

Appendix A: Additional Tables and Figures

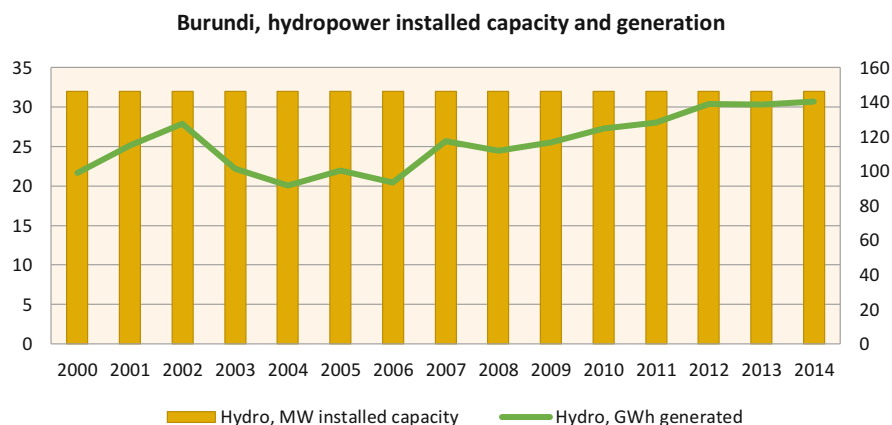
Burundi

Installed capacity and share of electricity generated, 2014 (AfDB)

Burundi	Installed capacity (MW)	Generation (GWh)
Total	41	304
Hydro	32 (78%)	253.3 (83.2%)
Thermal	9 (22%)	51 (16.8%)

Electricity consumption by sector, 2014 (UNdata)

Burundi	Sector's consumption (GWh)
Total	264.9
Manufacturing, construction and non-fuel industry	108.6 (41%)
Households	129.8 (49%)
Other	26.5 (10%)



Hydropower installed capacity and generation, 2000–2014 (UNdata)

Kenya

Installed capacity and share of electricity generated, 2014 (UNdata)

Kenya	Installed capacity (MW)	Generation (GWh)
Total	2094.4	9138.6
Hydro	797 (38%)	3569 (39%)
Geothermal	558 (26.6%)	2917.4 (31.9%)
Thermal	734.1 (35%)	2635.2 (29%)
Wind	5.3 (0.3%)	17 (0.2%)

Installed capacity and share of electricity generated, 2015 (Energy Regulatory Commission)

Owner	Fuel	Capacity (MW)	Generation (GWh)
KenGen	Hydro	820 (36.1%)	3308 (36.2%)
	Thermal	263 (11.6%)	492 (5.4%)
	Geothermal	488 (21.5%)	3104 (34%)
	Wind	25.5 (1.1%)	37.7 (0.4%)
	Sub-total	1596 (70.3%)	6943 (76%)
REA (Off-grid)	Thermal	18 (0.9%)	35.1 (0.4%)
	Solar	0.569 (0.03%)	0.9 (–)
	Wind	0.55 (0.02%)	0.003 (–)
	Sub-total	19 (0.8%)	36 (0.4%)
IPPs	Thermal	516.82 (22.8%)	1188.9 (13%)
	Small hydro	0.814 (0.04%)	2.1 (0.02%)
	Geothermal	110 (4.9%)	955 (10.5%)
	Biomass	26 (1.2%)	14 (0.2%)
	Sub-total	654 (28.8%)	2160 (23.6%)
	Total	2269	9139

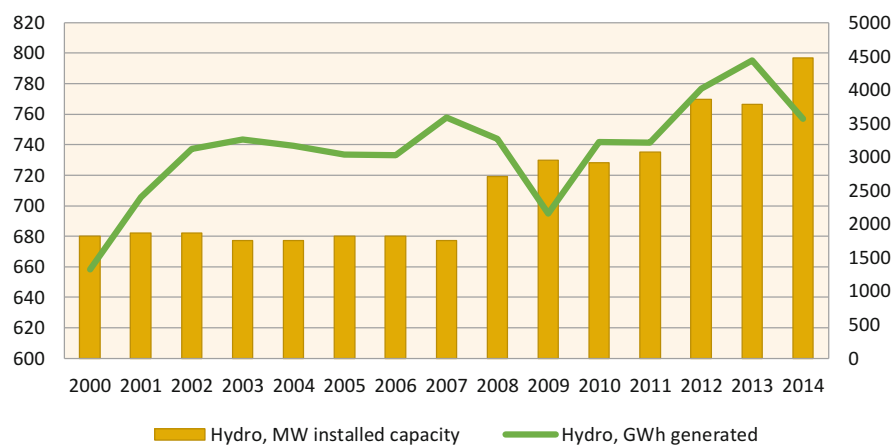
Electricity consumption by sector, 2014 (UNdata)

Kenya	Sector's consumption (GWh)
Total	7785.7
Food and tobacco	293 (3.8%)
Other industries	3695 (47.5%)
Households	1947.2 (25%)
Commercial and public services	1485.6 (19.1%)
Other	364.9 (4.7%)

