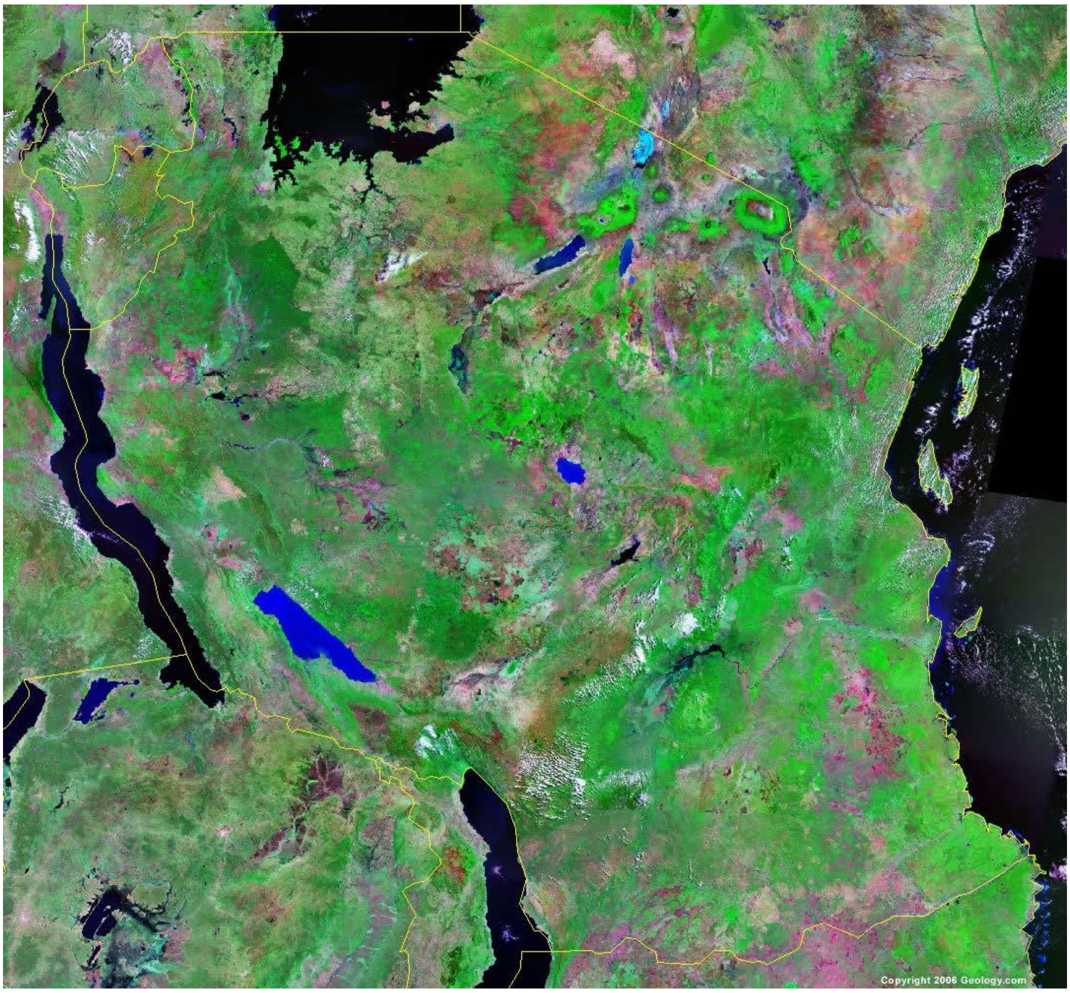


100% RENEWABLE ENERGY FOR TANZANIA

Access to renewable and affordable energy for all within One Generation

Prepared for: Bread for the World

Executive summary

UTS Institute for Sustainable Futures

2017

1 SETTING THE SCENE

Global energy markets are rapidly changing. 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. This trend continued throughout 2015 and 2016[2]. Currently, oil and coal prices are at record lows, which has halted the development of most new coal and oil mining projects.

While electric vehicles still have a negligible share of global car transport this is likely to change as most international car manufacturers prepare for a massive shift toward electric vehicles. It is possible that the market for electric vehicles could follow the same exponential development pathways as the solar photovoltaic (PV) market. Between 2010 and 2015 solar technology suddenly took off, with increasing market shares and a significant drop in investment costs. Solar photovoltaic at the household level is now cheaper than retail electricity prices (tariffs) in most industrialised countries. As such, it is now cost-effective for many households to produce their own power. Wind power is now the cheapest technology worldwide for new power plants. This led to a huge global market for wind with 54,000 MW of capacity added during 2016 – equivalent to installing a new turbine every 20 minute.

These global developments are in favour of Tanzania's goal to provide access to energy for all as renewable energy technologies are more economic and faster to build as fossil fuel based power generation and it will reduce dependencies on fuel imports.

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. Especially young people leave the rural areas for large cities due to the lack of professional opportunities. Access to energy provides a basic fundament for economic activities and to fight 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 many rural areas of developing countries as well as some urban slums and peri-urban areas, connections to central electric grids are economically prohibitive and may take decades to materialize, if at all (REN21-GSR 2016). Recent progress has been too slow to reach the new objectives

In 2013, the United Nations Development Programme (UNDP) started the "Sustainable Energy for All" initiative that was aimed to accelerate the pace of increase energy access for the least developed countries. The first step was, to provide a central database in order to make previously dispersed information available for decision makers. The UNDP - in cooperation with a number of other energy advocacy organizations such as the IEA and REN21 - published the Global Tracking Framework[3] report that provides a statistical overview about the progress of energy access between 1990 and 2010. In order to set the scene, this section is based on the UNDP information and new data from REN21 Global Status report.

Between 1990 and 2010, an additional 1.7 billion people gained the benefits of electrification, while 1.6 billion people secured access to generally less-polluting non- solid fuels. Furthermore, energy efficiency measures were successfully implemented leading to a significant drop of energy intensity. Thus, economic growth and the growth of energy demand started to disconnect – a major success which avoided 2,300 Exa-joules of new energy supply over the past 20 years, in other words, without these measures, the global energy demand would have been 25% higher during that period. Furthermore, renewable energy supplied a cumulative total of more than 1,000 exa-joule globally over 1990–2010 -an amount comparable to the cumulative final 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:

1. population with access to electricity and non-solid fuels grew 1.2% respectively 1.1 % per year
2. renewable energy supply grew around 2% per year
3. energy demand grew 1.5 % per year

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

[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

overall urban electrification rate remained relatively stable, growing from 94 to 95 percent across the period (UNDP 2013). Improved cooking devices are important to increase public health especially in developing countries. Worldwide almost two million deaths annually from pneumonia, chronic lung disease, and lung cancer are associated with exposure to indoor air pollution resulting from cooking with biomass and coal, and 99 percent of them occur in developing countries. Almost half the global population (45 percent) still relies on solid fuels for household use, resulting in dramatic impacts on health, especially for children and women. Some 44 percent of these deaths occur in children; of the adult deaths, 60 percent occur in women in developing countries (UNDP 2013).

