Tanzania Journal of Engineering and Technology 2023, **42**(**3**):101-113
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Websites: https://ajol.org/tjet; https://tjet.udsm.ac.tz

ISSN 1821-536X (**print**); ISSN 2619-8789 (**electronic**)
https://doi.org/10.52339/tjet.v42i3.956

Regular Research Manuscript

Renewable Energy Potential Assessment for Improving Electric Power Availability in Urban Area: A Case of Msigani Ward in Ubungo Municipal, Tanzania

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ABSTRACT

The demand for electricity in urban areas of the developing countries like Tanzania is increasing rapidly due to factors such as increasing population, expansion of economic activities and industrialization. Msigani ward is one of the fourteen (14) administrative urban wards in Ubungo Municipal, Dar es Salaam, located at latitude 6.8031 °S and longitude 39.1188 °E. Recently, there has been observed increase in power demand in this ward. This in turn has caused a supply deficit that sometimes led to large number of interruptions caused by frequent power outage and load shedding. The total capacity of the national grid is limited by long-standing drought. Therefore, the study whose results have been presented in this paper, focused on the assessment of renewable energy resources potential comprising solar and wind that can be used in improving electric power availability in urban areas particularly in Msigani ward. Wind speed data and solar insolation level for a long term of the past twelve years (2010-2021) acquired from NASA Power Data Access Viewer were used in this study. The study considered the worst-case scenarios for monthly solar insolation and wind speeds in order to have sustainable energy system at the time of little wind or solar. Homer Pro software was used for simulation and optimization of renewable energy resources. The study revealed that there is enough potential of wind and solar which can generate electricity for Msigani ward and supplement to the national grid. The cost simulation shows that the system can provide a cost of energy (COE) of $0.0399 per kWh ≈ TZS 93.3 per kWh which is lower in comparison to the residential grid tariff of TZS 350/kWh for residential consumers using above 75 kWh per month.

ARTICLE INFO
First submitted: **June 29, 2023**

Revised: **Aug. 16, 2023**

Accepted: **Sep. 15, 2023**

Published: **Oct. 2023**

Keywords: *Renewable energy*; *power outage*; *wind speed*; *solar insolation*; *load demand*

INTRODUCTION

Electric energy is an essential factor in many sectors such as health, industries, education, agriculture, economic activities and social matters (Panhwar et al., 2017; Mondal & Denich, 2010). Any nation requires sufficient and reliable power supply for its development (Bataineh et al., 2014). Therefore, available and reliable power is required to satisfy energy requirements of the consumers for sustainable development (Oyedepo, 2014). The demand for electricity in urban areas of the developing countries like Tanzania is increasing tremendously. High demand causes a supply deficit which in turn leads to large number of interruptions that may cause frequent power outage. Renewable energy such as solar and wind are considered as reliable and sustainable energy sources and can be used to mitigate power outage (Khare et al., 2016).

Various researchers have studied about the technical and financial suitability of the Solar-Wind hybrid systems in either stand-alone or grid-connected system. As example, Castillo et al. covered the construction of a hybrid solar PV and wind turbine renewable energy system for house applications to obtain electric energy at low cost (Castillo et al., 2015). Their design expected to sustain some part of the daily domestic electricity consumption with an efficient utilization of solar and wind power. Another study by Singh et al. came up with a grid-connected solar-wind hybrid system to supply the electrical load demand of a small shopping complex located in India (Singh et al., 2021). In their study, it was determined that a cost-effective and reliable system can be designed by the proper management of renewable power generation and load demands. Another example, is the design of solar PV and wind hybrid system by Khan et al. that examined the techno-financial, and social viability of the solar PV and wind hybrid system for applications in the rural sites of the northern India (Khan et al., 2021). In most of the studies, the optimization was attained by performing techno-economic study with the help of the HOMER software. The results from these researchers indicate that it is feasible to invest in the solar PV and wind turbine hybrid system as the alternative approach to mitigate power outage caused by a supply deficit.

In the year 2022, Tanzania Electricity Supply Company Limited reported power outage at many places (TANESCO Limited, 2022). One of the places that experienced power outage was Msigani Ward. Msigani Ward is located in Ubungo Municipal, Tanzania. This ward experienced power outage mostly during the month of July, August and September 2022 (TANESCO Limited, 2022). Msigani ward being located in Dar es Salaam, where the place experiences sunlight and wind currents may have potential solar and wind resources for generation of electricity. This in turn may assist in mitigating the power outage at this ward. However, to date, there is no any study conducted on the assessment of the energy resources specifically solar and wind potentials for electricity generation. The solar and wind energy resources are dependent on the geographical locations. In this regard, it is difficult to copy directly the existing design of solar PV and wind turbine hybrid systems for implementation in Msigani Ward. This paper presents the techno-economic study for assessing the potential of solar and wind energy resources for electricity generation in Msigani Ward. The performance of renewable energy resources was assessed using past twelve years' weather data with the assumption that it will provide good benchmark.

MATERIAL AND METHOD

The optimization of the hybrid system was arrived by utilizing Homer Pro Software x64, 3.14.2 (Pro Edition). The Homer Pro Software requires input variables that include coordinates of the study area, load profile, energy resources (solar and wind) and system component specification that include the ratings, efficiencies, lifetime and costs. The costs include the initial cost and the operational cost.

Description of the study area

Msigani ward is one of the fourteen (14) administrative urban wards in Ubungo Municipal, Dar es Salaam, Tanzania. This area is connected to the national grid which its generation mainly depends on natural gas, hydro, Heavy Fuel Oil (HFO) and biomass. These sources are challenging because hydro power generation fluctuates during the time of drought. On the other hand, the cost of fuel and natural gas is relatively high. This in turn has caused Msigani ward to experience reduced availability of power supply due to power outages and load shedding.