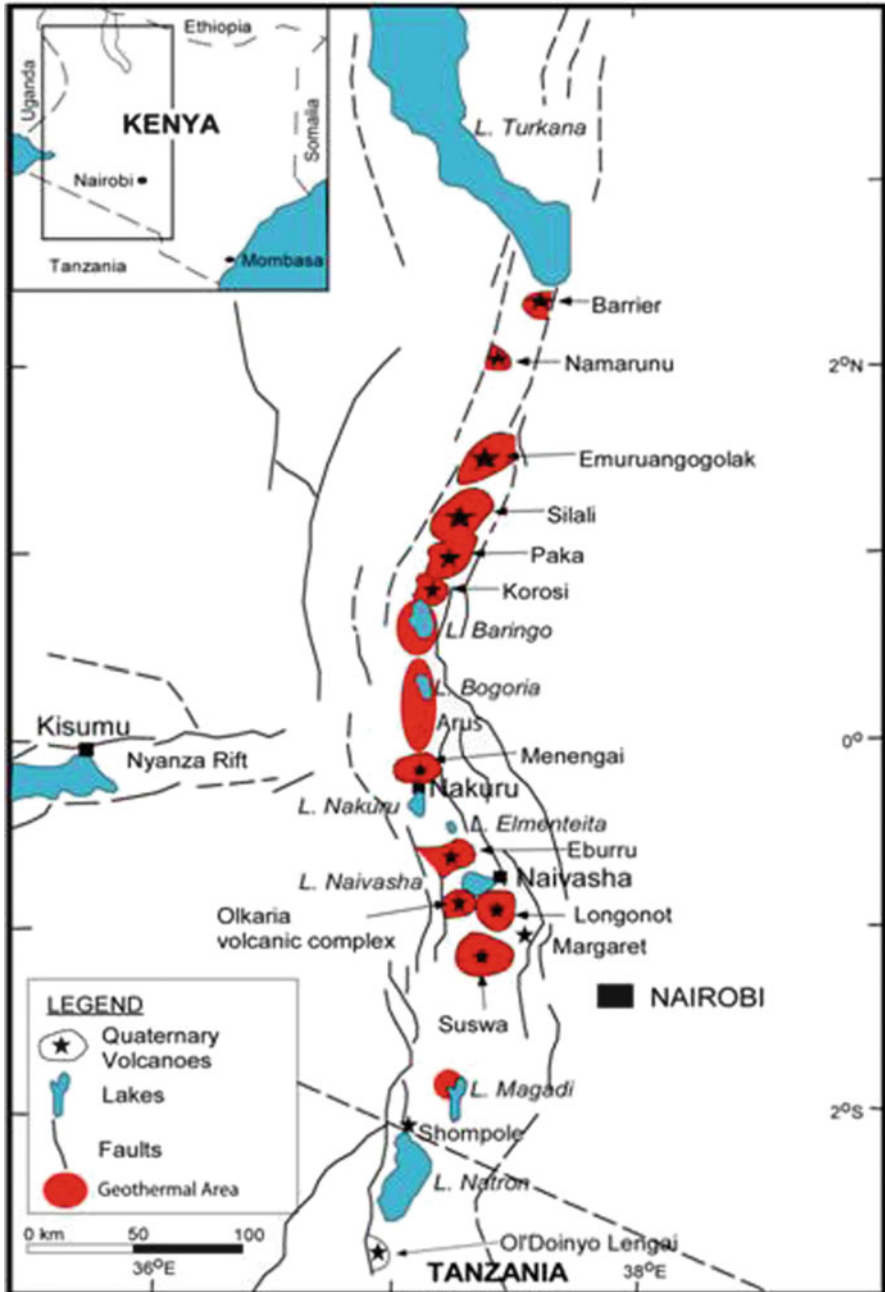
Electricity consumption by customer type, 2015 (ERC)

Type of customer	Sales (GWh)
Domestic	1866 (26.3%)
Small commercial	1143 (16.1%)
Commercial and industrial	4030 (56.8%)
Off-peak (interruptible)	15 (0.2%)
Street lightning	35 (0.5%)
Total	7090

Kenya, hydropower installed capacity and generation



Hydropower installed capacity and generation, 2000–2014 (UNdata)



Geothermal potential in Kenya (Kenya Energy Regulatory Commission)

Malawi

Installed capacity and share of electricity generated, 2014 (UNdata)

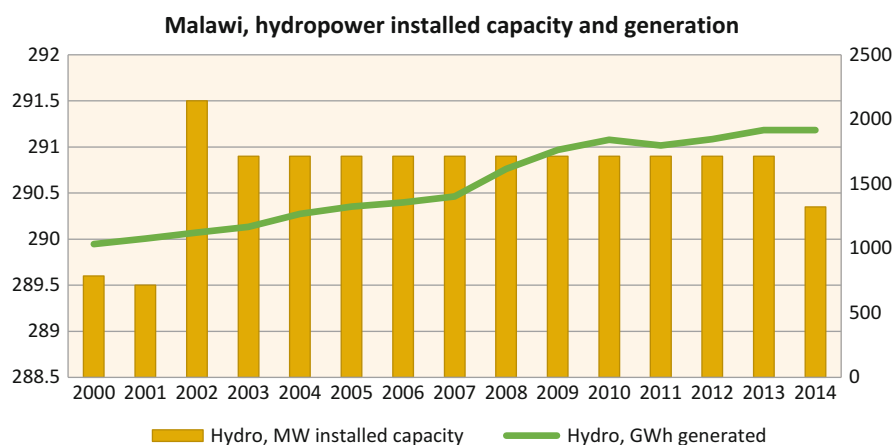
Malawi	Installed capacity (MW)	Generation (GWh)
Total	501.45	2097.51
Hydro	290.35 (57.9%)	1916.5 (91.4%)
Thermal	211.1 (42.1%)	181.01 (8.6%)

Installed capacity as of ESCOM site table (2017)

