical and economic concept along with a real test case, to interconnect SHS to a micro-grid in a first step and – in a second step – a number of micro grids to a distribution power grid, equal to those in industrialised countries. As the third and final step, distribution grids will be interconnected to a transmission grid.

  The industry will continue to expand on-site power generation (auto-produce) for their own supply – wherever possible with cogeneration plants – and as dispatch power plants for balancing high shares of grid-connected utility scale solar PV and wind. The fuel will move from natural gas to biogas and/or hydrogen and synfuels after 2030.

Households: Closing the gap to industrialised countries

The EAS assumes a graduate transition towards a full electrified household. Nine different household types have been developed to calculate the rising power demand, beginning with very basic needs such as light and mobile phone charging towards a household-standard matching that of industrialised countries. In order to phase out unsustainable biomass for cooking, a direct leap from cook stoves to electrical cooking is assumed. The third phase of a rural household includes an electric oven, fridge, washing machine, air-conditioner and entertainment technologies and aims to provides the same level of comfort as households in urban areas in industrialised countries. An adjusted level of comfort for households in the city and in rural areas aims to prevent residents – especially young people – from leaving their homeland and moving to big cities. Rapidly expanding cities proved problematic as infrastructure for transport and energy supply and the requirement for residential apartment buildings cannot match the demand, often leading to social tensions.

Table3: Equipment per household type – assumptions for all scenarios

		Rural-Phase1	Rural-Phase 2	Rural-Phase 3	Urban-Single	Urban-Shared App	Urban-Family 1	Urban-Family 2	Surburbia 1	Surburbia 2
Persons per household		12	10	8	2	4	8	8	4	4
equipment										
	Lightbulbs	1	3	5	10	14	10	15	15	20
	TV/Radio	0	1	2	1	2	2	3	1	3
	Computer	0	1	2	1	2	2	3	1	3
	Cooking	0	1	1	1	1	1	1	1	1
	Washing machine	0	1	1	1	1	1	1	1	1
	Drier	0	1	1	1	1	1	1	1	1
	Fridge	0	1	1	1	1	1	1	1	1
	Freezer	0	1	1	1	1	1	1	1	1
	Other appliances	0	1	1	1	1	1	1	1	1
	Fan	0	1	2	1	2	2	3	1	3
	Aircon	0	0	1	1	2	2	2	2	3
	Water (heating technology)	0	1	1	1	1	1	1	1	1

According to the most recent survey published by the Ministry of Energy and Mineral (MEM) and the National Bureau of Statistics in December 2016, 67.3 per cent of Tanzania's households have access to electricity. The percentage varies significantly between urban households (97.3 per cent) and rural households (49.3 per cent)[15].

However, the majority of households had an annual per capita demand under 100kWh per year. The analysis presented in this report assumes a higher degree of electrical applications leading to higher annual power demands per household.

The development of the country-wide share of various household types is presented in Tab. The electrification starts with basic household types such as rural phase 1, urban family 1 and suburbia 1 and moves to better equipped households. Thus, the shares of fully-equipped households grow constantly while the more basic households increase in the first years and decrease towards the end of the modelling period. By 2050, the majority of households have a medium to high comfort equipment degree.

The authors of this report have deliberately chosen a higher standard for Tanzania's households in order to close the gap between households in industrialised countries and developing countries and achieve greater equity.

Table 4: Households Types – development of shares countrywide

Household Types - Development of shares - average countrywide		2015	2020	2025	2030	2035	2040	2045	2050
Annual electricity consumption below 100 kWh/a		**90.0%**	**85.0%**	**50.0%**	**30.0%**	**25.0%**	**10.0%**	**5.0%**	**0.0%**
1	Rural - Phase 1	3.0%	4.0%	10.0%	10.0%	5.0%	3.0%	2.0%	1.0%
2	Rural - Phase 2	2.0%	2.0%	10.0%	25.0%	30.0%	35.0%	35.0%	30.0%
3	Rural - Phase 3	1.0%	2.0%	10.0%	10.0%	15.0%	25.0%	30.0%	40.0%
4	Urban - Single	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5	Urban/Shared App.	1.0%	2.0%	2.0%	3.0%	3.0%	3.0%	3.0%	3.0%
6	Urban - Family 1	1.0%	2.0%	5.0%	6.0%	6.0%	7.0%	7.0%	7.0%
7	Urban - Family 2	0.5%	1.0%	5.0%	6.0%	6.0%	7.0%	7.0%	9.0%
8	Surburbia 1	1.0%	1.0%	5.0%	6.0%	6.0%	6.0%	6.0%	6.0%
9	Surburbia 2	0.5%	1.0%	3.0%	4.0%	4.0%	4.0%	4.0%	4.0%

ENERGY ACCESS SCENARIO – REGIONAL BREAKDOWN INFRASTRUCTURE AND RENEWABLES

For regional modelling, the following eight regions have been allocated (see Figure):