Status quo: Access to energy services

Currently, about 1.5 billion people in developing countries lack access to electricity and about 3 billion people rely on solid fuels for cooking. More than every second person who has no access to electricity lives in Sub-Sahara Africa. The entire African continent has a total installed capacity of about 150 GW - 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 factor 12 larger. In East Asia and 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 about key statistics.

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

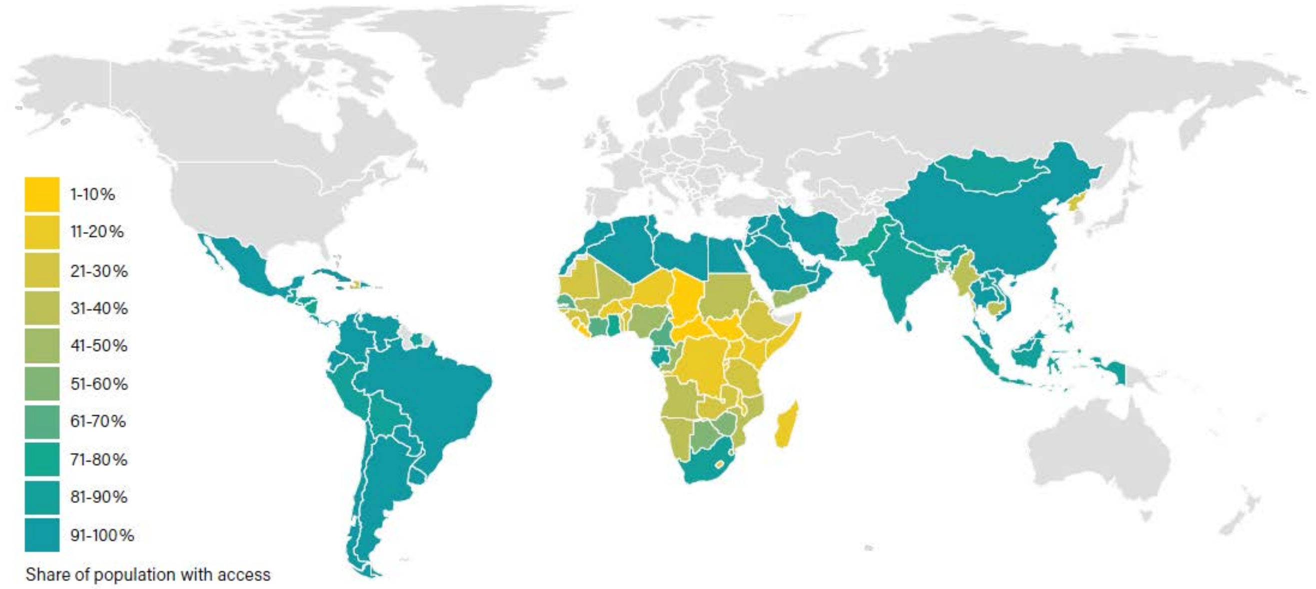
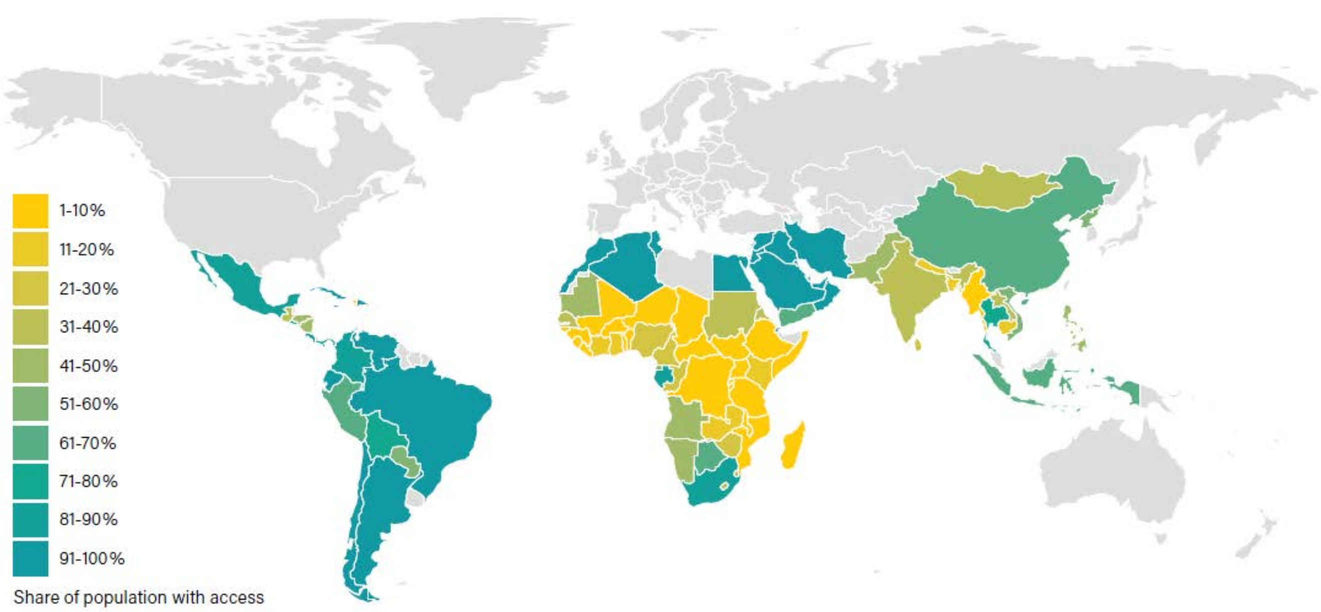


Figure 2: Access to clean cooking facilities in developing countries, 2014 (REN21-GSR 2017)



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 e.g. for the agricultural sector and cooking. DRE systems can serve as a complement to centralized energy generation systems, or as a substitute (REN21-GSR 2016). These technologies must operate reliable and with low maintenance requirement over many years, while the multiple benefits of those systems are proven such as:

1 Improved health through the displacement of indoor air pollution

2 Reduced emissions of greenhouse gases

3 Enable small business activities

4 Increase security e.g. via street lighting at night

5 Affordable lighting enhances communications and facilitate greater quality and availability of education

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, higher-value crops, greater reliability of irrigation systems, enabling of crop growth during periods when market prices are higher	Wind, solar PV, biomass, micro-hydro
Illumination	Reading, extension of operating hours	Wind, solar PV, biomass, micro-hydro, geothermal
Grinding, milling, husking	Creation of value-added products from raw agricultural commodities	Wind, solar PV, biomass, micro-hydro
Drying, smoking (preserving with process heat)	Creation of value-added products, preservation of products that enables sale in higher-value markets	Biomass, solar heat, geothermal
Expelling	Production of refined oil from seeds	Biomass, solar heat
Transport	Reaching new markets	Biomass (biodiesel)
TV, radio, computer, Internet, telephone	Support of entertainment businesses, 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, micro-hydro, geothermal
Refrigeration	Selling cooled products, increasing the durability of products	Wind, solar PV, biomass, micro-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):