Determination of the coordinates for the study area and renewable energy potentials

The assessment of renewable energy potential concentrated more on wind and solar energy resources which are available in the Msigani area. Global Navigation Satellite System (GNSS) equipment, Trimble Juno 3B was used to capture locational data (geographic coordinate) of the study area in the form of latitude and longitude. Msigani ward is located at the latitude of -6.8031°S, longitude of 39.1188 °E and at an altitude of 161 m above the sea level. These data were used in NASA power Data Access Viewer to get wind speed values and solar insolation levels for the period of 12 years. The longer time wind speed values and solar insolation levels are essential in evaluating the performance of hybrid renewable energy. Statistical application Microsoft Excel was used to analyze renewable energy (RE) data in order to obtain the maximum and average values, which are useful parameters for assessing renewable energy potential. Homer Pro Software x64, 3.14.2 (Pro Edition) was used for simulation of renewable energy resources.

Solar energy resources potential

The assessment of renewable energy potential is initial requirement prior to the design of renewable energy systems (Mondal & Denich, 2010). In this study, the assessment of solar energy potential was done using solar data acquired from NASA Power Data Access Viewer. Figure 1 shows the average solar insolation level and clearness index of the Msigani ward each year for the past twelve years.

As shown in Figure 1, over the considered period, i.e. from 2010 to 2021, there were not much difference in average values of the solar insolation and clearness index; however, through data reading from the graph, it can be observed that the worst-case scenarios for solar insolation and clearness index occurred in the year 2014 with the average values of 6.817 kWh/m^2/day and 0.556 respectively. This study has considered monthly solar insolation level and clearness index of the year 2014, which had the worst-case situation. This in turn helps to have an assurance of power availability even during a worst-case condition when there is little solar. The monthly solar insolation and clearness index for the year 2014 are indicated in Table 1. The performance of the solar system is estimated using past weather data in the assumption that it will provide good results. The lowest average insolation level was found during June 2014 which was about 5.848 kWh/m^2/day. The lowest clearness value of 0.483 was recorded in May 2014 which indicates that the atmosphere was fairly clear. According to NASA power, a good value of the clearness index ranges from 0.25 to 0.75. The solar insolation in Table 1 were used as input into HOMER Pro software for simulation and optimization of the developed hybrid model.

Table 1: Monthly solar insolation and clearness index for the year 2014

Month	Solar insolation (kWh/m^2/day)	Clearness index
January	7.303	0.598
February	7.116	0.504
March	7.208	0.509
April	6.823	0.531
May	6.244	0.483
June	5.848	0.547
July	5.929	0.561
August	6.417	0.586
September	6.958	0.565

Month	Solar insolation ($kWh/m^2/day$)	Clearness index
October	7.322	0.601
November	7.420	0.598
December	7.212	0.586

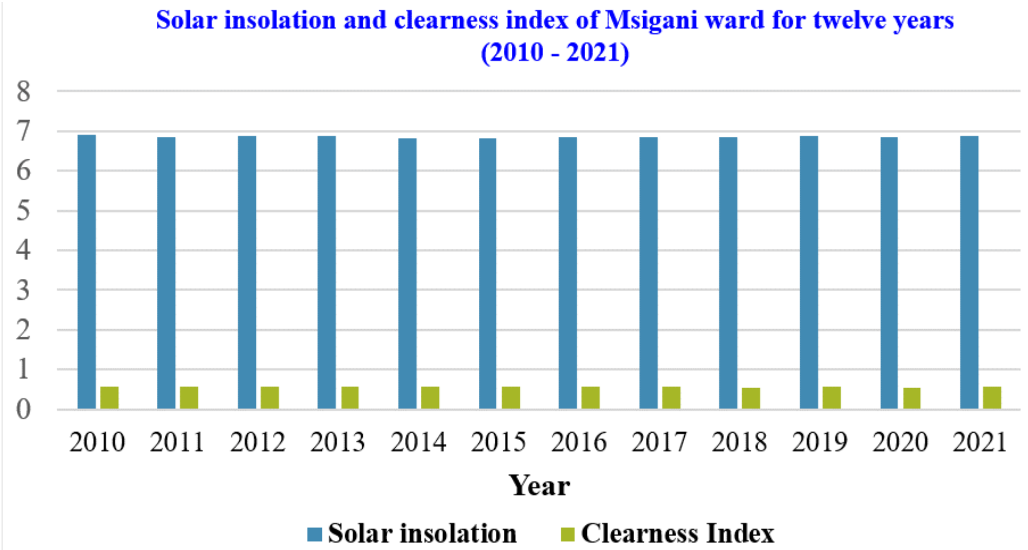


Figure 1: Solar insolation and clearness index for the past twelve years

Wind energy resource potential

Wind data for the determination of wind energy potential was obtained from the NASA power Data Access Viewer. The wind speed measurement was taken at the heights of 10 m and 50 m for a period of 12 years from 2010 to 2021. The maximum and minimum wind speed (m/s) at a height of 10 metres for the past twelve years are shown in Figure 2 and at the height of 50 metres are shown in Figure 3. Combined Maximum and minimum wind speed (m/s) at the heights of 10 metres and 50 metres are shown in Figure 4.

From Figure 4, it can be observed that wind speed at 50 m height is much higher than that at 10 m height. This implies that the higher the height, the greater wind energy potential. The optimization design in this study, has however, considered the year with the worst scenario of the average of the maximums wind speed at 50 m height. It was 7.258 m/s in the year 2011. This approach assures power availability even during a worst-case condition when there is little wind. It is also overcome the stochastic behaviour of wind resources and provides a robust design for sustainable energy. Maximum and minimum monthly wind speed based on the worse year 2011 at 50 m height is indicated in Table 2. Maximum monthly wind speeds based on the worse year 2011 at 50 m height as shown in Table 2 were used as input into Homer Pro software for simulation and optimization of the developed hybrid model.