Name	Capacity (MW)	Type
Kapichira Falls	129.6	Hydro
Nkula	124	Hydro
Tedzani	92.7	Hydro
Wovwe Mini Hydro	4.35	Hydro
Mzuzu Diesel Unit	1.1	Diesel
Likoma Islands Diesel Units	1.05	Diesel
Chizumulu Islands Diesel Units	0.3	Diesel
Total	353.1	

Electricity consumption by sector, 2014 (UNdata)

Malawi	Sector's consumption (GWh)
Total	1779
Manufacturing, construction and non-fuel industry	570 (32%)
Households	550 (30.9%)
Commercial and public services	230 (12.9%)
Other	429 (24.1%)



Hydropower installed capacity and generation, 2000–2014 (UNdata)

Mozambique

Installed capacity and share of electricity generated, 2014 (UNdata)

Mozambique	Installed Capacity (MW)	Generation (GWh)
Total	2682.4	17,739
Hydro	2322 (86.6%)	16,358.8 (92.2%)
Thermal	359 (13.4%)	1379 (7.8%)
Solar	1.36 (0.06%)	1.2 (0.01%)

Installed capacity available to Electricidade do Moçambique, 2015 (World Bank)

Project	Source	Installed capacity (MW)
Total		679 ^a
HCB firm	Hydro	300
HCB non-firm	Hydro	200
Mavuzi	Hydro	52
Chicamba	Hydro	44
Corumana	Hydro	16
Pequenes Libombos	Hydro	2
Sub-total	Hydro	614 (90.4%)
Aggreko	Gas	15
Aggreko 2	Gas	32
Aggreko (Nacala)	Diesel	18
Sub-total	Thermal	65 (9.6%)

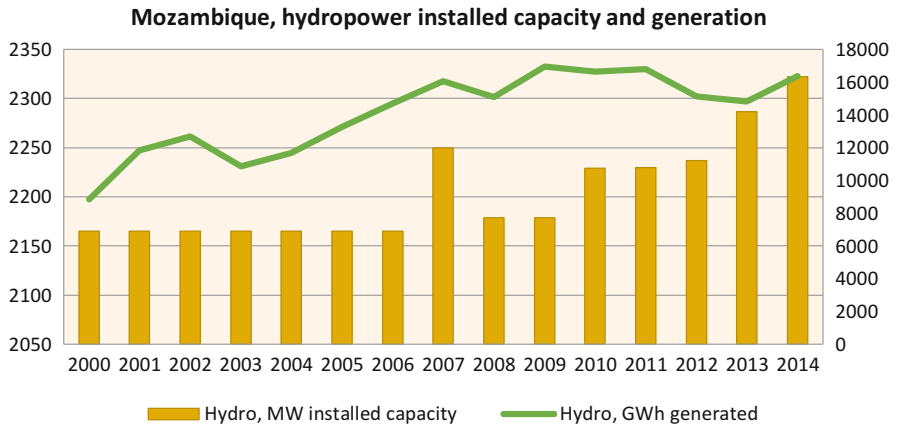
^aThis figure excludes the exports of electricity generated at Cahora Bassa dam to South Africa

Electricity consumption by sector, 2014 (UNdata)

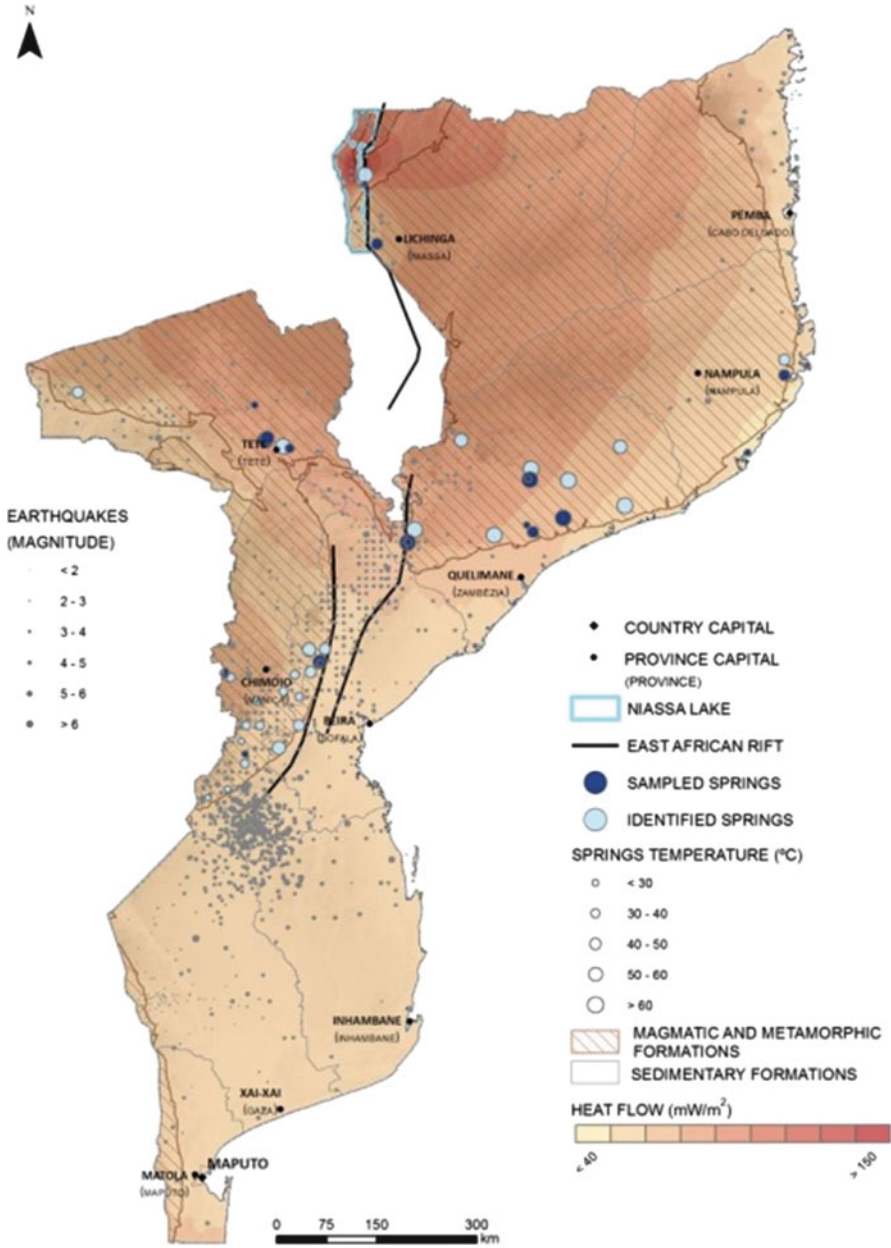
Mozambique	Sector's consumption (GWh)
Total	12,342
Non-ferrous metals	8764 (71%)
Other industry	1887 (15.3%)
Households	1629 (13.2%)
Agriculture, forestry and fisheries	2.32 (0.02%)
Commercial and public services	60 (0.5%)