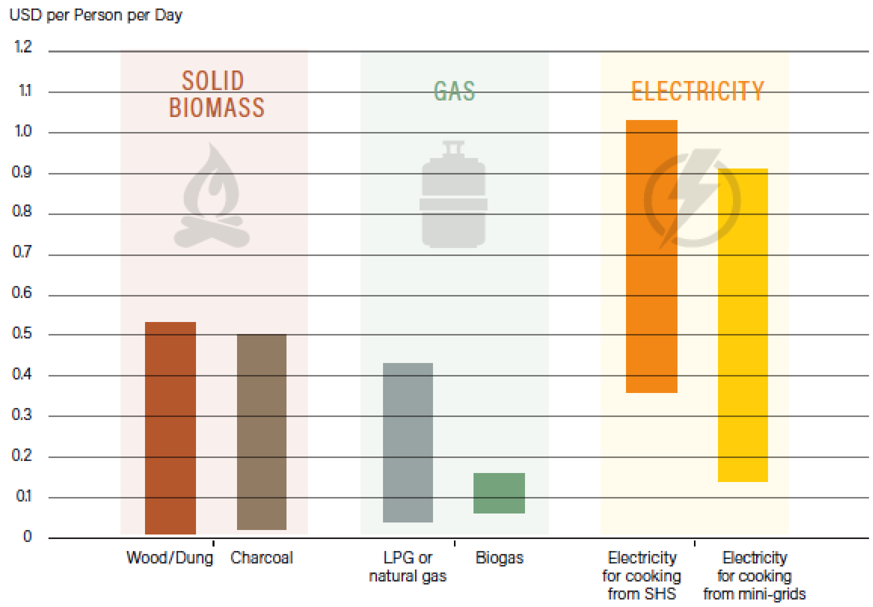
1. 20 million households with solar home systems
2. 5 million households with renewables-based mini-grids (mainly micro- hydro)
3. 0.8 million households supplied by small-scale wind turbines

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

Cooking with firewood, gas or electricity

A variety of technologies can provide cooking services in different capacities, which correspond to differences in performance and cost. Wood, charcoal and dung are still widely used around the world for cooking purposes: dung is a major cooking fuel for about 185 million people.61 Existing substitutes include improved and cost-efficient biomass cook stoves, biogas cook stoves and electric hot plates powered by SHS or mini-grids. Electric cooking has reduced the consumption of firewood and/or charcoal between 10% and 40%, whereas biogas stoves, which are more widely used, have reduced these consumption levels between 66% and 80% (REN21-GSR 2017). Costs for electric cooking are expected to come down with decrease electricity generation costs for decentralised renewables, mainly solar photovoltaic.

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



Population development

Tanzania is East Africa's largest country, with a population of 53.470.420 inhabitants, of which 45% is under the age of 15. Ranking 27th in the world in terms of its population[4], Tanzania's population average annual growth rate (1960-2015)) has been 3.1%, and it is expected to reach 82.6 million by 2030[5]. Tanzania's population is widely dispersed, with 70 per cent of the population living in rural regions and a population density of 60 per km^2 [6]. In rural areas, the distribution of population varies significantly. For instance, in the arid regions, population density is as low as 1 person per square kilometre, and about 53 people per square kilometre in the water-rich mainland highland[7]. Future population and economic growth are important factors in energy scenario building because they affect the size and composition of energy demand, directly and through its impact on economic growth and development. For population development projections of the Worldbank are used (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)	[$/a]	46,400,000,000	93,326,973,500	187,713,878,937	316,056,673,674	422,585,748,426	499,405,181,975	578,947,480,035	671,158,803,986
	GDP/Person (calculated)	[$/capita]	868	1,502	2,614	3,826	4,469	4,640	4,759	4,917
	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]	3.1%	3.1	2.9	2.8	2.7	2.6	2.5	2.3

Economic Context

Tanzania is one of the world's poorest economies in terms of per capita income, US$864,9 a year, which is equivalent to less than 9% of the world's average. The country's per capita income is slightly ahead of low income countries average per capita income (US$615,6), but still far from lower middle-income countries (US$1.988,2) and even further from middle income countries (US$4736,7)[8]. Nevertheless, the country has achieved high growth rates based on its vast natural resource wealth and tourism. GDP growth in 2009-15 was 6-7% per year[9], making it one of the 20 fastest growing economies in the world. Over the same period Tanzania's inflation has been brought down to a single digit of 5.4% as of March 2016, from an average of 12.6% during 2011. Trade deficit also shrank over the last 5 years, from US$5bn in 2010 to US$3bn in 2015[10].

The economy depends largely on the agricultural sector, which accounts for more than one-quarter of GDP, provides 85% of exports, and employs about 80% of the work force[11]. Tourism is another key sector. At an average of $2bn a year, tourism has brought Tanzania the largest amount of foreign currency in the past 3

[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
[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

years[12]. Construction, wholesale and retail trade, public administration and manufacturing contribute respectively to 12%, 10%, 7% and 6% of Tanzania GDP[13].

The economic development of Tanzania is based on the GDP breakdown of 2015. It is assumed that the overall structure of the economy does not change and that all sector grows equally to the GDP growth. Agriculture and services & trade remains to be the backbone of Tanzania's economy, followed by construction and chemical and other industries, mining.

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

With the decrease in the price of 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% 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 power system. The government 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.

[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

2 KEY RESULTS

Long-term and energy access scenario

The Institute for Sustainable Futures (ISF) / University of Technology Sydney (UTS) calculated three long-term scenarios with a special energy model which has been develop from the German Aerospace Center (DLR). Based on those results, an hourly simulation of the entire electricity market for Tanzania has been done. The [R]E24/7 model used for the hourly calculation has been developed from the UTS/ISF. The following scenario have been calculated:

1. The **REFERENCE scenario (REF)** reflects a continuation of current policies and is based on Tanzanian Government forecast 'Tanzania Power System Masterplan 2016'
2. The **RENEWABLES scenario (RE)** is designed to meet Tanzania's energy related targets to achieve 100% renewable energy for electricity, buildings and industry as soon as possible. The renewable energy trajectories for the first years are taken from the World Future Council *"Policy Roadmap for 100% Renewable Energy and Poverty Eradication in Tanzania"* published in May 2017.
3. The **ADVANCED Renewables Scenario (ADV RE)** takes a more ambitious approach to transforming Tanzania's entire energy system towards 100% 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 is based on results of the Renewables scenario (RE) and simulates hourly supply and demand curves as well as 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 use renewable energy as cost efficient as possible and to 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 2.0% per year over the scenario period.