1. Lake Zone: Shinyanga, Geita, Mara, Simiyu, Mwanza and Kagera
2. Northern Highlands Zone: Manyara, Arusha, Kilimanjaro
3. Southern Coast Zone: Mtwara and Lindi
4. Western Zone: Tabora, Katavi and Kigoma
5. Southern Highlands Zone: Iringa, Njombe, Songwe, Rukwa and Mbeya
6. Northern Coastal Zone: Tanga, Morogoro and Pwani, Dar-es-Salaam and Zanzibar Island
7. Southern Zone: Ruvuma
8. Central/Capital: Dodoma and Singida

[15] Energy Access Situation Report, 2016, Tanzania Mainland, The United Republic of Tanzania, February 2017, http://www.nbs.go.tz/nbs/takwimu/rea/Energy_Access_Situation_Report_2016.pdfhttp://www.nbs.go.tz/nbs/takwimu/rea/Energy_Access_Situation_Report_2016.pdf

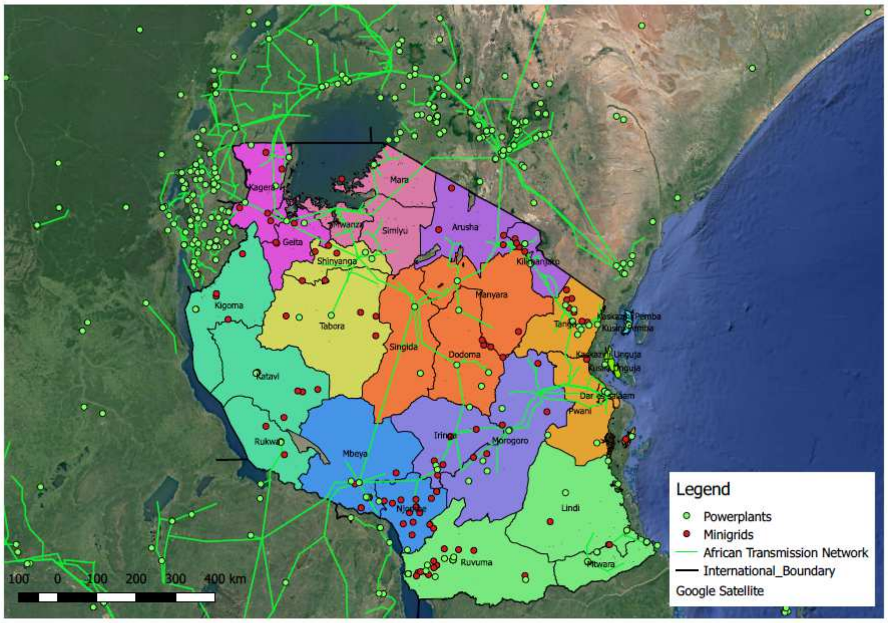

Figure 10: Regional breakdown for this project

***Source*:** ISF mapping, August 2017

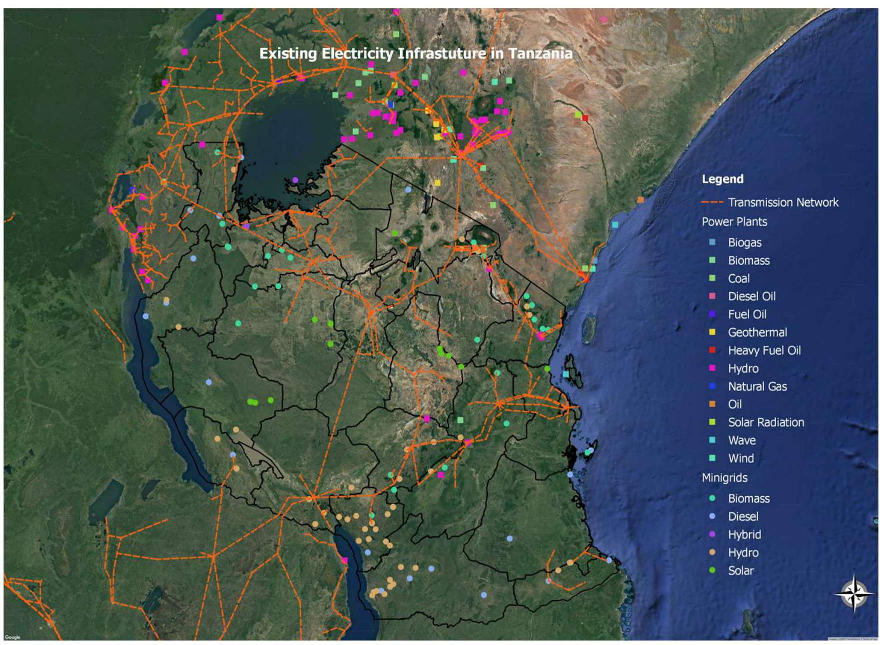

Figure 11: Existing electricity infrastructure by type

***Source*:** ISF mapping, August 2017

Figure shows the existing energy infrastructure in Tanzania. The Energy Access Scenario will significantly expand renewable-supplied mini grids and interconnect them with each other in a first step, joining them with the transmission grid as a 'bottom-up build distribution grid' at a later stage, starting around 2030. This significantly accelerates the expansion of the power grid as it 'grows together' from the distribution and transmission level concurrently.