Electricity consumption by customer type, 2014 (World Bank)

Type of customer	Sales (GWh)
Total	3620
Transmission connected customers	371 (10.3%)
Residential customers	1536 (42.4%)
Commercial	345 (9.5%)
Agriculture	27 (0.7%)
Large customers low voltage	182 (5%)
Large customers medium/high voltage	1159 (32%)



Hydropower installed capacity and generation, 2000–2014 (UNdata)



Geothermal potential in Mozambique (Energy Atlas Mozambique 2014)

Rwanda

Installed capacity and share of electricity generated, 2014 (UNdata)

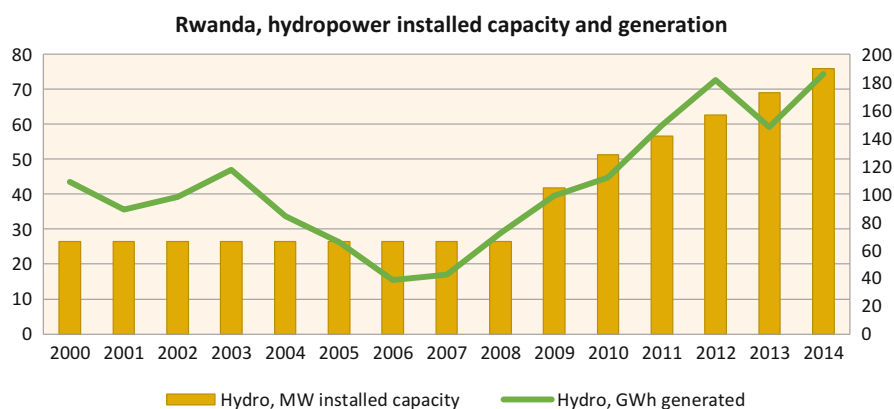
Rwanda	Installed capacity (MW)	Generation (GWh)
Total	118.6	476.1
Hydro	76 (64.1%)	185.8 (39%)
Thermal	42 (35.4%)	290 (60.9%)
Solar	0.6 (0.5%)	0.3 (0.6%)

Evolution of installed capacity (MW) in Rwanda, 2010–2016 (Rwanda Energy Group)

Rwanda	2010	2011	2012	2013	2014	2015	2016
Total (MW)	84.9	90.3	100.3	104.1	140.6	170.6	174.6
Hydro	43.3	48.6	48.6	52.4	80.4	80.4	84.4
Diesel	37.8	37.8	47.8	47.8	47.8	51.8	51.8
Gas	3.6	3.6	3.6	3.6	3.6	29.6	29.6
Solar	0.3	0.3	0.3	0.3	8.8	8.8	8.8

Electricity consumption by sector, 2014 (UNdata)

Rwanda	Sector's consumption (GWh)
Total	438.3
Manufacturing, construction and non-fuel industry	82.9 (18.9%)
Households	355.4 (81.1%)



Hydropower installed capacity and generation, 2000–2014 (UNdata)

South Africa

Installed capacity and share of electricity generated, 2014 (UNdata)

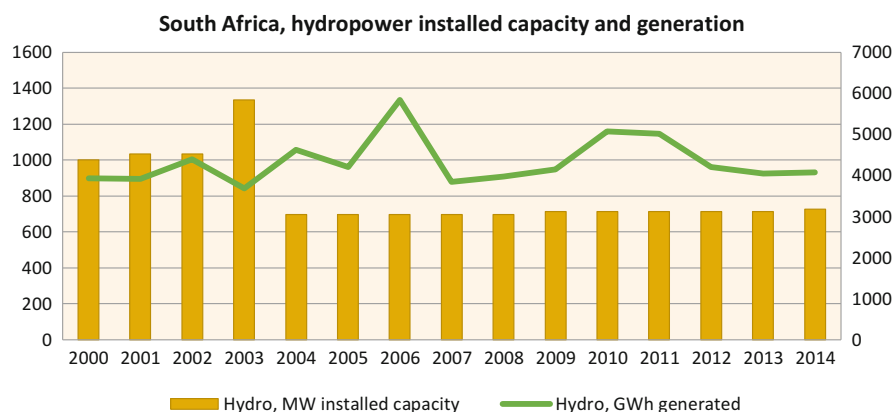
South Africa	Installed capacity (MW)	Generation (GWh)
Total	46,963	252,578
Nuclear	1880 (4%)	13,794 (5.5%)
Hydro	725 (1.5%)	4082 (1.6%)
<i>(of which pumped)</i>	<i>411 (0.9%)</i>	<i>3107 (1.2%)</i>
Thermal	43,538 (92.7%)	232,512 (92.1%)
Wind	450 (1%)	1070 (0.4%)
Solar	370 (0.8%)	1120 (0.4%)