Key results of the long-term energy pathway for Tanzania

- **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% 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

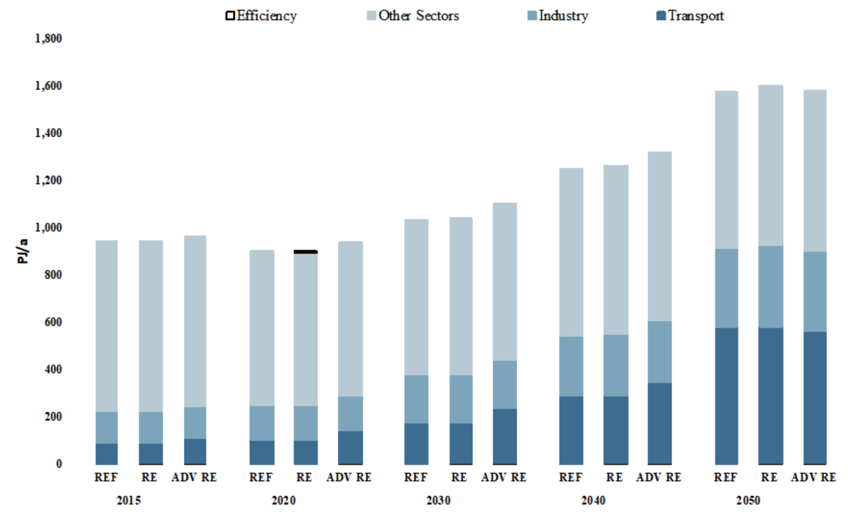
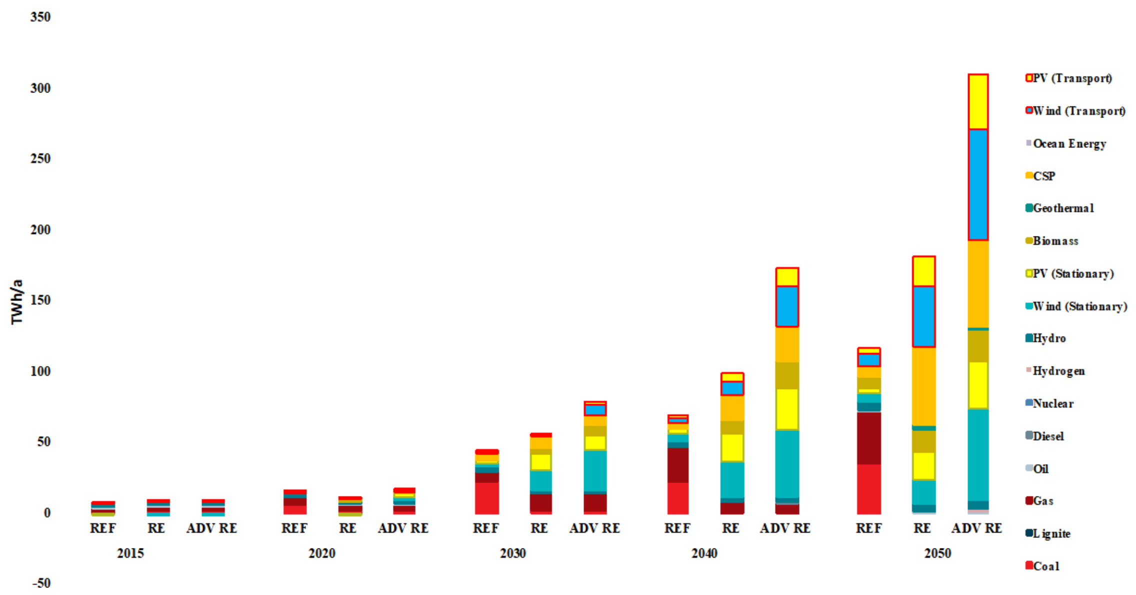


Figure 4: Projection of total final energy demand by sector

- **Electricity demand:** will rise from about 5 TWh/a to 110 TWh/a by 2050 in the basic RE scenario. For the heating sector assumed renewable heating technologies for residential and commercial building, mainly geothermal heat pumps and solar collectors, will influence the building and construction standard significantly.
- **Electricity generation, capacity and breakdown by technology**: The renewable energy market grows dynamically and the required electricity supply has increasing share of renewable electricity. 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. By 2050, 100% of the electricity produced in Tanzania will come from renewable energy sources in the basic RENEWABLE scenario. 'New' renewables – mainly wind, PV, Ocean and geothermal energy – will contribute 75% to the total electricity generation. Already by 2020 the share of renewable electricity production will be 53% and 75% by 2030. The installed capacity of renewables will reach about 20. GW in 2030 and 60. GW by 2050.

Figure 5: Breakdown of electricity generation by technology

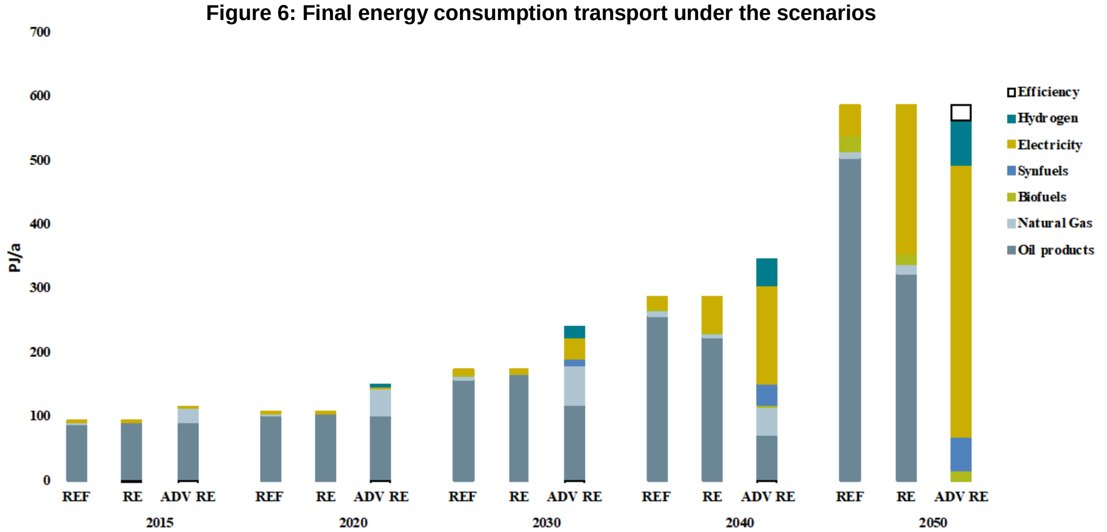


- **Energy supply for heating:** In 2015, renewables meet around 90% of Tanzania's energy demand mainly traditional use of biomass for cooking. Dedicated support instruments are required to ensure a dynamic development in particular for renewable technologies for cooking, buildings and renewable process heat

production for increased industrial process heat requirements. In the basic RENEWABLE scenario, renewables already provide 90% of Tanzania's total heat demand in 2030 and 100% in 2050.
Energy efficiency measures help to reduce the currently growing energy demand for fuel wood of cooking stoves and shifts 100 % to modern sustainable biomass, solar- and geothermal heating as well as electric cooking and heating by 2050.

- **Transport:** A key target is to introduce incentives for people to keep public transport as the preferred transport and to significantly increase the convince. 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 expanding large metropolitan areas. Due to population increase, GDP growth and higher living standards, energy demand from the transport sector is expected to increase in all scenarios by around 601% to 590 PJ/a in 2050.
Additional modal shifts and technology switches lead to energy savings in the ADVANCED scenario of 4% (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 bring about large efficiency gains. By 2030, electricity will provide 4% of the transport sector's total energy demand in the RENEWABLE, while in 2050 the share will be 40% (75% in the ADVANCED scenario).