2.4 Regional distribution of solar and wind resources

Tanzania has almost 72,850 square kilometres of available land where 1821 gigawatts of solar power can potentially be harvested through utility scale solar farms. In order to avoid conflicts with National Parks and other competing uses of land, only bare soil, perennial cropland and open bushland land cover types were included in the analysis. Both utility scale solar photovoltaic and concentrated solar power (CSP) are included in the analysis. CSP would be built in-region with the highest direct normal irradiance, which accounts for approximately 15 per cent to 20 per cent of this area. In Table it is assumed that 80 per cent of the suitable area will be used for utility scale solar photovoltaic and 20 per cent for concentrated solar power.

Less than 5 per cent of these need to be harvested to meet the current and future energy needs of the country, thus offering a diversity of options for interested investors to set up renewable energy plants.
Figure shows the distribution of potential sites that are ideal for setting up utility scale solar plants.

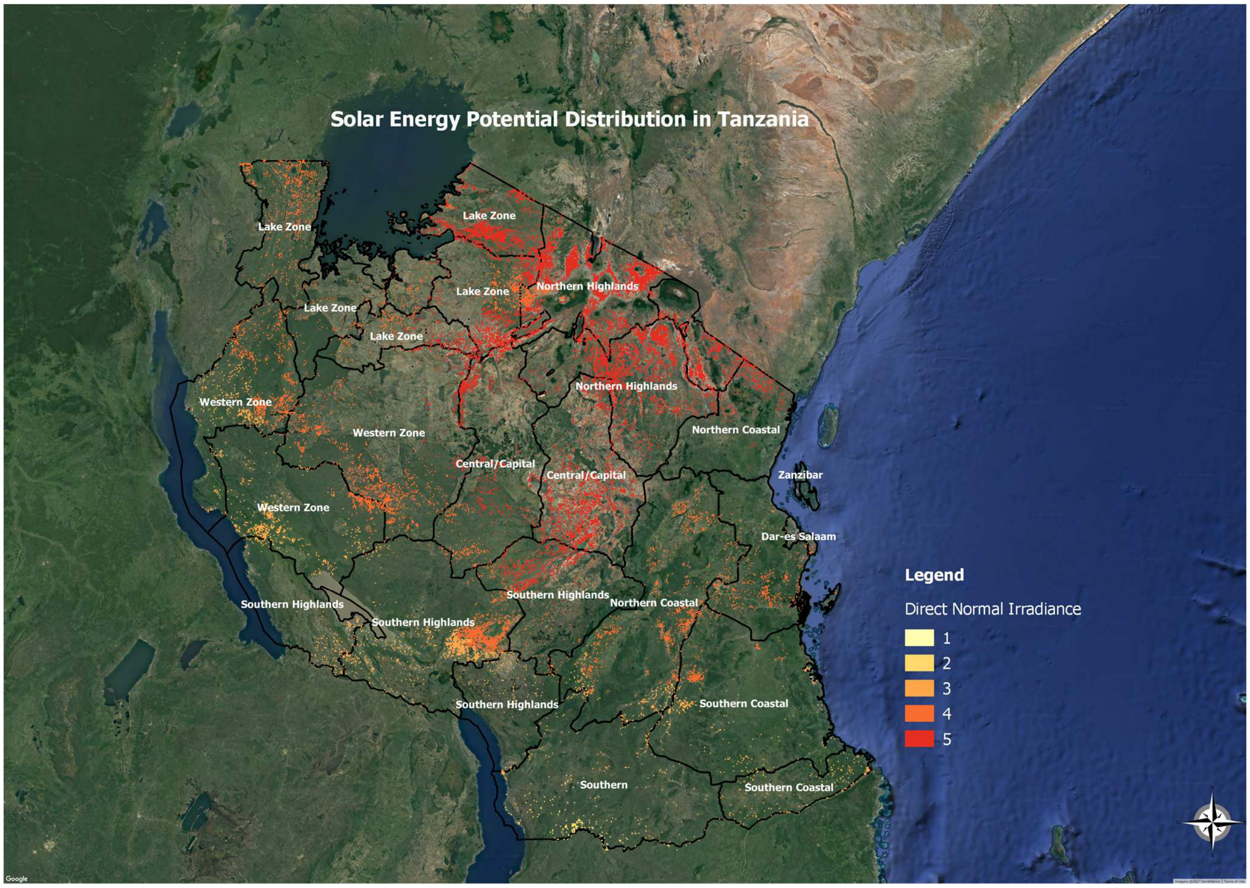

Figure 12: Solar energy generation potential in Tanzania

Source: ISF mapping, August 2017

The distribution of potential sites for optimal wind power generation is shown in Figure . The map highlights the large potential of land available for renewable energy generation.