Table 2: Maximum and minimum monthly wind speed (m/s) for the year 2011

Month	Max wind speed at 50m	Min wind speed at 50m
January	6.718	3.771
February	6.498	3.102
March	5.035	2.216
April	6.117	3.066
May	7.682	4.321
June	8.435	4.710
July	9.441	5.454
August	9.132	5.145
September	8.422	4.597

October	7.184	3.707
November	5.765	2.674
December	6.666	3.173

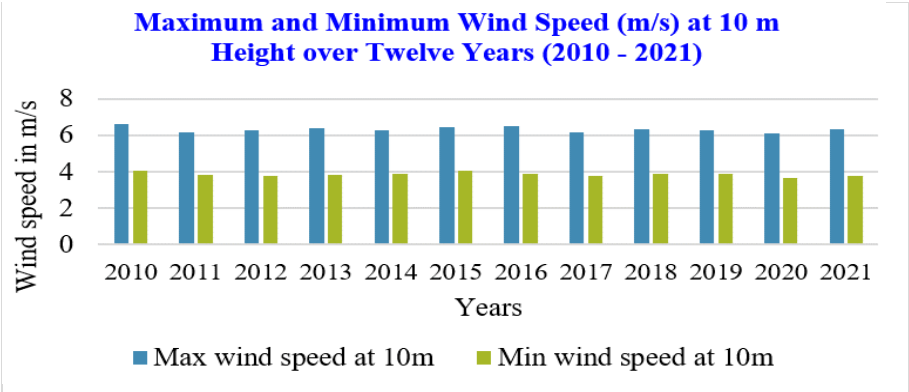


Figure 2: Maximum and minimum wind speed (m/s) at 10 metres height

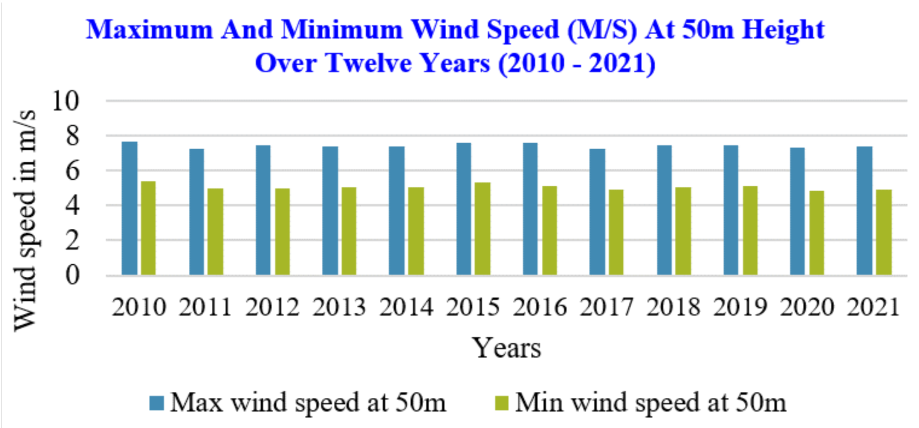


Figure 3: Maximum and minimum wind speed (m/s) at 50 metres height.

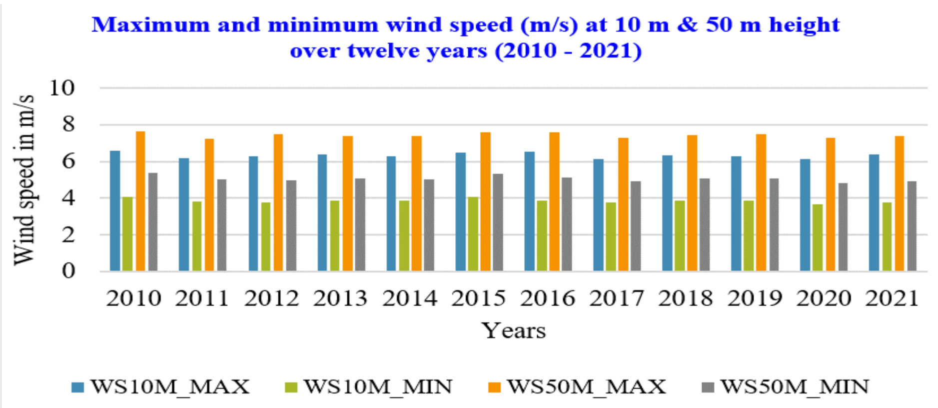


Figure 4: Combined maximum and minimum wind speed (m/s) at 10 m and 50 m height.

Electrical load profile of Msigani Ward

A load profile or load curve in electrical engineering is a graph of electrical load variation against time (Damayanti et al.,2017). It is a chart illustrating the variation in electrical load over a specific time. Load profile will fluctuate according to the load of the customers depending on the customer category such as residential, commercial and industries. This information is used by Power Utility to plan how much power to be generated to meet the requirement of the consumers. Sizing and modelling of Renewable Energy Systems (RES) can be achieved by using a load profile.

Based on the distribution network infrastructure and customer data provided by TANESCO from the Distribution GIS database as shown in Figure 5, distribution transformers feeding Msigani ward were identified using ArcGIS software. Distribution network data from the GIS database was overlaid with the Msigani map in ArcGIS software to identify distribution transformers feeding the Msigani ward as shown in Figure 6. The ratings of the distribution transformers and the number of customers per each transformer were extracted from the GIS database. It was found that Msigani ward is supplied by about 33 distribution of kVA rating ranging from 50 kVA to 500 kVA, giving the total of 7895 kVA. On the other hand, the determined real power rating was raging from 40 kW to 400 kW, giving a total real power of 6316 kW. The total connected customers were about 6327.

Data for energy demand, power consumption, current and voltage for the power line feeding the areas of Msigani ward were extracted from the boundary energy meter installed by TANESCO through Automatic Meter Reading (AMR) Centre (TANESCO Limited, 2022). The electrical load profile is presented in Figure 7 and energy consumption profile is presented in Figure 8.

The analysis shows that peak electricity demand of 3500 kW occurred between 16:00 hrs and 19:00 hrs. During this time, residents of Msigani ward return from work and the appliances such as television sets, refrigerators, radio sets, flat irons, and cookers are turned on. The low electricity demand below 2000 kW occurred between 22:00 and 02:00 hrs. At this time the residential load is low because residents are sleeping and therefore most of the appliances were turned off. The maximum energy consumption at Msigani ward was found to be 1,180 kWh. The load demand data will be an input to the development of a model for the grid-connected hybrid renewable energy system.