Eskom installed capacity as of February 2017 (Eskom)

Coal-fired stations	Nuclear station
Arnot: 2352 MW	Koeberg: 1940 MW
Camden: 1561 MW	Conventional hydro stations
Duvha: 3600 MW	Gariep: 360 MW
Grootvlei: 1180 MW	Vanderkloof: 240 MW
Hendrina: 1893 MW	Pumped storage schemes
Kendal: 4116 MW	Drakensberg: 1000 MW
Komati: 990 MW	Palmiet: 400 MW
Kriel: 3000 MW	Ingula: 1332 MW
Lethabo: 3708 MW	Gas-fired stations
Majuba: 4110 MW	Acacia: 171 MW
Matimba: 3990 MW	Port Rex: 171 MW
Matla: 3600 MW	Ankerlig: 1338 MW
Medupi: 794 MW (Unit 6)	Gourikwa: 746 MW
Tutuka: 3654 MW	Windfarm: Sere: 100 MW

Electricity consumption by sector, 2014 (UNdata)

South Africa	Sector's consumption (GWh)
Total	198,093
Iron and steel	3698 (1.9%)
Chemical and petrochemical	11,314 (5.7%)
Non-ferrous metals	16,797 (8.5%)
Mining and quarrying	30,609 (15.5%)
Other manufacturing, constr. and non-fuel ind.	57,842 (29.2%)
Transport (Rail)	3172 (1.6%)
Transport (Other)	601 (0.3%)
Households	37,777 (19.1%)
Agriculture, forestry, fishing	5562 (2.81%)
Commercial and public services	27,455 (13.9%)
Other	3266 (1.7%)



Hydropower installed capacity and generation, 2000–2014 (UNdata)

Tanzania

Installed capacity and share of electricity generated, 2014 (UNdata)

Tanzania	Installed capacity (MW)	Generation (GWh)
Total	1115	6219
Hydro	561.8 (50.4%)	3611 (58.1%)
Thermal	546.2 (48.99%)	2590 (41.7%)
Solar	7 (0.63%)	18 (0.3%)

Installed capacity, 2014 (Ministry of Energy and Mineral)

Fuel	Installed capacity (MW)
Total	1583
Hydro	561 (35.4%)
Natural gas	527 (33.3%)
HFO ^a /GO ^b /Diesel	495 (31.3%)

^aHeavy fuel oil

^bGasoil

Installed capacity, 2016 (Ministry of Energy and Mineral)

Owner	Name	Capacity (MW)	Fuel
TanESCO	Hale	21	Hydro
	Nyumba Ya Mungu	8	Hydro
	Pangani Falls	68	Hydro
	Kidatu	204	Hydro
	Mtera	80	Hydro

(continued)

Owner	Name	Capacity (MW)	Fuel
	Uwemba	0.843	Hydro
	Kihansi	180	Hydro
IPPs	Mwenga	4	Hydro
	Mapembasi	10	Hydro
	EA Power	10	Hydro
	Darakuta	0.46	Hydro
	Yovi	0.96	Hydro
	Tulila	5	Hydro
	Ikondo	0.6	Hydro
	Mbangamao	0.5	Hydro
	Sub-Total	593.4 (42.69%)	
TanESCO	Ubungu 1	102	Gas
	Tegeta GT	45	Gas
	Ubungu 2	105	Gas
	Zuzu D	7	IDO ^a
	Nyakato	63	HFO ^b
	Kinyerezi	150	Gas
IPPs	Songas 1	42	Gas
	Songas 2	120	Gas
	Songas 3	40	Gas
	Tegeta IPTL	103	HFO
	TPC	17	Biomass
	TANWAT	2.7	Biomass
	Sub-Total	796.7 (57.31%)	
	Total	1390	

^aIndustrial diesel oil

^bHeavy fuel oil

Electricity consumption by sector, 2014 (UNdata)

Tanzania	Sector's consumption (GWh)
Total	4976
Manufacturing, construction and non-fuel industry	1270 (25.5%)
Households	2227 (44.8%)
Commercial and public services	1141 (22.9%)
Agriculture, forestry and fishing	180 (3.6%)
Other	158 (3.2%)

Electricity consumption by sector, 2015 (Ministry of Energy and Mineral)

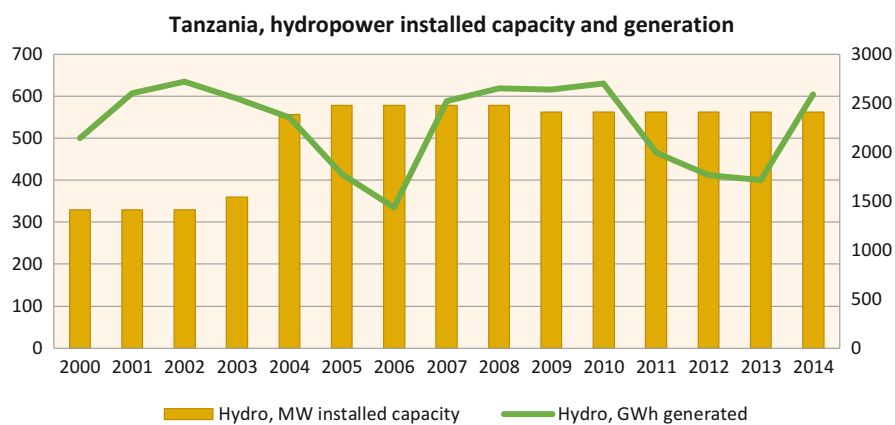
Sector	Consumption (GWh)
Total	6320
Industry	2410 (38.1%)