Potential exists to install at least 447 gigawatts of wind power (on- and offshore) from sites spread over 89,400 square kilometres across Tanzania. This analysis takes into account only wind speeds of 6 metres per second and above in order to plot optimal sites. Site selection is restricted to include only the following land cover types; bare soil, annual cropland, perennial cropland, grassland and ocean. Offshore water bodies (ocean) within 50 to 60 kilometres of the coast were included in the analysis. This leads to an estimated offshore wind potential of 150 gigawatts and an onshore wind potential of around 300 gigawatts.
Only a small percentage of this needs to be tapped to meet the current and projected demands of the country.

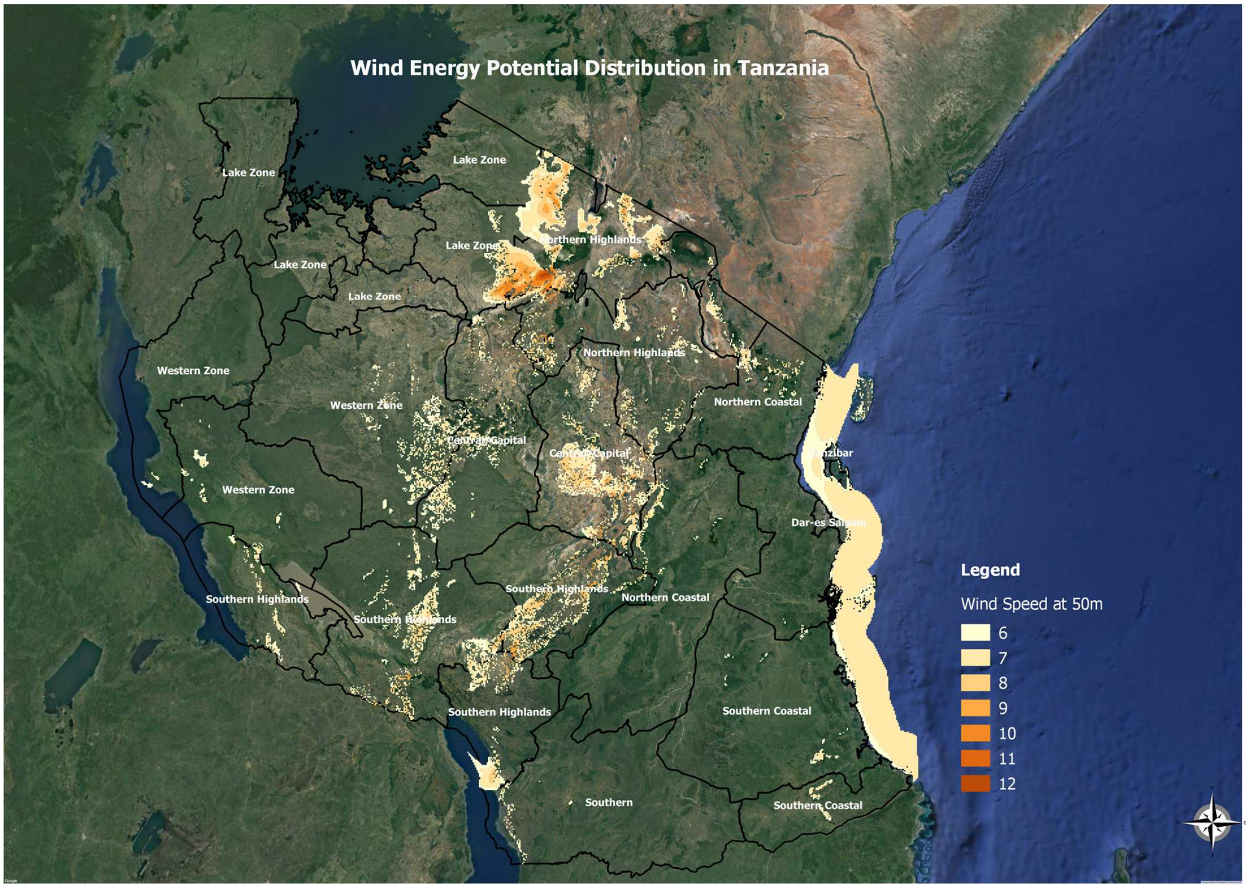

Figure 13 : Wind energy generation potential in Tanzania
Source: ISF mapping, August 2017

