

Monthly Average Irradiation Forecasting For Malawi's Solar Resources

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Abstract Irradiation forecasting for the years 2019, 2020 and 2021 were the main focus in this piece of paper, the established basis was the year 2018 using data from the previous past five years that is 2013 to 2017. The predicted radiation values were from a selected few locations from the country which were sixteen in total, this paper has established an overview of the expected sun's energy using a model that was established using Artificial Neural Network (ANN) computed with matlab, from the output the results indicate all the monthly averages from the sixteen locations exceeding 6 kWh/m²/day. A total of six inputs and one target which were sunshine hours, Relative Humidity, Wind speed, Rainfall, Maximum and Minimum Temperature and daily solar radiation respectively were used to ensure that solar radiation is predicted properly, this was done with the purpose of tapping into the potential of a readily available renewable energy resource which is apparently not fully exploited. The year 2018 registered Chitheche and Nkhotakota with the lowest value of 6.79 kWh/m²/day and Mangochi registering the highest value of 7.10 kWh/m²/day. The predictions for the year 2019 registered the lowest value from Kasungu of 6.51 kWh/m²/day and the Ngabu the highest value of 7.26 kWh/m²/day, 7.77 kWh/m²/day was predicted as the highest value from Chikwawa in 2020 and Mzimba registered 6.76 kWh/m²/day as the lowest value. Lastly the year 2021 registered Chitedze with lowest value and Mzuzu had the highest value, the lowest and highest irradiation were 6.91 kWh/m²/day and 8.26 kWh/m²/day respectively.

Key words: ANN, Irradiance, MAPE, prediction.

I. INTRODUCTION

Solar resource is one of the renewable energy resources that is available in abundance in Malawi, the country's average solar irradiation per day is 5.8 kWh/m² on a horizontal surface and solar energy's potential ranges from 1642.5 to 2555 kWh/m² per annum on a horizontal surface [1], like most third world countries most of their renewable energy resources remain unexploited fully hence the energy potential remains unexploited. The renewable energy resources being talked about here are the clean and modern forms of energy not the traditional and old forms which have adverse effects on the environment, such as biomass in terms of firewood and charcoal.

Most countries in Africa Malawi included are experiencing increasing high rates of deforestation due to the dependence of biomass as a primary source of energy, this is so because it can be argued that this is a readily available resource for meeting people's energy needs hence it is a solution to energy problems. Due to the unsustainable use of this resource the country has seen a lot of forestry reserves being depleted, degradation of land and soil erosions due to lost vegetative cover. Electrical energy is the main focus in this piece of work, Malawi as a country sees only 10% of its population having access to electricity from a population of about 18 million people, the demand for electrical energy is not being met and is ever increasing at the same time putting pressure on the already small generation capacity of 351 MW [1],[2] leading to heavy and massive power blackouts as well as loading shedding up to eight hours a day. Evidently there is an energy crisis as well as imbalance in the country not only electrical wise but overall that's why there is unsustainable use of some of the resources in the pursuit to meet energy needs. This paper therefore has investigated the potential of electrical energy that can be realised from solar energy in the country considering the fact that it is a country blessed with a lot of sunshine almost all year round, this piece of work therefore predicts the energy yield from solar in the years 2018, 2019, 2020 and 2021 from a number of selected locations from all the regions of the country, forecasting is of great significance in the sense that it helps in the actual planning of say a project before putting it in place and setting it in motion which reduces time consumption when work is being done on the ground and as well ensuring that there is smooth operation of the activities of supply because with forecasting one is able to commit as to how much energy can be delivered at each and every varying climatic condition but most importantly painting a clear picture of how much energy is to be expected.

Table 1. Key facts [3], [4].