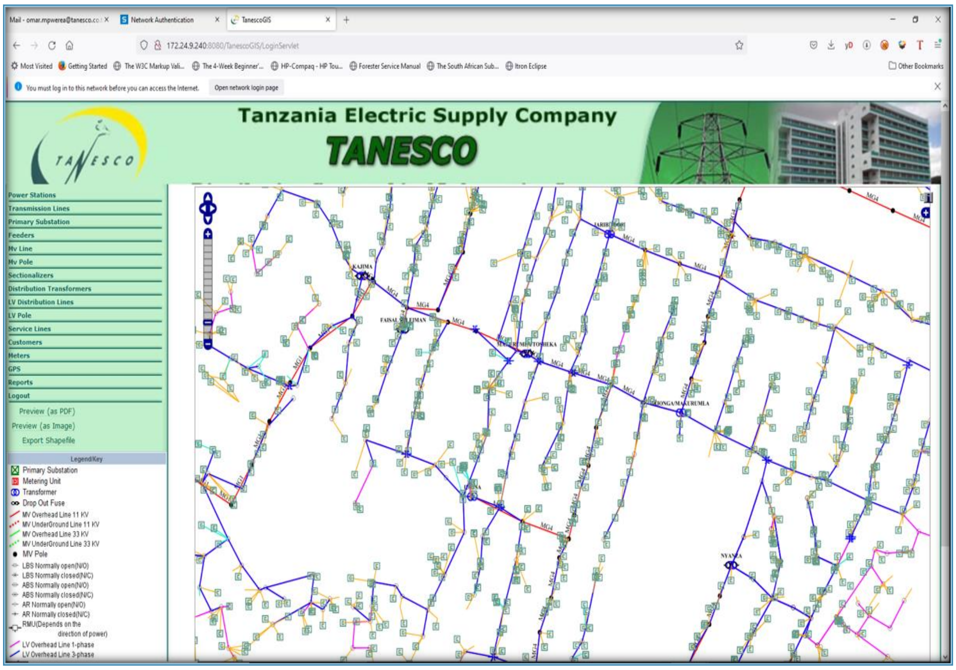
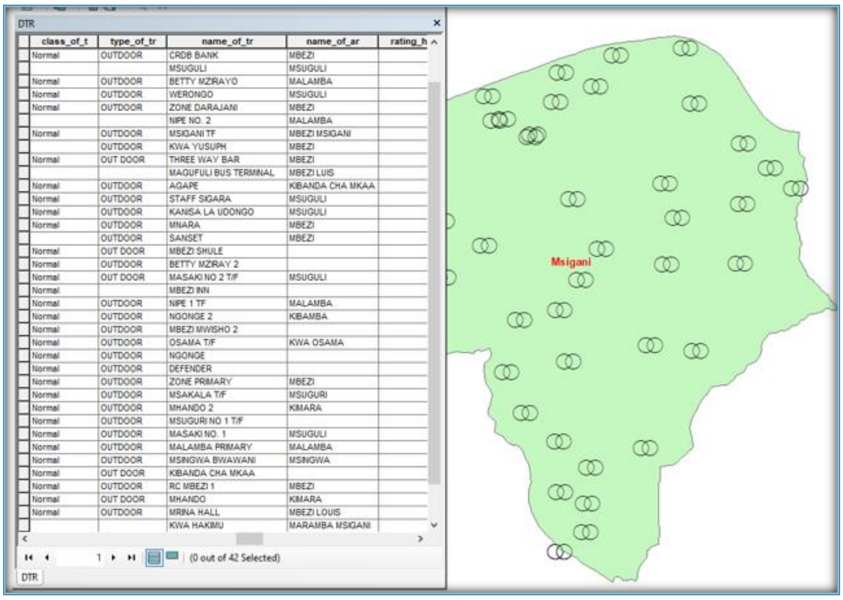


Figure 5: TANESCO Distribution GIS Database.



DTR

class_of_t	type_of_tr	name_of_tr	name_of_ar	rating_h
Normal	OUTDOOR	CRDB BANK	MBEZI	
		MSUGULI	MSUGULI	
Normal	OUTDOOR	BETTY MZIRAYO	MALAMBA	
Normal	OUTDOOR	WERONGO	MSUGULI	
Normal	OUTDOOR	ZONE DARAJANI	MBEZI	
		NIPE NO. 2	MALAMBA	
Normal	OUTDOOR	MSIGANI TF	MBEZI MSIGANI	
	OUTDOOR	KWA YUSUPH	MBEZI	
Normal	OUT DOOR	THREE WAY BAR	MBEZI	
		MAGUFULI BUS TERMINAL	MBEZI LUIS	
Normal	OUTDOOR	AGAPE	KIBANDA CHA MKAA	
Normal	OUTDOOR	STAFF SIGARA	MSUGULI	
Normal	OUTDOOR	KANISA LA UDONGO	MSUGULI	
Normal	OUTDOOR	MNARA	MBEZI	
	OUTDOOR	SANSET	MBEZI	
Normal	OUT DOOR	MBEZI SHULE		
Normal	OUTDOOR	BETTY MZIRAY 2		
Normal	OUT DOOR	MASAKI NO 2 T/F	MSUGULI	
Normal		MBEZI INN		
Normal	OUTDOOR	NIPE 1 TF	MALAMBA	
Normal	OUTDOOR	NGONGE 2	KIBAMBA	
Normal	OUTDOOR	MBEZI MWISHO 2		
Normal	OUTDOOR	OSAMA T/F	KWA OSAMA	
Normal	OUTDOOR	NGONGE		
Normal	OUTDOOR	DEFENDER		
Normal	OUTDOOR	ZONE PRIMARY	MBEZI	
Normal	OUTDOOR	MSAKALA T/F	MSUGURI	
Normal	OUTDOOR	MHANDO 2	KIMARA	
Normal	OUTDOOR	MSUGURI NO 1 T/F		
Normal	OUTDOOR	MASAKI NO. 1	MSUGULI	
Normal	OUTDOOR	MALAMBA PRIMARY	MALAMBA	
Normal	OUTDOOR	MSINGWA BWAWANI	MSINGWA	
Normal	OUT DOOR	KIBANDA CHA MKAA		
Normal	OUTDOOR	RC MBEZI 1	MBEZI	
Normal	OUT DOOR	MHANDO	KIMARA	
Normal	OUTDOOR	MRINA HALL	MBEZI LOUIS	
		KWA HAKIMU	MARAMBA MSIGANI	

(0 out of 42 Selected)

DTR

Figure 6: Identification of distribution transformers and customers in Msigani ward.