Table 5: Renewable energy potential – results from QGIS mapping

Resource	Maximum installable generation capacity [GW]	Maximum recoverable electricity [TWh/year]	ADVANCED RENEWABLES 2050: Installed Capacity [GW]	ADVANCED RENEWABLES 2050: Generation [TWh/year]
Wind – onshore	300	750	30	75
Wind – offshore	150	480	21	68
Solar Photovoltaics	1,450	2,320	45	72
Concentrated Solar Power (CSP)	365	700	31	61
Total	**2,265**	**4,250**	**127**	**276**

Source: ISF mapping, August 2017, values are rounded

2.5 Security of supply and storage requirements

The [R]E 24/7model calculates demand and supply by cluster and four different voltage levels. The long-distance transmission grid (TA) serves as an interconnector across the country, while the regional transmission grid (TZ) connects to the medium (DA) and finally to the low (DZ) voltage level.

Storage technologies – particularly decentralised batteries and pumped hydro – are used to avoid curtailment of solar photovoltaic and wind power and to guarantee security of supply. Batteries are assumed to be installed as decentralised application on the lowest voltage level, while pumped hydro power is likely to be connected to the medium or high voltage level.

Table and Table show the results of the storage demand calculation for 2030 and 2050. The storage requirements are still relatively minor in 2030, and short-term storage demand to even out day and night variations of solar photovoltaic systems are required most. In 2050, batteries continue to shoulder more than half of the entire storage demand, mainly in connection with solar photovoltaic systems. The uneven results of charge and discharge from pumped hydro indicate a regional and seasonal storage requirement.

Both technologies play an important role: batteries for short term storage requirement, for example to balance demand and supply over a few hours or days; and hydro power for seasonal storage, for example wind power to bridge several weeks or months. Pumped hydro can also balance demand and supply across regions as they are connected to transmission grid. The table shows a significant regional storage demand; for example, there is a need to balance the generation difference of the Lake Zone and the Northern Coast, which have significantly higher discharge then charging rates.

Table 6: Storage demand by region in 2030

2030		Battery charge	Battery discharge	Hydro Pumpstorage charge	Hydro Pumpstorage discharge	Total Storage Through-put
		[MW/h]	[MW/h]	[MW/h]	[MW/h]	[MW/h]
NORTH WEST	Lake-Zone	85,493	85,585	13,557	118,197	302,832
	Western Zone	122,746	122,902	4,830	38,520	288,998
	Northern Highlands	120,803	120,970	4,233	16,517	262,523
	Central/Capital	134,263	134,405	11,659	48,345	328,671
SOUTH WEST	Southern Highlands	131,633	131,787	5,550	45,974	314,944
	Northern Coast	89,278	89,361	13,740	117,021	309,399
	Southern Industrial Zone	127,209	127,386	5,359	10,276	270,230
	South Coast	157,738	157,874	18,651	29,951	364,214
Total		**969,161**	**970,269**	**77,578**	**424,801**	2,441,810

Table 7: Storage demand by region in 2050

2050		Battery charge	Battery discharge	Hydro Pumpstorage charge	Hydro Pumpstorage discharge	Total Storage Through-put
		[MW/h]	[MW/h]	[MW/h]	[MW/h]	[MW/h]
NORTH WEST	Lake-Zone	674,676	674,688	497,550	1,179,574	3,026,488
	Western Zone	566,153	566,581	220,010	357,512	1,710,256
	Northern Highlands	476,318	476,485	142,348	102,376	1,197,526
	Central/Capital	600,983	601,361	395,408	392,484	1,990,236
SOUTH WEST	Southern Highlands	653,790	654,197	262,849	422,471	1,993,307
	Northern Coast	610,368	610,362	464,536	1,198,562	2,883,828
	Southern Industrial Zone	347,017	346,909	165,290	42,291	901,507
	South Coast	511,569	511,569	480,013	173,018	1,676,169
Total		**4,440,873**	**4,442,153**	**2,628,003**	**3,868,288**	15,379,317

Table8 and Table9 show that the overall supply share from storage technologies under the assumed regional demand and supply situation for 2030 and 2050. The overall share of storage technologies to ensure security of supply and to avoid un-economic curtailment for solar photovoltaics and wind power is still very minor, with an average of 6 per cent across Tanzania.

Variable power generation in some regions exceed demand, while in other regions generation cannot supply regional demand. The analysis does not include an optimisation process of regional generation, but places variable generation where demand, solar- and/or wind resources are highest. Regional difference indicates power transport demand (= transmission network expansion).