Figure 6: Final energy consumption transport under the scenarios



- **Primary energy consumption:** Under the basic RENEWABLE scenario, primary energy demand will increase by 82% from today's 1100. PJ/a to around 2000. PJ/a. Compared to the Reference scenario, overall primary energy demand will be reduced by 2% in 2050 under the RE scenario (REF: around 2000. PJ in 2050). The ADVANCED scenario results due to additional conversion losses in a primary energy consumption of around 2200. PJ in 2050.The overall renewable primary energy share of the basic RENEWABLE case will be 72% in 2030 and 82% in 2050 100% in 2050 in the ADVANCED case (incl. non-energy consumption).

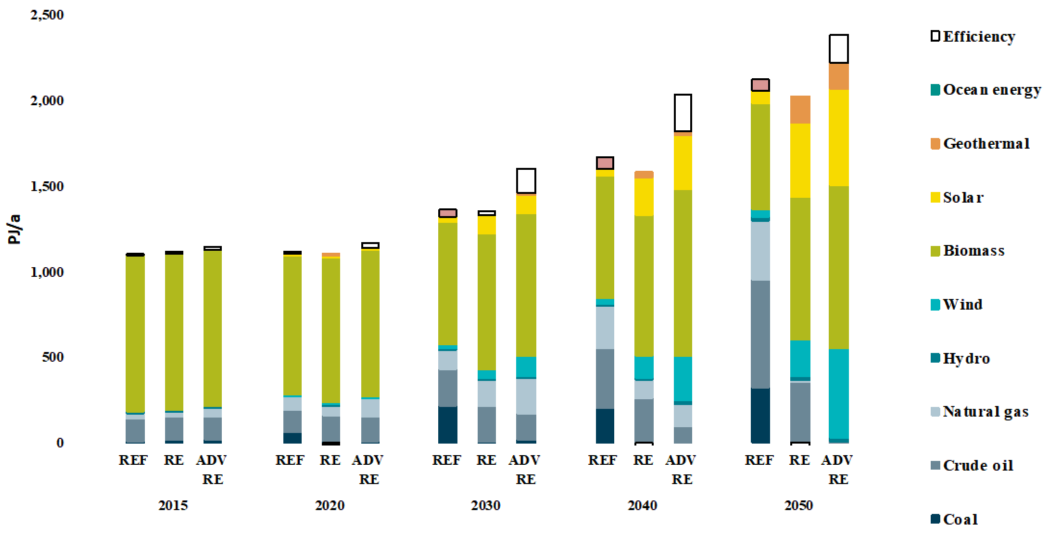


Figure 7: Projection of total primary energy demand by energy carrier (incl. electricity import balance)

- **CO_2 emissions trajectories:** Whilst Tanzania`s emissions of CO_2 will increase by 676% between 2015 and 2050 under the Reference scenario, under the RENEWABLE scenario they will decrease from 10 million tones in 2015 to 25 million tones in 2050. Annual per capita emissions will remain at 0.2 t. 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 strongly reduce emissions in the transport sector as well. With a 98% 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 increased by 15 million tons above 2015 levels in the RENEWABLE scenario while energy consumption is fully decarbonized in the ADVANCED case.
- **Future costs of electricity generation:** The introduction of renewable technologies under both RENEWABLE scenarios might increase the future costs of electricity generation 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 full cost of generation will be less than 1.7 $ct/kWh in the basic RE and about 1.4 $cent/kWh in the ADVANCED scenario. Electricity generation costs will fall under the REFERENCE case around 2030 under the RENEWABLE scenarios. By 2050, the cost will be 4.5 / 2 $cent/kWh, respectively, below those in the Reference case.
- **Future investments in the power sector:** Under the RENEWABLE case the additional investment cost are estimated to be billion $3.2 compared to REFENCE case, the fuel cost saving would add up to billion $5.3. Thus, required additional investment cost will more than re-finance via fuel cost saving. With high uncertainties both for future investment cost for power generation equipment as well as fossil fuel prices, it seems certain, that the overall cost balance is economically beneficial for the RENEWABLE case.
  Under the ADVANCED RENEWABLE case the additional investment cost is estimated to be at around billion $7.6 compared to REFENCE case, the fuel cost saving would add up to billion $2.4 without the transport sector and billion $8.1including transport fuel cost savings. Just like in the RENEWABLES case, the ADVANCED case leads to fuel cost savings with will more than re-finance investment cost for renewable power generation.

Tanzania Energy Access Scenario

The Energy-Access-Scenario (EAS) aims to increase access to energy – especially electricity – for all by 2050 while increase the electrification and comfort standard to the level of industrialized countries.
The growing economy requires 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 organized "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 start-up companies such as "Mobisol" and/or "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 further household and consumer appliances. However currently this development is not coordinated with national grid expansion plans of the Tanzania government. The project aims to develop a technical and economic concept as well as 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 distribution power grid; equal to those in industrialized countries. As the last and 3rd step, distribution grids will be interconnected to transmission grid.

  The industry will continue and expand onside power generation (auto producer) 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 industrialized 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 starting from very basic needs such as light and mobile phone charging towards a household-standard of industrialized countries. In order to phase-out unsustainable biomass for cooking, it is assumed to leapfrog from cook stoves directly to electrical cooking. The third phase of a rural household includes electric oven, fridge, a washing machine, air-condition and entertainment technologies and aims to provides the same level of comfort as households in urban areas in industrialized countries. An adjusted level of comfort for households in the city and in rural areas aims to prevent - especially young people - from leaving their homeland and moving into big cities. Rapidly expanding cities proved to be problematic, as infrastructure for transport and energy supply as well as required residential apartment buildings cannot match the demand, which often leads social tensions.

Table 3: Equipment per household type – assumptions for all scenarios

	Rural - Phase 1	Rural - Phase 2	Rural - Phase 3	Urban - Single	Urban/Shared App.	Urban - Family 1	Urban - Family 2	Suburbia 1	Suburbia 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 Maschine	0	1	1	1	1	1	1	1	1
Dryer	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 applicances	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 from the Ministry of Energy and Mineral (MEM), and National Bureau of Statistics in December 2016, 67.3% of Tanzania's households have access to electricity. The percentage varies significantly between urban households (97.3%) and rural households (49.3%)[14].

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

The development of the country wide share of various household types is presented in Table 5. The electrification starts with basic households' types such as rural phase 1, urban family 1 and suburbia 1 and moves to better equipped ones. Thus, the shares of full equipped households grow constantly while the basic once 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 industrialized countries and developing country and to achieve 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%