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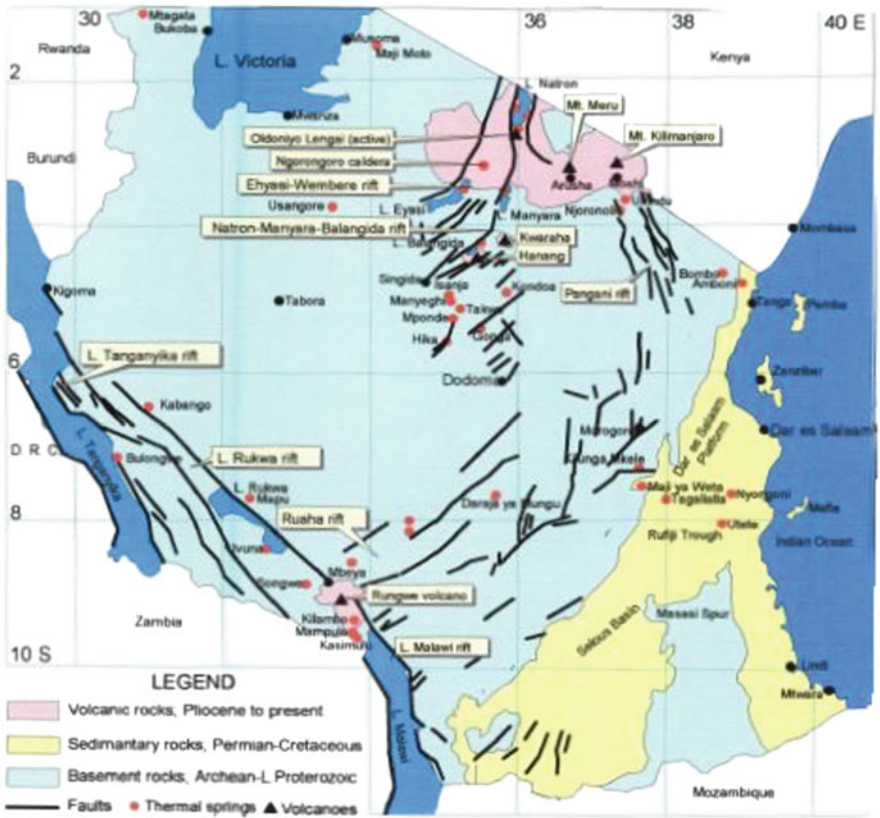
Sector	Consumption (GWh)
Commercial and services	300 (4.7%)
Zanzibar	340 (5.4%)
Gold	200 (3.2%)
Residential	1990 (31.5%)
T/D loss	1080 (17.1%)

Gas and coal plants under development, 2016 (Ministry of Energy and Mineral)

Name	Capacity (MW)	Fuel
Kynierezi I–IV	1355	Gas
Somanga/Somanga Fungu	860	Gas
Bagamoyo	200	Gas
Mtwara	318	Gas
Mchuchuma I–IV	600	Coal
Kwira I–II	400	Coal
Ngaka I–II	400	Coal



Hydropower installed capacity and generation, 2000–2014 (UNdata)



Geothermal potential in Tanzania (Geothermal Survey of Tanzania)

Uganda

Installed capacity and share of electricity generated, 2014 (UNdata)

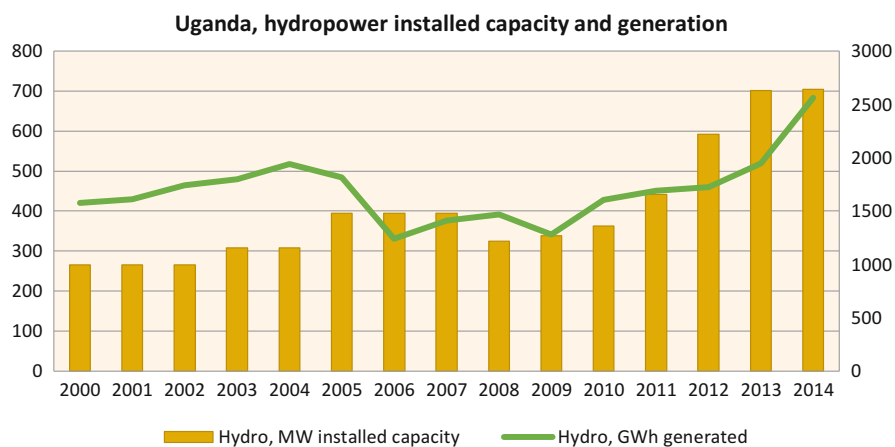
Uganda	Installed capacity (MW)	Generation (GWh)
Total	883.3	3257.7
Hydro	705 (79.8%)	697.1 (21.4%)
Thermal	178.3 (20.2%)	2560.6 (78.6%)

Installed capacity and share of generated electricity, 2017 (Electricity Regulatory Authority)