Table 8: Dispatch, storage and variable generation by region in 2030

	2030	Variable Renewables	**Dispatch Renewables**	Storage charge	**Storage discharge**	Supply via Storage	Import (positive values) Export or Curtailment (negative values)
		[%]	[%]	[%]	[%]	[%]	[%]
NORTH WEST	Lake-Zone	37%	55%	1%	2%	3%	9%
	Western Zone	49%	48%	3%	4%	7%	3%
	Northern Highlands	66%	42%	6%	6%	12%	-8%
	Central/Capital	58%	44%	3%	3%	6%	-2%
SOUTH WEST	Southern Highlands	45%	50%	3%	4%	7%	4%
	Northern Coast	41%	53%	1%	2%	3%	6%
	Southern Industrial Zone	83%	37%	8%	8%	16%	-20%
	South Coast	78%	37%	4%	4%	9%	-15%
Total		**50%**	**49%**	**2%**	**3%**	**6%**	**1%**

Concentrated solar power (CSP) with 8-hour molten salt storage technologies play an important role after 2040 and are seen as 'limited dispatchable' renewable power generation. In 2050, the assumed CSP capacity for Tanzania is 13,875 megawatts and contributes to around one fifth of the dispatchable power generation.

Table 9: Dispatch, storage and variable generation by region in 2050

	2050	Variable Renewables	**Dispatch Renewables**	Storage charge	**Storage discharge**	Supply via Storage	Import (positive values) Export or Curtailment (negative values)
		[%]	[%]	[%]	[%]	[%]	[%]
NORTH WEST	Lake-Zone	55%	39%	5%	8%	13%	6%
	Western Zone	75%	43%	9%	10%	19%	-18%
	Northern Highlands	106%	43%	14%	13%	27%	-49%
	Central/Capital	90%	38%	9%	9%	18%	-28%
SOUTH WEST	Southern Highlands	70%	45%	9%	11%	20%	-15%
	Northern Coast	60%	36%	5%	9%	14%	3%
	Southern Industrial Zone	138%	48%	16%	12%	28%	-86%
	South Coast	128%	43%	12%	8%	20%	-71%
Total		**77%**	**40%**	**8%**	**9%**	**17%**	**-17%**

Demand and supply by voltage level

The [R]E24/7 generates demand and supply curves for each voltage level and season. This section shows an example of the South Eastern Transmission region where a significant proportion of Tanzania's industry is located. A negative residual load indicates an export to the next lower voltage level.

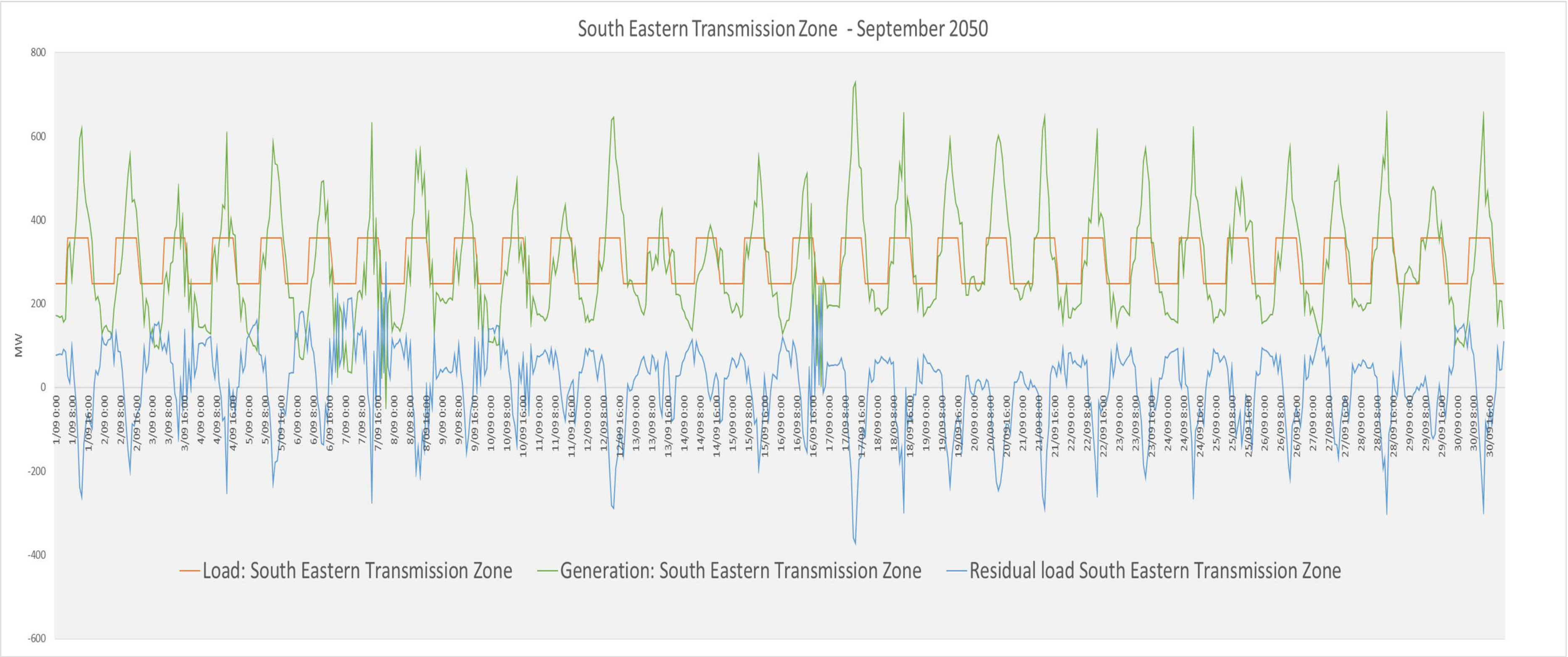

Figure 14: Demand and supply: Case South Eastern region – Transmission Zone / September 2050