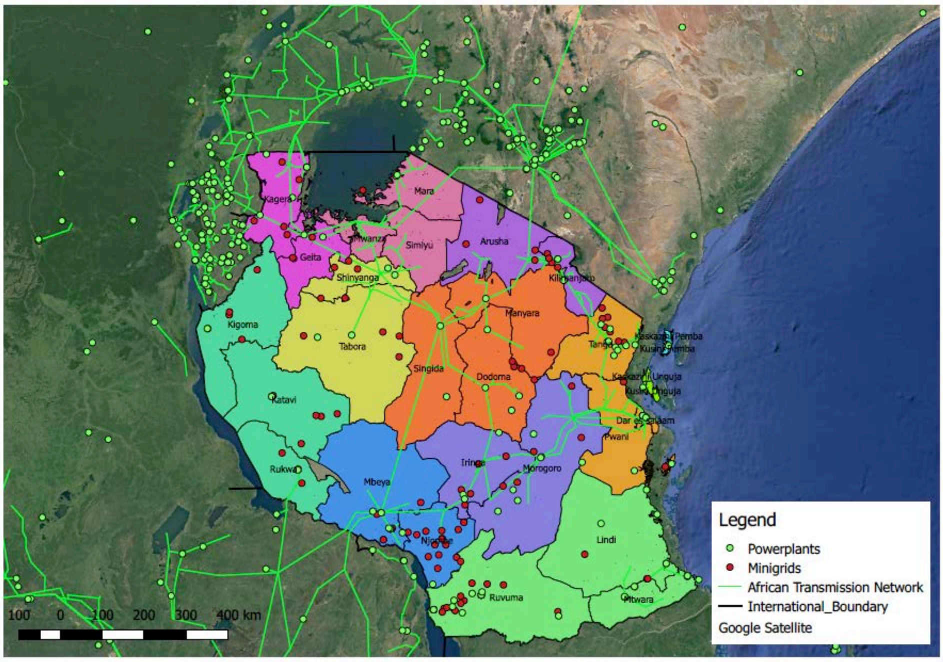
ENERGY ACCESS SCENARIO – REGIONAL BREAKDOWN INFRASTRUCTURE AND RENEWABLES

For regional modelling, the following 8 regions have been allocated (see Figure 8):

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 Zanziba Island
7. Southern Zone: Ruvuma
8. Central/Capital: Dodoma and Singida

[14] 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 8: Regional breakdown for this project



Source: ISF mapping, August 2017

Figure 9: Existing Electricity Infrastructure by type

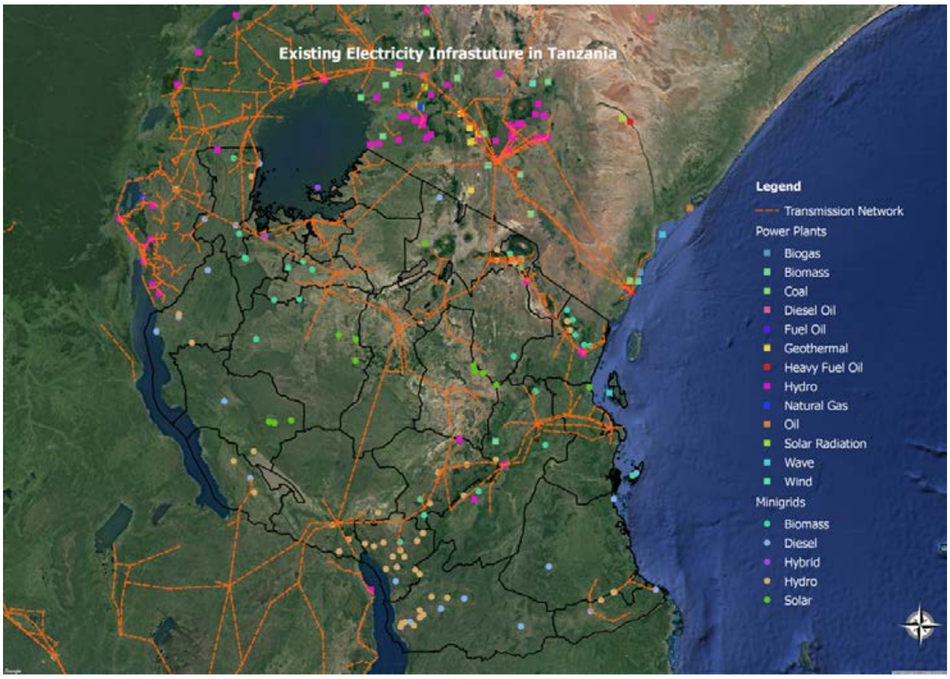


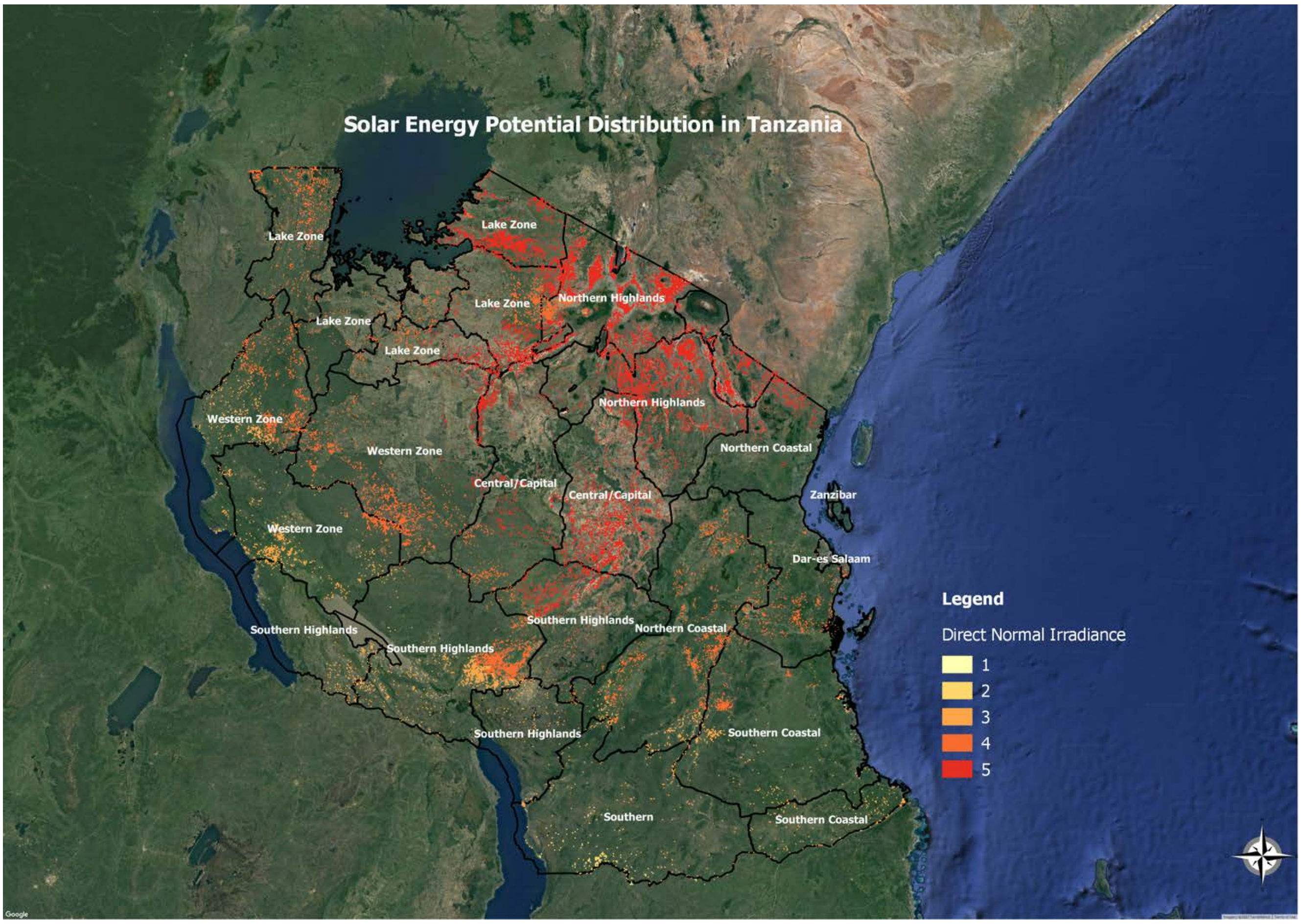
Figure 9 shows the existing energy infrastructure in Tanzania. The Energy Access Scenario will significantly expand renewable supplied mini grids and interconnect them with each other in a first step and join them as a “bottom-up build distribution grid” with the transmission grid at a later stage, starting around 2030. This accelerates the expansion of the power grid significantly as the grid “grows together from the distribution and from the transmission level at the same time.