Area	118,484 km ²
Population	Over 17 million
Topography	Narrow elongated plateau with rolling plains, rounded hills, some mountains
Average irradiation	21.1 MJ/m ² /day
Access to grid electricity	10%
Climate	Subtropical climate, relatively dry and strongly seasonal

Source: World Small Hydropower Development Report [3]

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II. BACKGROUND ON INSTALLED SOLAR ENERGY SYSTEMS

Most of the renewable energy advancements in the country are on a small scale, the major one is hydro resource that generates a large portion of the country's electricity making up the main grid. Solar resource on the hand is used mostly used on household levels like the use of lanterns and solar powered gadgets since solar technologies are still in their infant stages, the most notable solar powered systems in the country include the backup system at Kamuzu International Airport, solar powered backup systems on institutional level and six solar (hybrid) villages in the whole country which are combined with wind turbines, some of these hybrid systems are not in full operation.



Fig. 1. Hybrid system powered in Elunyeni

This paper establishes the solar energy potential in the next coming three years from the selected different sixteen locations with the idea of painting a clear picture of what should be expected in terms of irradiation and overall outline the country's potential. The predicted values were

considered on the basis of Clear Sky Insolation Incident on a Horizontal Surface in kilo Watt hour per metre squared per day ($kWh/m^2/day$), these values were computed on average monthly values per each location.

III. LITERATURE REVIEW

Solar is regarded as a means to meet energy needs on a large and small scale whilst maintaining affordability, reliability and environmental friendliness, on the other hand solar thermal power plants convert solar radiation into high temperature heat which can be used in supplying energy for domestic, industrial, commercial and agricultural use[5]. According to a study that Roberto Langella et al. conducted it was revealed that many photovoltaic applications for their inclusion in standalone systems or day-ahead market offering require forecasting PV production for variability along different time scenario [6].

Renewable energy technologies is the most viable economical option for off-grid and mini grid electrification for rural and remote areas, the energy received by the earth's surface is enough to provide 7900 times as much energy the population of the world uses currently and on a global average 17000kWh can be produced from each square of land that received sufficient sunlight each year and all places on the earth receive 4380 daylight hours per annum[7].

Photovoltaic cells are used to convert this form of energy into electrical energy, studies have revealed that the most notable work on solar power installation by the end of the year 2014 was as follows 38.24 GW for Germany, 28.05GW for China, 18.31GW for Italy, 23.3 GW for Japan, 18.28 for USA, 5.39GW for Spain and these studies revealed that Germany is the world's top customer and installer of PV power[8]. On the other hand, utilizing the maximum renewable energy opportunities would have a positive impact on climate change[9].

E.N Maluta et al reported that Radiation on the Horizontal Surface from Temperature Data for the Vhembe district in the Limpopo Province of South Africa found that the solar energy resource is necessitated as an alternative energy resource in the rural areas of South Africa due to the lack of grid lines[10]

It is therefore very important to be able to predict the solar radiation effectively especially in case of high energy integration so that an electrical operator should be able to ensure a precise balance between the electricity production and consumption at any moment[5], because of increasing integration of solar energy into the electrical network solar irradiance forecasting is becoming essential and in fact, this integration can offer a better quality of service if the solar irradiation variation can be predicted with great accuracy[11]. Accurate forecasting of surface irradiance remains an ongoing research issue, due to variability of solar and wind resource Verbois H. et al. found that increasing the penetration of

distributed renewable power also means reliable generation forecasts are required for grid operation[11]. Forecasting of solar power has a lot to do with several parameters but it is mostly the high precision of sunlight knowledge that plays a major role and carries more weight[12], this is to say local solar intensity knowledge is required because planning of solar energy systems require data on solar irradiation at the site where the system will be installed because this data is used for estimating the performance of solar energy systems[13], before forecasting the solar systems output, it is essential to focus the prediction on the solar irradiance[14]. Time, date and weather variables are most influential driving variable for solar PV generation forecasting model and on the other hand for selecting predictors in solar energy forecasting model sky cover, relative humidity, dew point, temperature, wind speed, pressure and precipitation are usually also considered weather variables [15], it is essential to know the particular energy demand and the potential of that energy available at that site[16].