Figure shows that the generation in the south-eastern region exceeds demand and that power generation capacity is exported. To allocate generation capacity where demand is highest and therefore power grid infrastructure must cope with high loads makes economic sense. Load centers therefore can also operate as a 'powerhouse' for the region and/or country.

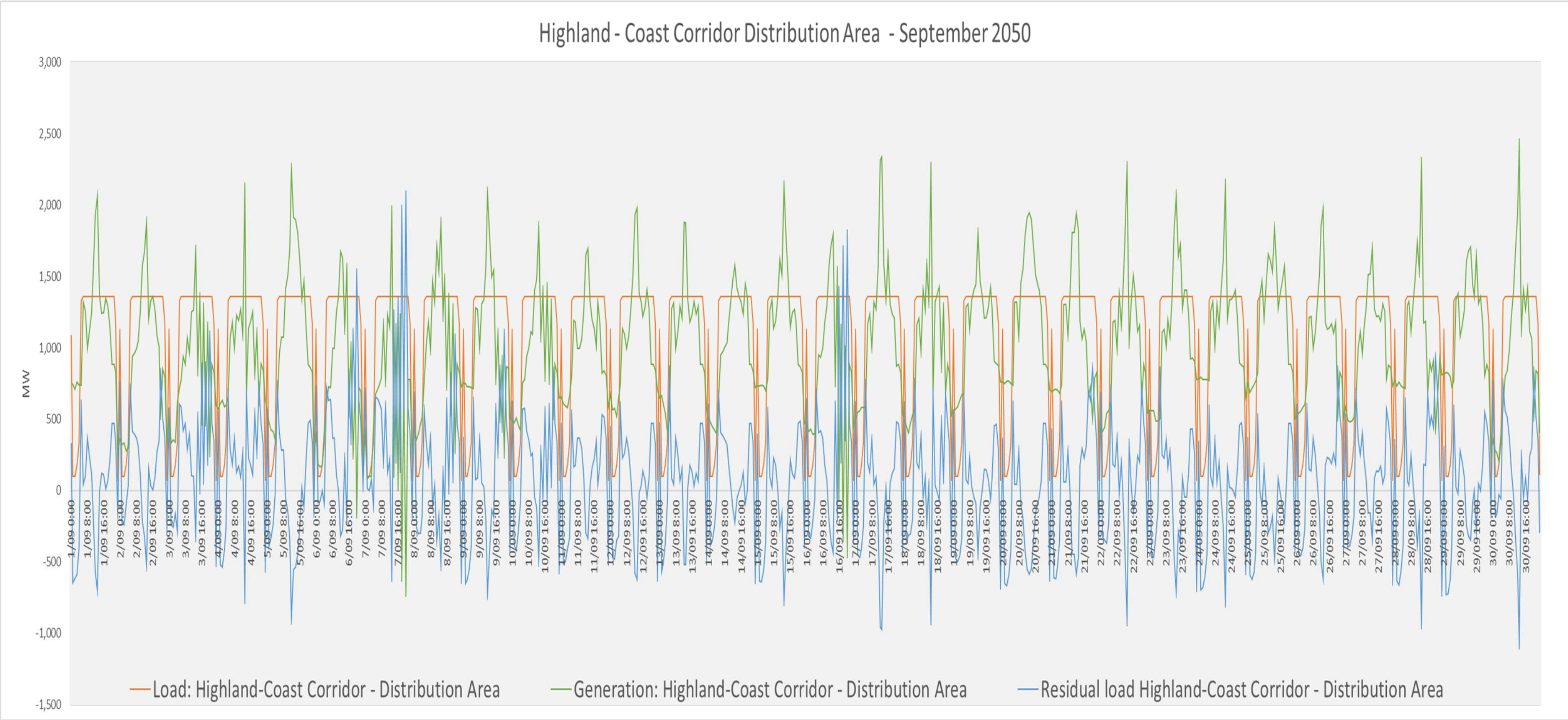

Figure 15: Demand and supply: Case South Eastern region – distribution area / September 2050

Figure shows the same region as Figure but for the distribution area. Demand and supply match better than at the transmission zone level, and less over-supply is exported to other voltage levels. The midday peak is from solar photovoltaics, while the evening generation peaks are from wind power.