Regional Distribution of solar and wind resources

Tanzania has almost 72,850 km^2 of available land where 1821 GW solar power can be potentially harvested through utility scale solar farms. In order to avoid conflict with competing uses of land, only land cover types of bare soil, perennial cropland and open bushland were included in the analysis. Both, utility scale solar photovoltaic and concentrated solar power (CSP) are included in this analysis. CSP would be built in region with the highest direct normal irradiance, which accounts for approximately 15% to 20% of this area. In Table 7 it is assumed that 80% of the suitable area will be used for utility scale solar photovoltaic and 20% for concentrated solar power.

Less than 5% of these needs to be harvested to meet the current and future energy needs of the country, thus offering a large variety of options for interested investors to set up renewable energy plants.
Figure 11 shows the distribution of potential sites that are ideal for setting up utility scale solar plants.

Figure 10 : Solar Energy Generation Potential in Tanzania

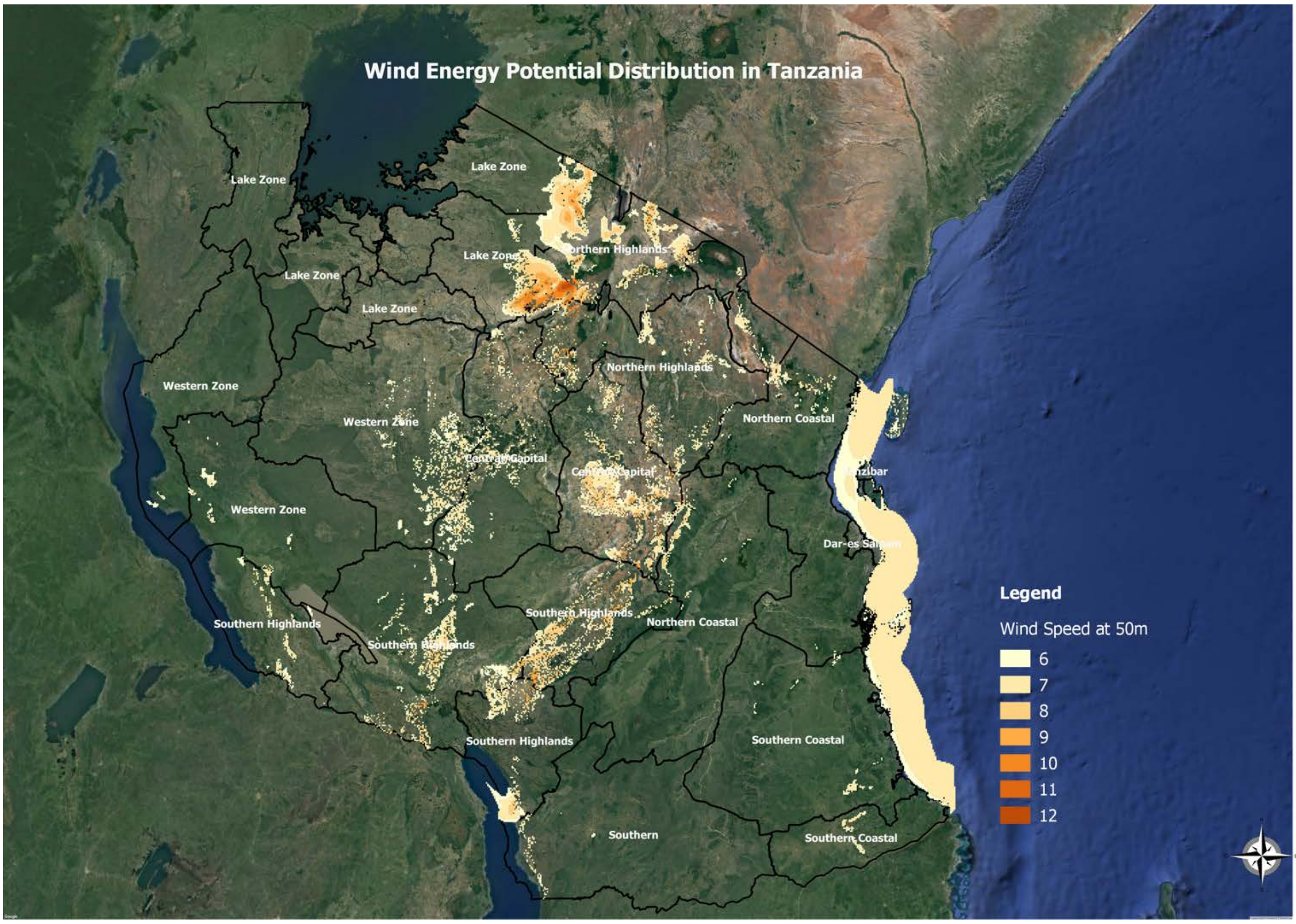


Source: ISF mapping, August 2017

The distribution of potential sites for optimal wind power generation is shown in Figure 12. The map highlights the large potential of land available for renewable energy generation.

There is a potential to install at least 447 GW of wind power (on- and offshore) from sites spread over 89,400 km^2 across Tanzania. This analysis takes into account only wind speeds of 6m/s 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 50-60 km of the coast were included in the analysis. This leads to an estimated offshore wind potential of 150 GW. The onshore wind potential is therefore around 300 GW.
Only a small percentage of this needs to be tapped to meet the current and projected demands of the country.

Figure 11 : 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

Security of supply and storage requirements

The [R]E 24/7model calculates demand and supply by cluster and 4 different voltage level. The long-distance transmission grid (TA) serves as an interconnection across the country, while the regional transmission grid (TZ) connects to medium (DA) and finally to the low (DZ) voltage level.

Storage technologies – especially decentralized 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 decentralized application on the lowest voltage level, while pumped hydro power is likely to be connected to the medium or high voltage level.

Table 7 and Table 8 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 un-even 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 e.g. to balance demand and supply over a few hours or days, while hydro power is required for seasonal storage for e.g. wind power to bridge several weeks or months. Pumped hydro can also balance of demand and supply across regions as they are connected to transmission grid. The table shows a significant regional storage demand e.g. 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**	**2,626,003**	**3,868,288**	**15,379,317**

Table 9 and Table 10 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% across Tanzania.