IV. METHODOLOGY

To have a clear understanding and general representation of irradiation that Malawi as a country receives 16 locations from all over the country were selected to base this study on, selection of these places was done basing on solar radiation data provided by the meteorological department of the country. Due to gaps and unavailable data in the other remaining locations, attention was given to those locations with consistent data of solar irradiance hence the 16 locations.

Data was gathered from the years 2013 to 2017 making it a period of five years, this data was therefore analysed using Artificial Neural Network computed with Matlab to predict

the solar energy yield of the year 2018 and the future 3 years; 2019, 2020 and 2021. The target was obviously solar irradiance together with six inputs namely; Sunshine hours, Relative humidity, Wind speed, Rainfall, Maximum temperature and minimum temperature. The main values that were gathered for analysis were the mean monthly values of each parameter for all the five years, this was done by calculating averages of the daily recordings of the parameters mentioned above. A combination of inputs and targets amounted to a total of 960 samples altogether. Inputs were combined on a separate excel file and so were the targets from the locations, these files were therefore fed into matlab upon opening the Artificial Neural Network by typing *nftool* as the key word in getting started, slots containing input and target were displayed upon which the mentioned files were fed upon. In order to be able to come up with accurate predictions a Multilayer Perception (MLP) was established to select a model that was used for the predictions, this was possible by calculating hidden layers, Mean Absolute Percentage Error (MAPE). The formula for hidden layers that was used is given below:

$$\text{Hidden Layers } (H_n) = \frac{I_n + O_n}{2} + \sqrt{S_n}$$

where I_n are the inputs which are six in total, O_n is the output which is one, S_n is total number of samples which is 960 and $H_n \pm 5$ is the range for the hidden layers which in this case was 29 to 39.

The formula for MAPE used was; $\left(\frac{1}{n} \sum \frac{|Actual - Forecast|}{|Actual|}\right) \times 100$

Where n is the number of inputs, actual stands the value of the target fed to the software, forecast is the predicted value after simulation has been done.

The model that was chosen was the one with a MAPE value of less than 1% and Regression (R) of a percentage above 80 at the same time.

MLP	R	MAPE (%)
6-29-1	0.80862	0.08281
6-30-1	0.55834	0.06346
6-31-1	0.80072	0.15481
6-32-1	0.75343	0.08327
6-33-1	0.79142	0.16142
6-34-1	0.69382	0.06064
6-35-1	0.84354	0.15128
6-36-1	0.67955	0.02736
6-37-1	0.76421	0.53446
6-38-1	0.81061	0.44456
6-39-1	0.80505	0.62100

As seen from the table the model 6-35-1 is the one that met the specified requirements hence it was the one that was picked for forecasting.

Validation of the results and testing was done by setting aside percentages of all the samples, that is to say some were for testing and some for validation. Training was 70%

(672 samples), validation and testing was 15% (144 samples) respectively, this breakdown makes a total of three kinds of samples namely training, validation and testing.

Training; the samples are presented to the network during its training, and the



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network is adjusted according to its error. Validation; these are used to measure network generalisation, and to halt training when generation stops improving. Testing; these After training outcomes of focus were Neural Network Training Error Histogram, Neural Network Training Performance, Regression and Neural Network Training

have no effect on training and so provide an independent measure of network performance during and after training.

State. Prediction was first started for the year 2018 using the gathered data from the past five years, these results were therefore the basis for the years 2019, 2020 and 2021.