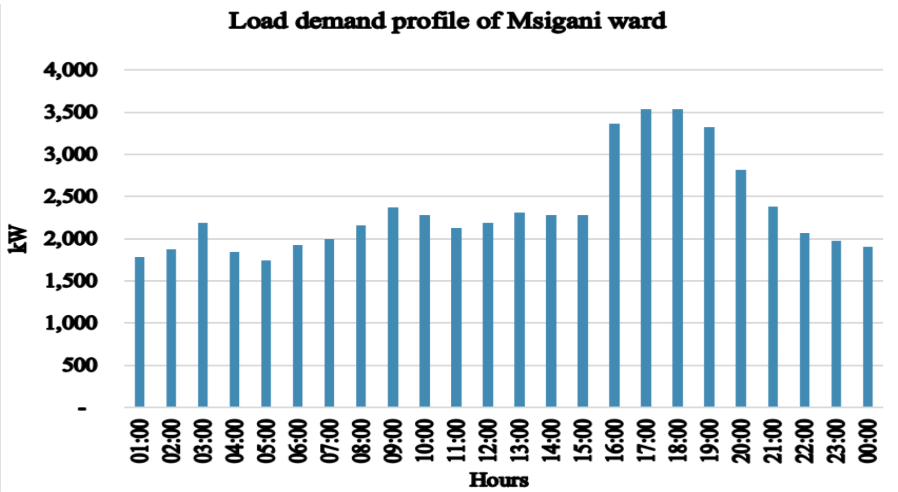


Figure 7: Load demand profile.

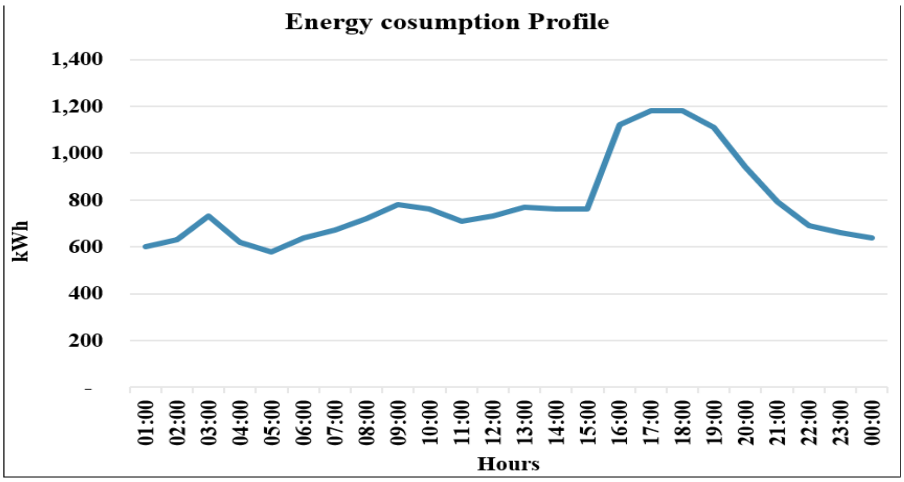


Figure 8: Energy consumption profile.

MODELLING AND SIMULATION

The topology of the hybrid was implemented in HOMER Pro software. HOMER Pro software is a micro-grid software developed by HOMER Energy for optimal design and optimization of off-grid and on-grid hybrid power systems such as Micro-hydro, Solar PV, Wind and hybrid systems (Khare et al., 2016; Panhwar, 2017). HOMER's optimization algorithms make it easier to evaluate many possible hybrid system configurations. In this study, HOMER Pro software was used to assess the performance of the developed Hybrid Renewable Energy Systems (HRES) and compare alternative solutions from different HRES component configurations. The model developed for this study was targeted to meet the power demand of 3540 kW. System sizing, simulation and optimization were performed by inputting parameters to HOMER software which included load demand profile, solar insolation level, clearness index value, wind speed and components cost in US dollars per kilowatt ($/kW) based on the current market price. Most of the values for components are already set in HOMER Pro. They depend on the component name. The designer is only required to enter the data related to energy resource potential, load profile and number of components. The model of Solar PV, wind turbine and Energy Storage Battery (ESB) based on the Model Types selected in HOMER Pro are presented in Figure 9, Figure 10 and Figure 11 respectively. In addition, the bidirectional converter was used to interface between the DC bus connected to the PV system and the AC bus powered by the wind turbine. A generic large free converter was selected from the HOMER database to enable battery sizing without having to size the converter for different Energy Storage Systems (ESS). The converter model in HOMER Pro is presented in Figure 12.

The data for optimization analysis focused on the Net Present Cost (NPC). The Net Present Cost (NPC) is considered to be the main economic variable of the system (Nesamalar et al., 2021). The Net Present Cost (NPC) or sometimes referred to as the life-cycle cost of a component is the present value of all the costs of installing and operating the component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. It is computed by equation (1) as presented in (Abdelhady, 2021).

$$NPC = \sum_{i=1}^{n} \frac{C_i}{(1+r)^i} - TIC \qquad (1)$$

where; C_i is the net cash flows in the year i, r is the discount rate and i is the year number counted from the date of investment. The net cash flows (C_i) is the difference between the cash inflows and the cash outflows. When referred to the Energy Systems, the cash inflows will result from selling the energy and the cash outflows will be constituted by the operation, maintenance and replacement costs.