Uganda	Installed capacity (MW)	Generation (GWh)
Total	947	3856
Hydro	700 (73.9%)	3441 (89.2%)
Thermal	140 (14.8%)	242 (6.3%)
Biomass	96 (10.1%)	150 (3.9%)
Solar	11 (1.2%)	23 (0.6%)

Electricity consumption by sector, 2014 (UNdata)

Uganda	Sector's consumption (GWh)
Total	2416.9
Iron and steel	1068.8 (44.2%)
Other industries	533.2 (22.1%)
Households	519.4 (21.5%)
Commercial and public services	287.5 (12%)
Other	8 (0.3%)



Hydropower installed capacity and generation, 2000–2014 (UNdata)

Appendix B: Methodology and Parameters of the Electrification Analysis

Input datasets and sources

Dataset	Description	Source
Administrative boundaries	National administrative boundaries to define the spatial extent and crop other datasets	Database of Global Administrative Areas (2018)
Digital elevation	Elevation (in meters)	NASA LP DAAC (2011)
Small hydropower potential	Position, potential (MW)	Korkovelos et al. (2017)
Land cover	Categories of predominant land-cover define land suitability for installing different generation technologies	Channan et al. (2014)
Night-time lights	Employed to calibrate the population without access	NASA (2017)
Population	Number and position of the population within national boundaries	WorldPop/Linard et al. (2012)
Roads	Employed to calibrate the population without access	CIESIN and ITOS (2013)
Slope	Calculated from DEM datasets	Authors' elaboration
Solar PV potential	Global horizontal irradiation to calculate solar PV potential	SolarGIS (2017)
Solar restrictions	Calculated from land cover dataset to restrict PV installation in certain land settings (e.g. cropland and water bodies)	Authors' elaboration
Electricity substations	Employed to calibrate the population without access	Energydata.info (2018)
Current and planned electricity transmission network	Employed to define the cost and potential for new connection and grid extension	Arderne/World Bank (2017)

(continued)

Dataset	Description	Source
Travel time to the nearest 50,000+ city	Defined to calculate the LCOE of diesel	Weiss et al. (2018)
Wind potential	In m/s, used to calculate the wind power capacity factor	DTU/Global Wind Atlas (2017)

Common user-defined parameters

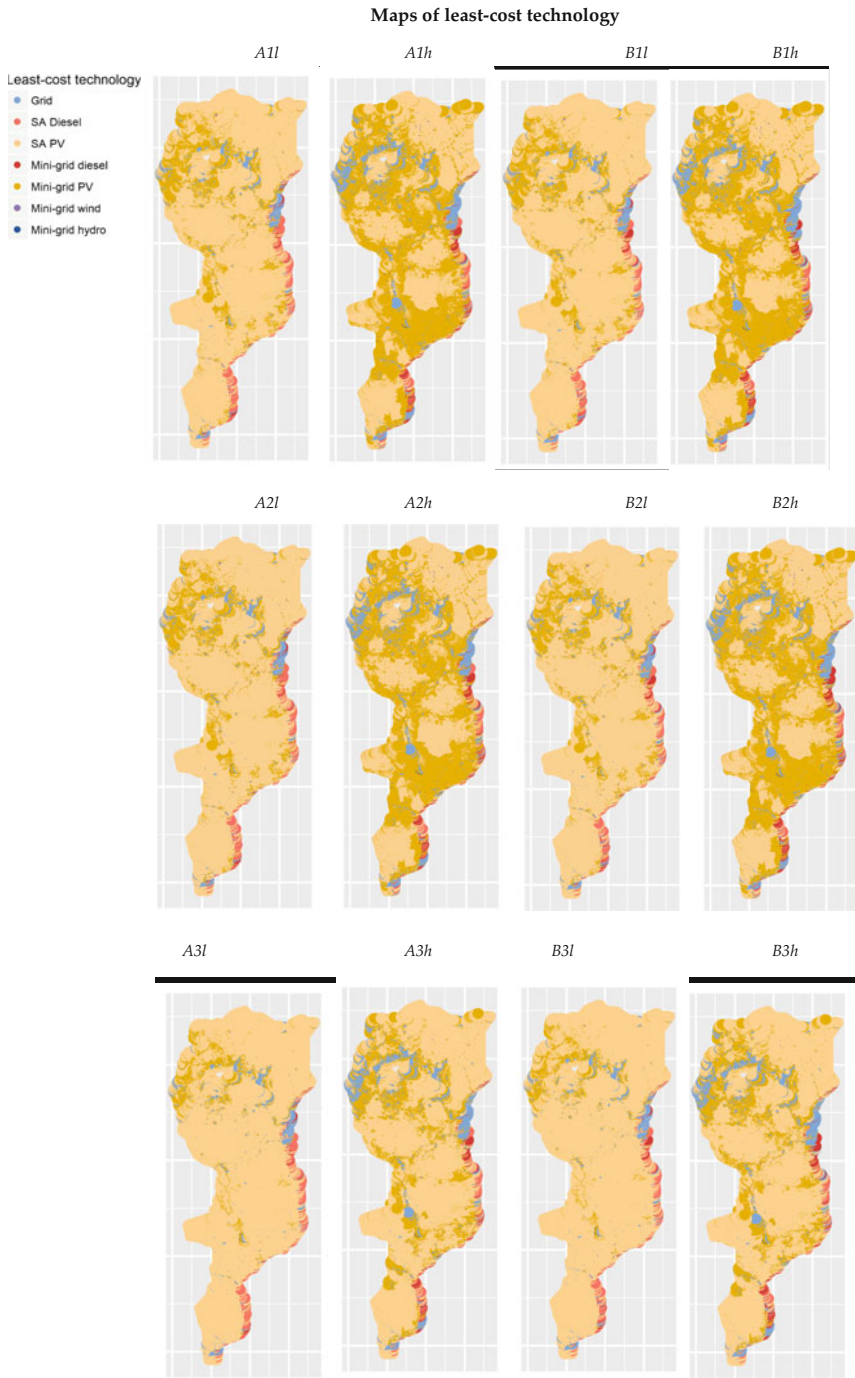
Parameter	Description	Value
Discount rate	To weight results from the present generation's perspective (relatively less importance is given to the future)	10% ^a
MV line cost (USD/km)	1–66 kV	6000 USD
LV line cost (USD/km)	<1 kV	3000 USD
HV line cost (USD/km)	>66 kV	30,000 USD
HV to LV transformer cost (USD/unit)	Cost of a transformer between transmission and distribution grid	4000 USD
Grid connection cost per household	The average charge to be borne by a household (unless a subsidy policy is in place) to get grid electricity at home	450 USD
Operation and maintenance costs of transmission and distribution lines as % of capital costs	Share of O&M costs over the total capital costs to be borne by the electricity supply company for grid O&M	5%
Grid capacity investment (USD/kW of on-grid added capacity excluding the grid itself)	The public or private average investment required to add new capacity to the national grid-connected electricity generation	Country-level, depending also on generation mix considered. Average of 2000 USD/KW
Diesel gen-set mini grid investment cost	Average unit (per kW) cost of installing, operating and maintaining the system	721 USD/kW + 10% O&M costs (% of investment cost/year)
Small hydro mini grid plant	Average unit (per kW) cost of installing, operating and maintaining the system	5000 USD/kW + 2% O&M costs (% of investment cost/year)
Solar PV mini grid	Average unit (per kW) cost of installing, operating and maintaining the system	3200 USD/kW + 1.5% O&M costs (% of investment cost/year)
Wind turbines mini grid	Average unit (per kW) cost of installing, operating and maintaining the system	3000 USD/kW + 2% O&M costs (% of investment cost/year)
Diesel standalone investment cost	Average unit (per kW) cost of installing, operating and maintaining the system	938 USD/kW + 10% O&M costs (% of investment cost/year)