Variable power generation in some region exceed demands while in other region generation cannot supply regional demand. The analysis does not include an optimization 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 seen as "limited dispatchable" renewable power generation. In 2050, the assumed CSP capacity for Tanzania is 13,875 MW and contribute to around on 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%**

2.1.1 DEMAND AND SUPPLY BY VOLATGE LEVEL

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

Figure 12: Demand and supply: Case South Eastern region – Transmission Zone / September 2050

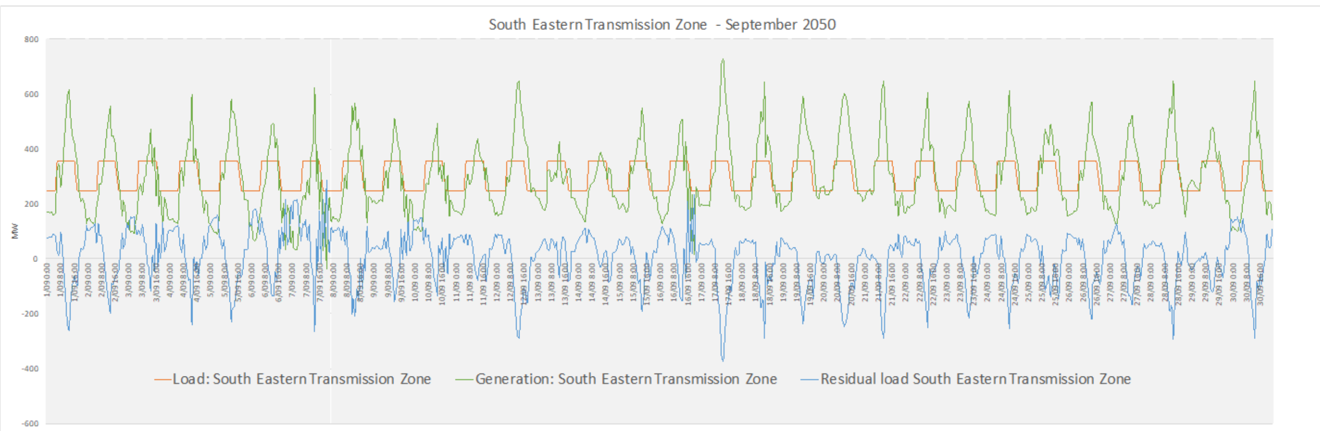


Figure 13 shows that the generation in the south-eastern region exceeds demand and that power generation capacity is exported. To allocate generation capacity where demand is highest and therefore power grid infrastructure must cope with high loads makes economic sense. Load centers therefore can also operate as a "power house" for the region and/or country.

Figure 13: Demand and supply: Case South Eastern region – Distribution Area / September 2050

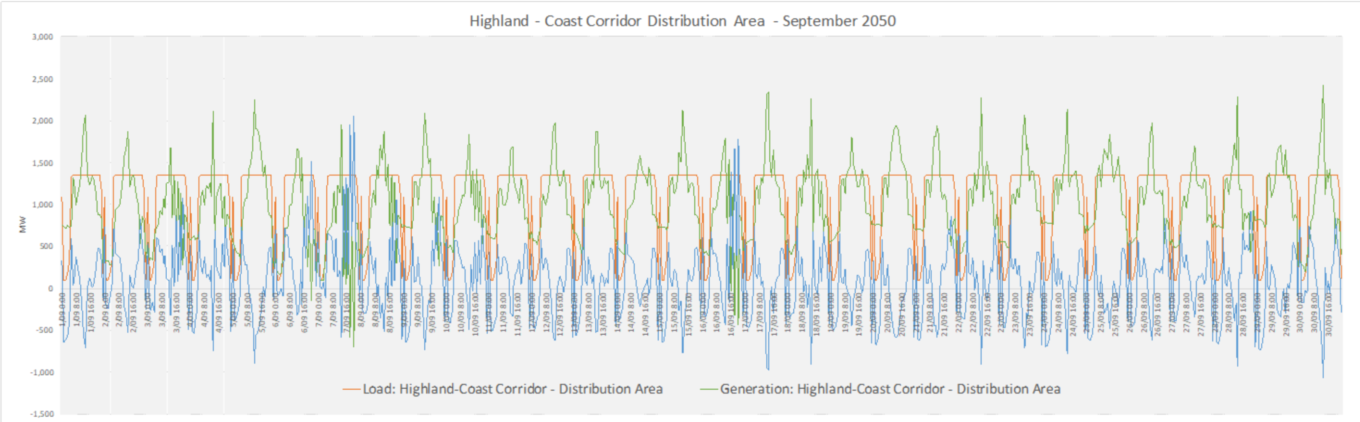
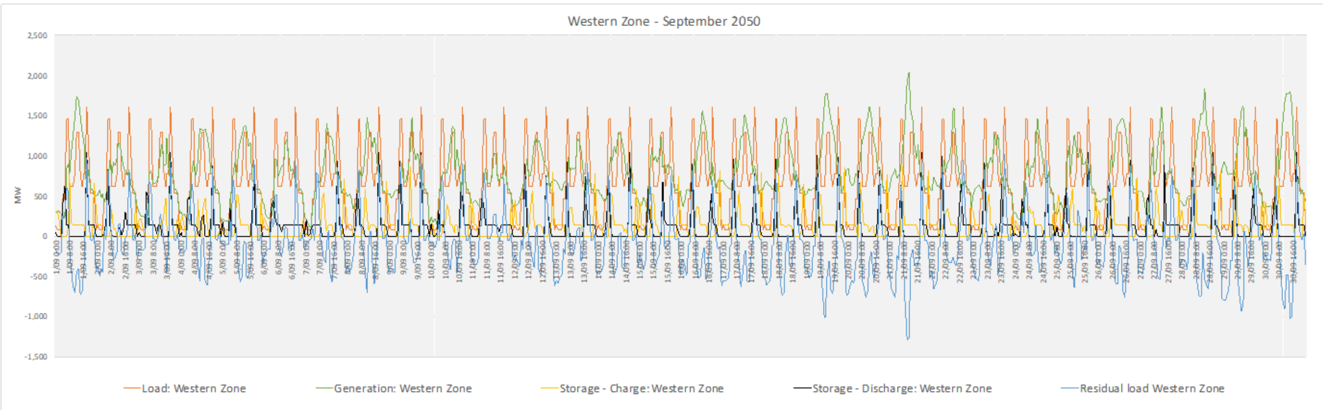


Figure 14 shows the same region as Figure 13 but for the distribution area. Demand and supply match better than at the transmission zone level and less over-supply is exported to other voltage levels. The mid-day peak is from solar photovoltaics while the evening generation peaks are from wind power.

Figure 14: 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 15. Battery storage shifts the mid-day generation peak to the early evening hours. Average load alternates between 1,500 MW and 700 MW, while the storage capacity oscillates between +/- 700 MW with frequent peaks at around 1000 MW. The installed solar photovoltaic capacity in this region is assumed with almost exactly 1,000 MW which correlates with the maximum storage demand. During the sample month of September 2050, the generation peak around the 21st 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 year has proven to be economically viable.

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% of total generation are sufficient. A regional distribution via an interconnected power grid can reduce storage demand as well as curtailment of variable renewable power generation However, the development of storage costs will have a huge influence whether or not all variable power generation will be stored, or whether the share of dispatchable renewable power generation will increased on the expense of variable power generation and storage.

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