HOMER Pro Software can be used to simulate different system configurations ranking the feasible ones according to the Net Present Cost provided that the input parameters that include TIC, operation cost, maintenance cost, replacement cost, discount rate and the life-time of the equipment are provided in the model (Khalil et al., 2021; Bataineh et al., 2014; Chen et al., 2007). The Net Present Cost usually considers the value for money due to the factor that the value of a certain amount of money at present will not be equal to the same amount of money in the coming years. In HOMER Pro software, the value for money is taken care by using the discount rate. To take into consideration the value for money, in the current simulation, the discount rate of 8% was assumed. This value was also used in (Abdelhady, 2021), however, in the future the simulation can be performed based on the discount rate as defined in the TANESCO Limited financial policies in case it does exist. In simple words, the discount rate takes the amount of money from different years to the same reference year for comparison purposes. It usually takes the future values to the equivalent values at the present.

The Cost of Energy (COE) in any currency per kWh is computed by the Homer Pro Software based on the project costs (investment cost and operation costs) and discount rate as per equation (2) that can also be retrieved from the work by Abdelhady, 2021,

$$COE = \frac{\sum_{i=1}^{n} \frac{TIC_i + M_i}{(1+r)^i}}{\sum_{i=1}^{n} \frac{E_0\left(1 - \frac{DR}{100}\right)^i}{(1+r)^i}} \qquad (2)$$

where; TIC_i is investment cost as referred to year i, M_i is operation and maintenance expenditure in year i, n is the expected life-time of proposed solar PV and wind turbine hybrid system, E_0 is the electricity produced in the first year of installation, and DR is the Degradation Factor for the proposed solar PV and wind turbine hybrid system, which in most cases, an annual Degradation Factor of 0.5% is assumed (Zayed et al., 2020).

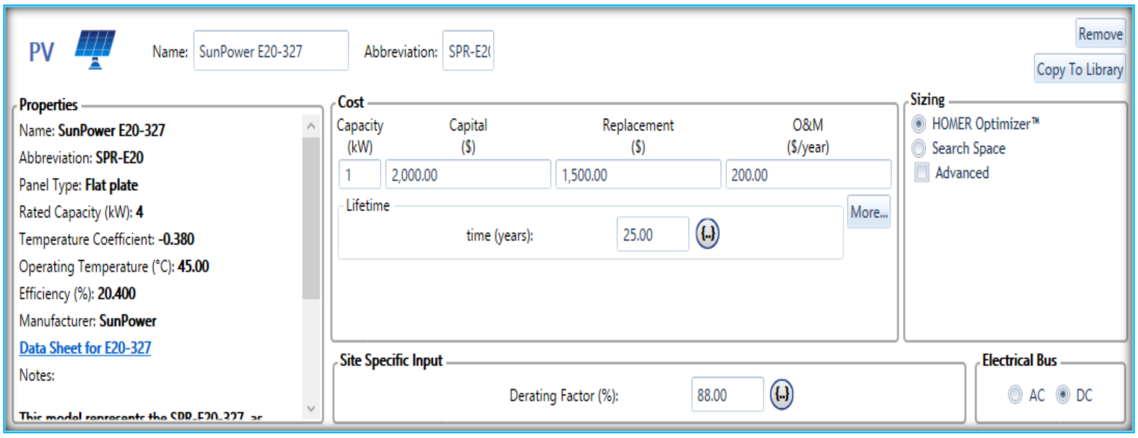


Figure 9: Solar PV modelling in HOMER Pro.