Pueyo et al. (2016)

Country-specific parameters

Country	Pop (mil.)	Urban pop (%)	Pop 2030 (mil.)	Urban pop. 2030 (%)	People per HH, rural	People per HH, urban	Grid capacity inv. cost (USD/kW)	Grid losses (%)	Electr. rate (%)
Burundi	10.20	12.06	17.36	35	5	3.5	2200	17.65	8
Kenya	47.24	25.62	65.41	35	4.5	5	1700	17.50	64.5
Malawi	17.57	16.27	26.58	30	6	4	2000	17.65	11.3
Mozambique	28.01	32.21	41.44	50	5.5	4	2000	14.70	28.6
Rwanda	11.63	28.81	15.78	40	4.5	3.5	2000	17.65	30.0
Tanzania	53.88	31.61	82.93	50	5.5	4	1700	17.65	32.7
Uganda	40.14	16.10	61.93	35	5	3.5	2000	17.65	19.4

All the remaining technical and economic parameters (e.g. technology investment costs, efficiency factors) for each technology were left as default in the model (refer to Mentis et al. 2017, to the OnSSET documentation, and to the model code)



Maps of least-cost technology

References

- Center for International Earth Science Information Network—CIESIN—Columbia University, Information Technology Outreach Services—ITOS—University of Georgia (2013) Global Roads Open Access Data Set, Version 1 (gROADSv1). NASA Socioeconomic Data and Applications Center (SEDAC), Palisades, NY
- Channan S, Collins K, Emanuel WR (2014) Global mosaics of the standard MODIS land cover type data. University of Maryland and the Pacific Northwest National Laboratory, College Park, MD
- DTU Technical University of Denmark (2017) Global wind Atlas. Retrieved from <http://globalsolaratlas.info/api/download>
- Energydata.info (2018) Energydata.info. <https://energydata.info>
- Korkovelos A, Mentis D, Hussain Siyal S, et al (2017) A geospatial assessment of mini/small hydropower potential in Sub-Saharan Africa, p 6825
- Linard C, Gilbert M, Snow RW, et al (2012) Population distribution, settlement patterns and accessibility across Africa in 2010. PLoS One 7:e31743. doi: <https://doi.org/10.1371/journal.pone.0031743>
- Mentis D, Howells M, Rogner H et al (2017) Lighting the world: the first application of an open source, spatial electrification tool (OnSSET) on Sub-Saharan Africa. Environ Res Lett 12:085003. <https://doi.org/10.1088/1748-9326/aa7b29>
- NASA LP DAAC (2011) ASTER global digital elevation map v2. <https://asterweb.jpl.nasa.gov/gdem.asp>. Accessed 6 Aug 2018
- Pueyo A, Bawakyillenuo S, Osiolo H (2016) Cost and returns of renewable energy in Sub-Saharan Africa: A comparison of Kenya and Ghana. IDS
- SolarGIS (2017) Potential solar PV output raster files. Retrieved from <https://solargis.com/maps-and-gis-data/download/>
- The World Bank (2017) World Bank Data. Accessed 20 Nov 2017
- Weiss DJ, Nelson A, Gibson HS et al (2018) A global map of travel time to cities to assess inequalities in accessibility in 2015. Nature 553:333–336. <https://doi.org/10.1038/nature25181>