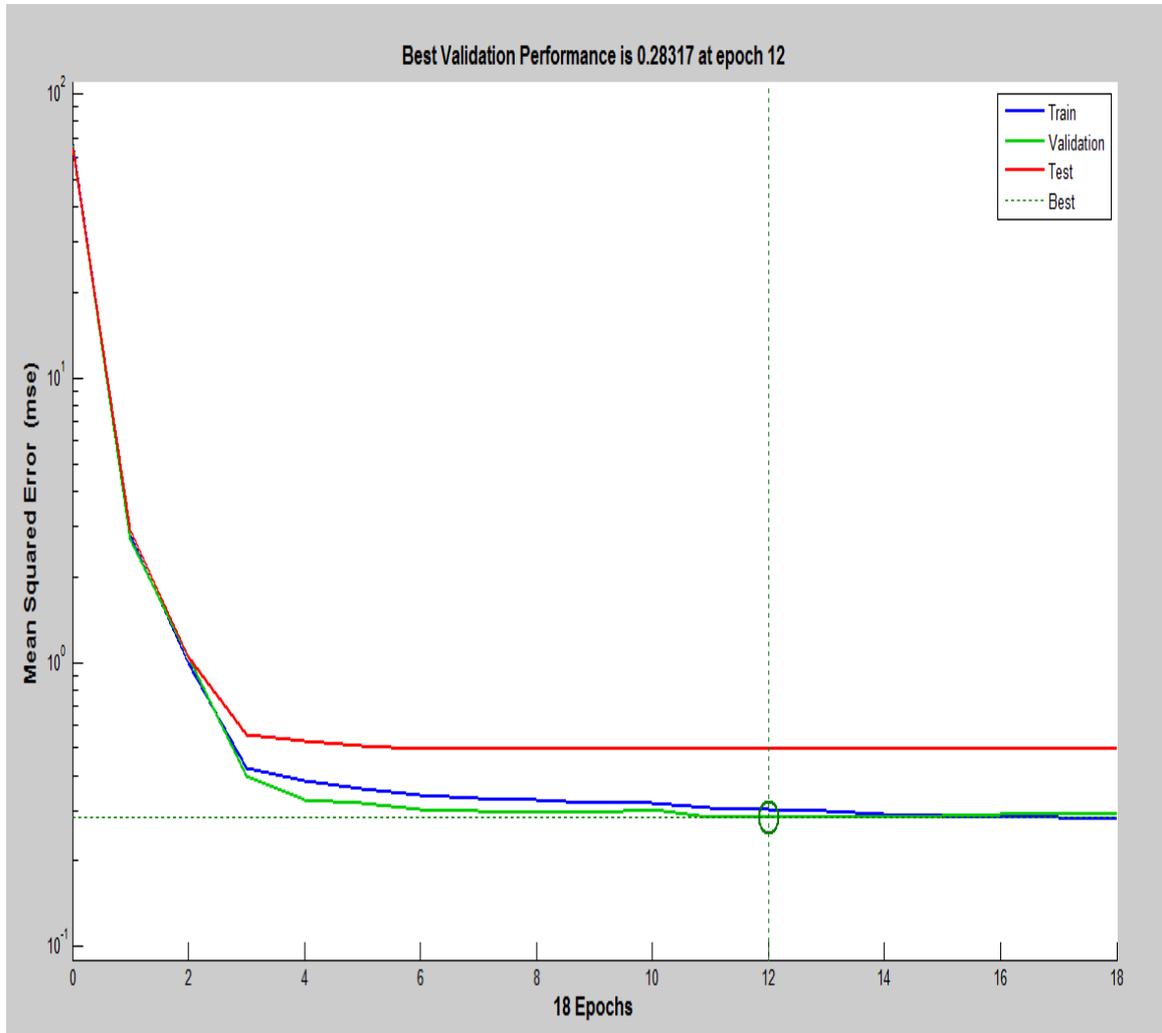


Fig. 2. Neural Network Training Performance for the year 2018

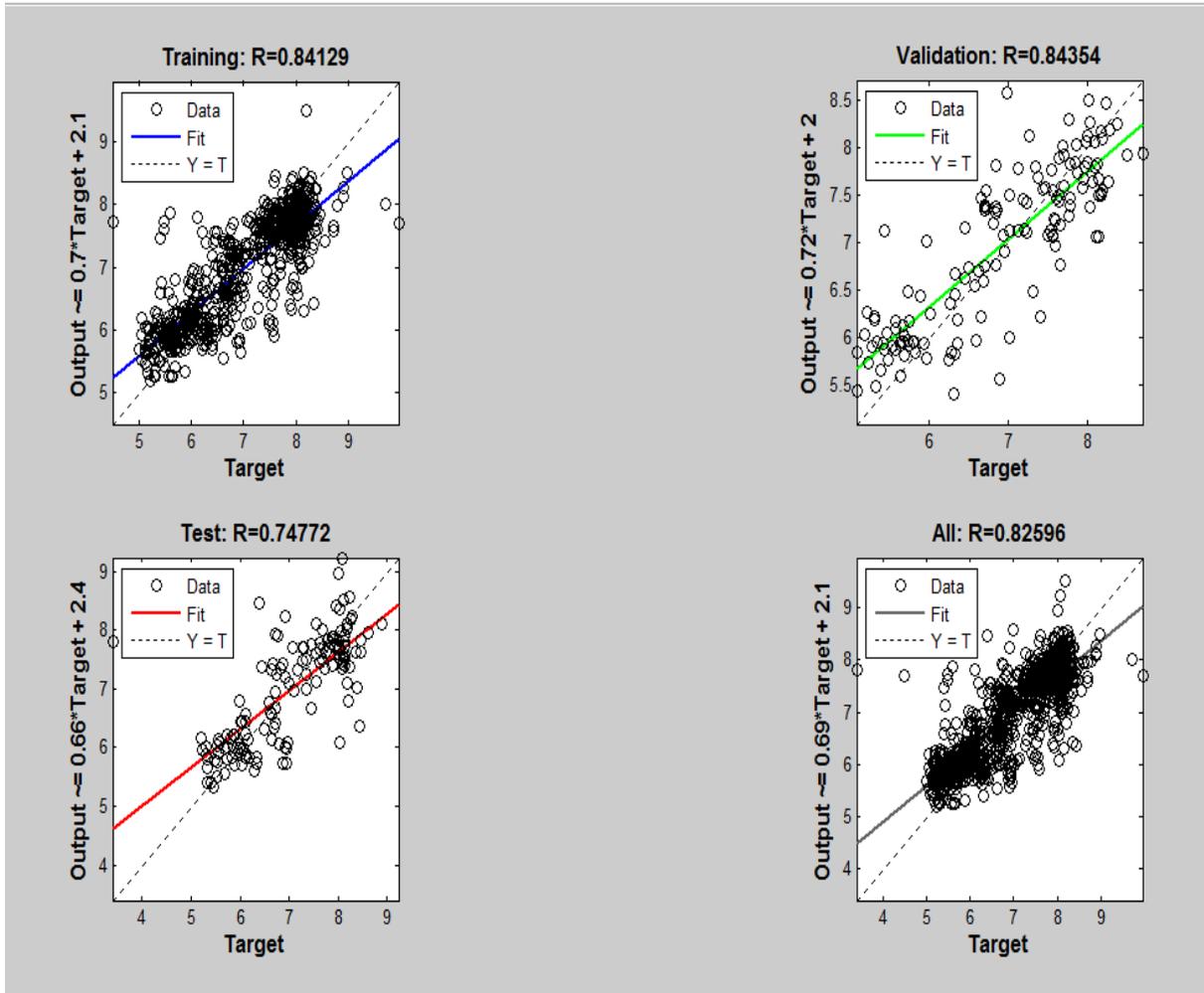


Fig. 3. Monthly averages Regression plot for the year 2018

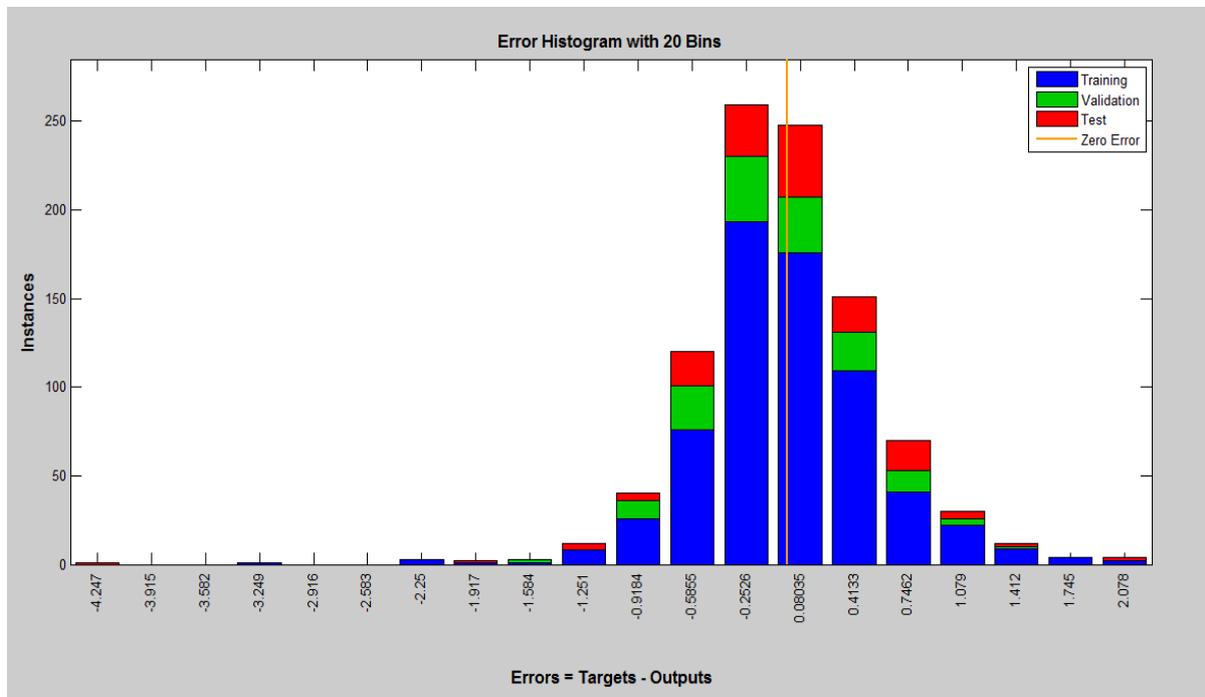


Fig. 3. Error histogram for the year 2018

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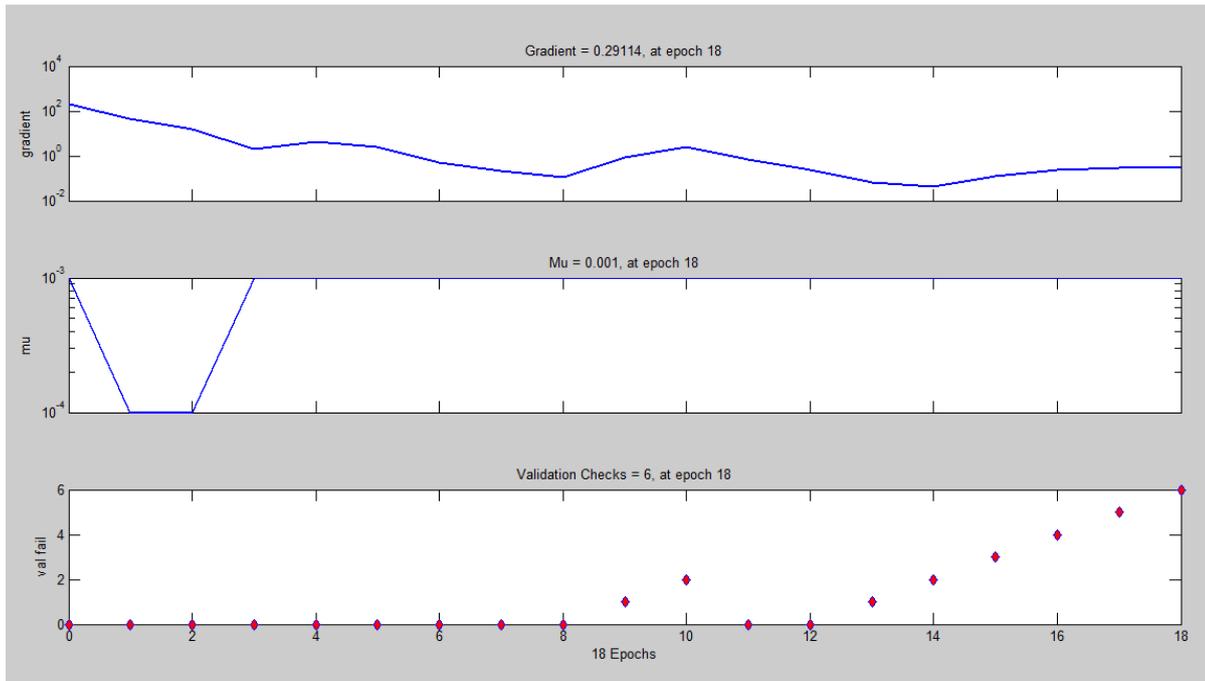


Fig. 4. Neural Network Training State for the year 2018

V. RESULTS

5.1 Solar irradiance in years, 2018 Mean Monthly Irradiance and Mean Absolute Percentage Error The