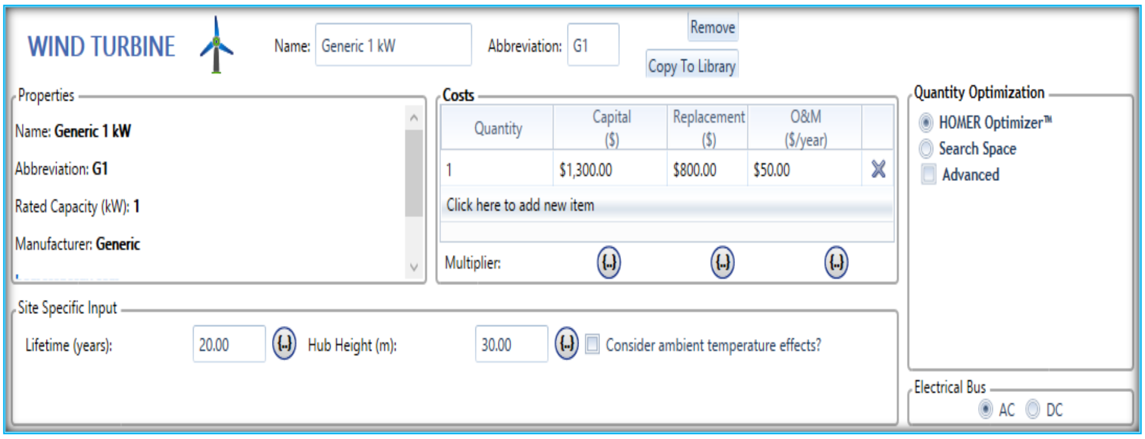


Figure 10: Wind turbine modelling in HOMER Pro

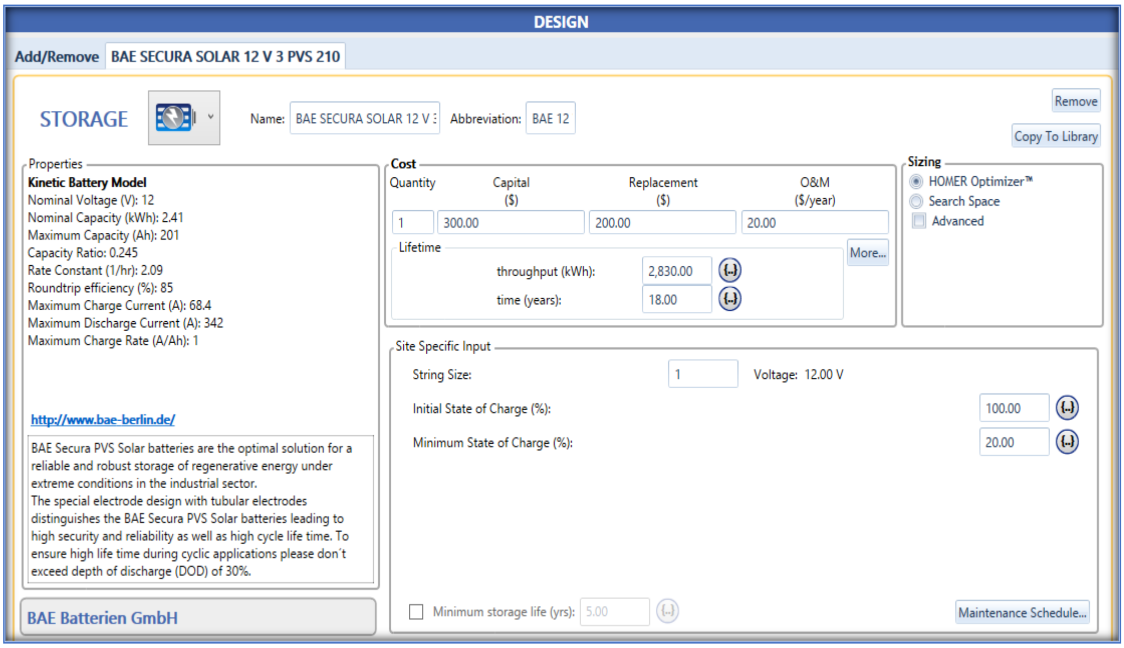


Figure 11: Energy Storage Battery (ESB modelling in HOMER Pro).

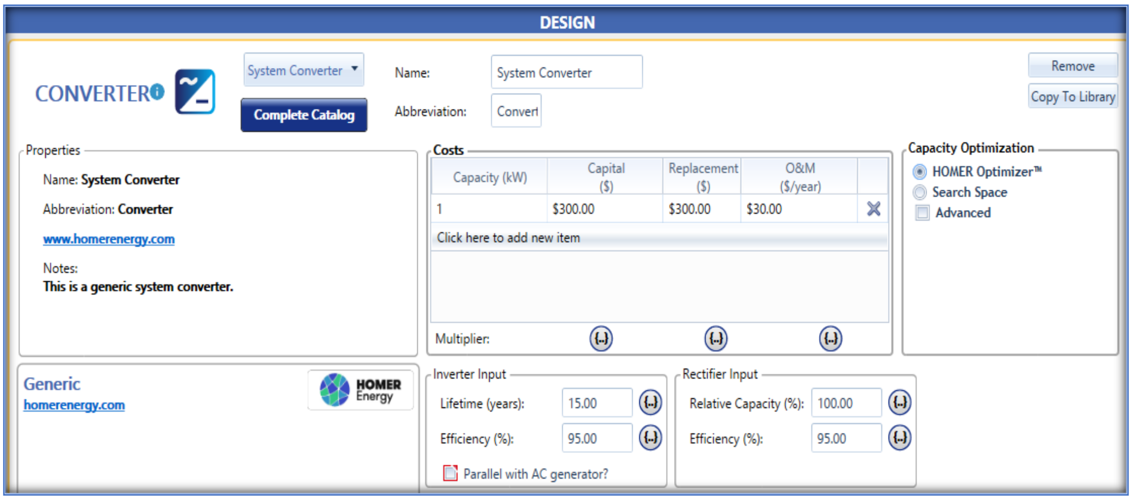


Figure 12: Converter modelling in HOMER Pro.

RESULTS AND DISCUSSIONS

Simulations and model optimization were performed using Homer Pro Software x64, 3.14.2 (Pro Edition) based on the input parameters provided to identify the potential of renewable energy. The yearly production and consumption are shown in Figure 13. Wind turbine contributes 74% to the total production whereas Solar PV contributes 0.085%. The rest of the percentage comes from the National Grid. The total consumption is 27,589,506 kWh/year of which 67.7% is daily load consumption and 32.3% is fed back to the grid. The renewable energy fraction is 74.1% and excess electricity produced is 9,829kWh/year.

The energy requirement from the grid and the energy fed to the grid on monthly basis are presented in Figure 14. The results in Figure 13 agree well with the results of the Wind Energy Resources presented earlier in Table 2. From Table 2, it can be observed that Msigani Ward experienced the highest maximum speed in July and the lowest maximum speed in March. In Figure 14, it can be observed that in July the generation with Wind Turbine (G_1) was the highest (9.441 m/s) and it was the lowest (5.035 m/s) in March, resulting to the highly dependent in the energy from the grid in March. The contributions of solar PV (SunPower E20-327), wind turbine (G1) and grid on monthly basis are presented in Figure 15.

Production	kWh/yr	%
SunPower E20-327	23,497	0.0851
Generic 1 kW	20,428,035	74.0
Grid Purchases	7,148,871	25.9
Total	27,600,403	100

Consumption	kWh/yr	%
AC Primary Load	18,687,818	67.7
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	8,901,689	32.3
Total	27,589,506	100

Quantity	kWh/yr	%
Excess Electricity	9,829	0.0356
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	74.1	%

Figure 13: Production and energy production.