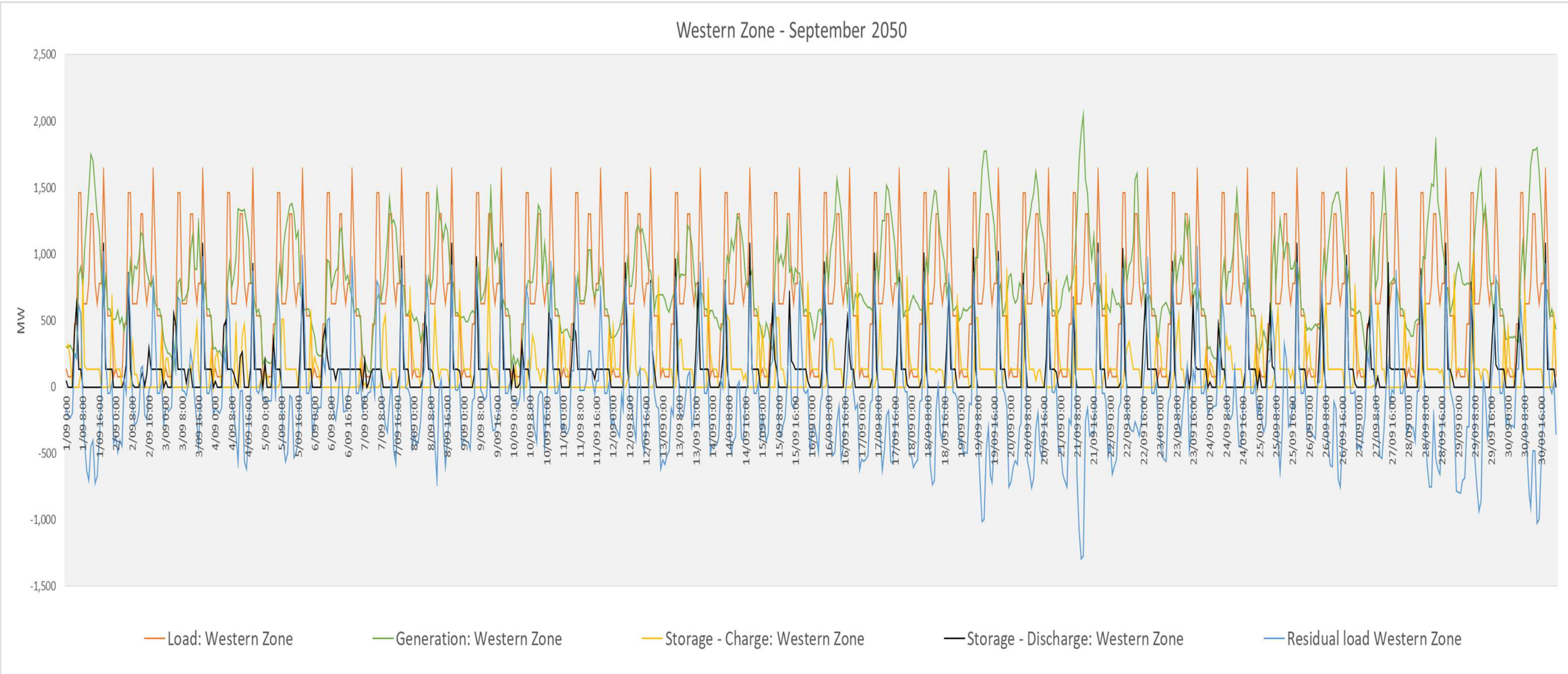

Figure 16: Demand and supply: Case South Eastern region – distribution zone / September 2050

The lowest voltage level – the distribution zone – of the Western Zone, which includes Tabora, Katavi and Kigoma, is shown in Figure. Battery storage shifts the midday generation peak to the early evening hours. Average load alternates between 1,500 megawatts and 700 megawatts, while the storage capacity oscillates between +/- 700 megawatts with frequent peaks at around 1000 megawatts. The installed solar photovoltaic capacity in this region is assumed at almost exactly 1,000 megawatts, which correlates with the maximum storage demand. During the sample month of September 2050, the generation peak around 21 September is a correlation of high solar and wind generation potential. The storage capacity should not be designed for the highest generation peak, but should take into account capacities needed on a regular basis. Extreme and seldom generation surplus peaks should be curtailed rather than stored. A curtailment rate of around 5 per cent per year has proven to be economically viable.

2.6. Conclusion [R]E 24/7 modelling

The hourly modelling of the long-term scenario shows that the chosen mix is suitable to guarantee security of supply, and that storage technologies in the order of 15 to 20 per cent of total generation are sufficient. A regional distribution via an interconnected power grid can reduce storage demand and curtail variable renewable power generation. However, the development of storage costs will have a huge influence on whether or not all variable power generation will be stored, or whether the share of dispatchable renewable power generation will increase at the expense of variable power generation and storage.