year 2018 saw the mean irradiance of each location exceeding 6 kWh/m²/day with seven location registering lower predicted values of irradiance and the remaining 9 registering higher

predicted values of irradiance, these observations were established from the values of Mean Absolute Percentage Error (MAPE), Ngabu registered the highest value and Nkhotakota registered the lowest value

Table 2. Mean Monthly Irradiance (kWh/m²/day) for the year 2018

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Mzuzu	7.91	8.02	7.28	7.00	6.58	5.49	5.70	6.22	6.98	7.45	7.15	7.80	6.96
Salima	8.06	7.99	7.50	6.53	5.52	5.07	5.68	6.04	7.03	7.19	7.94	8.34	6.90
Mimosa	8.30	7.98	7.21	6.66	5.45	5.21	4.76	5.89	6.79	7.47	8.43	8.56	6.89
Chikwawa	8.40	8.06	7.30	6.37	5.96	5.15	5.52	6.12	6.80	7.33	8.16	8.39	6.96
Chintheche	8.42	7.97	7.12	6.36	5.70	5.10	5.36	5.82	6.56	7.55	7.73	7.91	6.79
Chileka	8.66	7.76	6.67	6.61	5.81	5.73	5.08	6.04	6.89	7.65	8.30	8.35	6.96
Chichiri	8.85	8.00	6.95	6.64	5.83	5.40	5.50	6.00	7.08	7.58	8.29	8.27	7.03
Chitedze	7.96	7.94	7.49	6.02	5.59	5.50	5.74	6.25	7.12	7.65	7.44	8.23	6.91
Kasungu	8.66	7.98	7.41	6.75	6.05	5.72	5.82	3.67	7.12	7.41	8.11	8.12	6.90
Ngabu	8.41	8.02	7.37	6.36	5.96	5.79	5.46	6.27	6.82	7.42	8.21	8.40	7.04
Mzimba	7.93	6.37	7.38	6.82	6.07	5.84	5.92	6.41	7.13	7.41	8.09	6.96	6.86
Mangochi	8.15	7.95	7.61	6.53	5.65	5.44	5.33	5.39	9.15	7.56	8.20	8.25	7.10
Makhanga	8.28	7.33	7.02	6.43	5.56	5.06	5.28	5.99	6.70	7.72	8.07	8.54	6.83
Karonga	8.01	7.83	7.70	7.08	6.32	5.78	5.91	6.26	6.55	7.74	8.04	7.16	7.03
Bvumbwe	9.03	7.62	7.41	6.41	5.62	5.04	5.21	6.07	7.05	7.64	8.09	8.46	6.97
Nkhotakota	7.86	7.62	7.23	6.01	5.72	5.63	5.78	5.95	6.75	7.01	7.86	8.12	6.79