Cost Summary | Cash Flow | Compare Economics | Electrical | Renewable Penetration | BAE SECURA SOLAR 12 V 3 PVS 210 | SunPower E20-327 | Generic 1 kW | Grid

Rate Schedule: All

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charge $	Demand Charge $
January	634,774	645,738	-10,963	3,478	$0	$0
February	623,821	551,958	71,862	3,353	$8,910.95	$0
March	993,886	229,802	764,084	3,480	$94,746.39	$0
April	718,732	471,909	246,822	3,363	$30,605.99	$0
May	503,286	876,330	-373,044	3,330	$0	$0
June	433,840	1,000,287	-566,448	3,231	$0	$0
July	383,093	1,179,595	-796,502	3,369	$0	$0
August	402,955	1,139,678	-736,723	3,313	$0	$0
September	435,792	1,004,420	-568,628	3,402	$0	$0

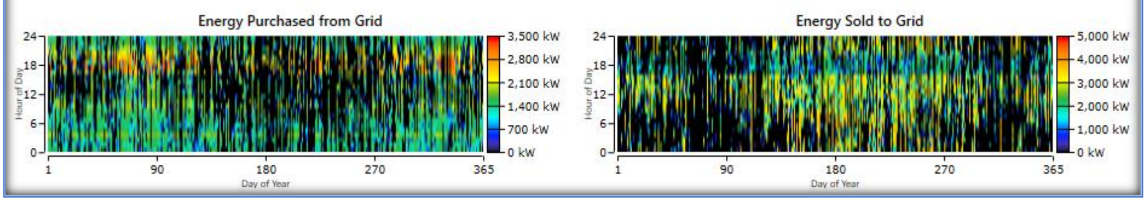


Figure 14: Energy requirement from the grid and energy fed to the grid

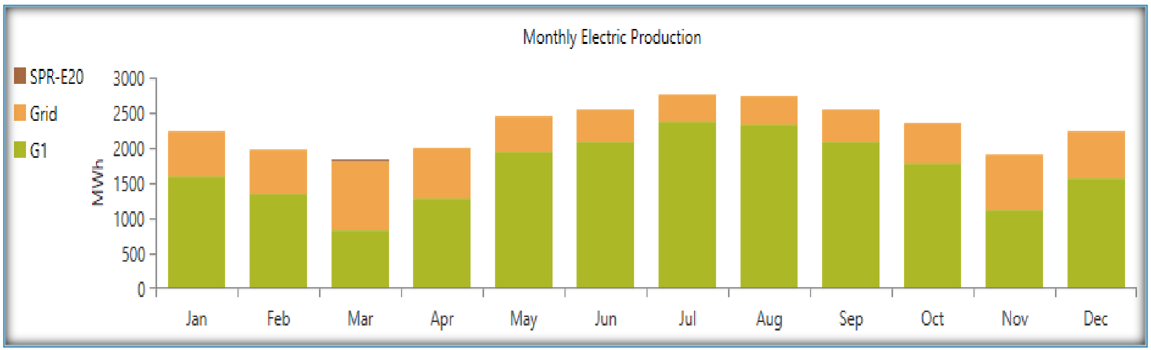
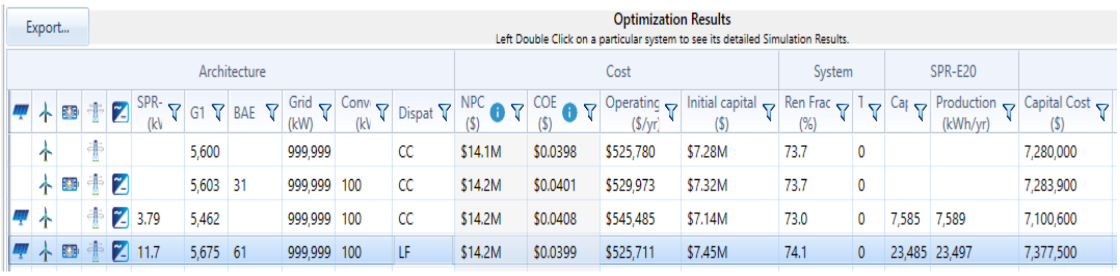


Figure 15: Contributions PV (SunPower E20-327), wind turbine (G1) and grid to the total energy generated.

The economies of the system are compared for option one and option four in Figure 16 for Net Present Cost (NPC) and cost of energy (COE). Option one has a grid and wind system for the Net Present Cost (NPC) of USD 14.1 million whereas option four comprising solar PV and wind has 14.2 million which is equivalent to a 0.7% increase. Consequently, COE increases from $0.0398 to $0.0399. Therefore, option one is more economical than option four. However, the difference is very small which can be ignored and option four has technical benefits such as a renewable fraction of 74%, an integrated grid-connected solar and wind energy system which takes care of the stochastic nature of Renewable Energy (RE).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Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture						Cost				System		SPR-E20		
SPR-(kV	G1	BAE	Grid (kW)	Conv (kV	Dispat	NPC ($)	COE ($)	Operating ($/yr)	Initial capital ($)	Ren Frac (%)	T	Caı	Production (kWh/yr)	Capital Cost ($)
	5,600		999,999		CC	$14.1M	$0.0398	$525,780	$7.28M	73.7	0			7,280,000
	5,603	31	999,999	100	CC	$14.2M	$0.0401	$529,973	$7.32M	73.7	0			7,283,900
3.79	5,462		999,999	100	CC	$14.2M	$0.0408	$545,485	$7.14M	73.0	0	7,585	7,589	7,100,600
11.7	5,675	61	999,999	100	LF	$14.2M	$0.0399	$525,711	$7.45M	74.1	0	23,485	23,497	7,377,500

Figure 16: Comparison of system combination.

CONCLUSION AND RECOMMENDATION

The performance of renewable energy was assessed using past twelve years' weather data with the assumption that it will provide good benchmark. The design considered the worst-case scenarios, which for solar resource, it occurred in the year 2014 with average solar insolation of 6.817 kWh/m^2/day and the level of clearness index of 0.556. For wind speed, the worst-case scenario occurred in the year 2011 with maximum wind speed of 7.258 m/s at 50 m height above the sea level. Under the current load at Msigani Ward and the available renewable resources, the results show that the energy resources can meet the requirements for Msigani Ward and can also result into the surplus that can be injected to the national grid in some of the months. The results also show that the resulting system had a Net Present Cost (NPC) of $14.2 M and the cost of energy (COE) is $0.0399 equivalent to TZS 93.3 which is lower in comparison to the residential grid tariff of TZS 350 for residential consumers using above 75 kWh per month.

DECLARATION OF COMPETING INTEREST

The authors declared that there have no any relations that appear to the inspiration of this work.

ACKNOWLEDGEMENTS

The authors incorporate their gratitude to Dar es Salaam Institute of Technology (DIT) and TANESCO Limited for their needful support.

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