Table 3. Mean Absolute Percentage Error for the year 2018

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Mzuzu	0.26	0.46	0.10	0.44	1.92	0.29	0.06	0.03	0.09	0.13	1.44	0.08	0.08
Salima	0.16	0.47	0.66	0.18	0.81	1.25	0.22	0.22	0.33	1.01	0.18	0.91	0.08
Mimosa	0.25	0.06	0.04	0.62	0.37	0.11	1.90	0.18	0.26	0.28	0.58	0.49	0.08
Chikwawa	0.20	0.38	0.29	0.37	1.13	0.14	0.55	0.64	0.54	0.41	0.08	0.38	0.36
Chintheche	0.24	0.19	0.12	0.22	0.37	0.05	0.07	0.35	0.07	0.06	0.21	0.15	0.04
Chileka	0.33	0.46	2.58	0.04	0.35	1.19	1.60	0.10	0.05	0.10	0.16	0.17	0.21
Chichiri	0.71	0.05	0.17	0.12	0.41	0.14	0.21	0.14	0.16	0.19	0.52	0.25	0.15
Chitedze	0.10	0.00	0.52	0.00	0.01	1.76	0.59	0.15	0.09	0.09	0.24	0.26	0.23
Kasungu	1.58	0.08	0.27	0.09	0.16	0.11	0.43	0.25	0.21	6.91	0.03	0.13	0.67
Ngabu	0.23	0.30	0.48	0.21	1.14	2.24	0.39	0.81	0.30	0.22	0.17	0.38	0.35
Mzimba	0.15	3.29	0.10	0.36	0.19	0.37	0.13	0.11	0.26	0.63	0.21	0.31	0.28
Mangochi	0.27	0.00	0.05	0.40	0.33	0.10	0.83	2.06	5.28	0.22	0.01	0.16	0.19
Makhanga	0.29	1.30	0.49	0.03	0.04	0.38	0.28	0.09	0.02	0.27	0.17	0.46	0.22
Karonga	0.04	0.20	0.22	0.28	0.27	0.34	0.39	0.77	1.37	0.20	0.26	1.62	0.38
Bvumbwe	1.20	0.69	0.41	0.02	0.16	0.33	0.49	0.32	0.88	0.08	0.13	0.30	0.30
Nkhotakota	0.09	0.25	0.15	1.64	0.08	0.40	0.23	0.55	0.21	1.17	0.12	0.42	0.27

5.2. Mean Monthly Irradiance and Mean Absolute Percentage Error for the year 2019

Table 4. Mean Monthly Irradiance (kWh/m²/day) for the year 2019

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Mzuzu	8.11	7.93	7.18	6.81	6.88	5.39	5.34	6.04	6.87	7.26	7.81	8.06	6.97
Salima	7.93	8.40	7.60	6.89	6.56	5.84	6.25	6.20	6.95	7.00	7.82	8.53	7.16
Mimosa	8.44	8.03	7.48	6.85	5.79	5.33	5.43	5.71	6.60	7.67	8.56	8.75	7.05
Chikwawa	8.34	8.15	7.39	6.57	6.25	5.81	5.86	6.61	6.77	7.10	7.81	8.47	7.09
Chintheche	8.51	8.28	7.36	6.32	5.36	4.84	5.04	5.70	6.38	7.11	7.68	7.96	6.71
Chileka	8.88	7.54	7.24	6.93	5.93	5.86	5.48	6.07	7.05	7.77	8.23	8.36	7.10
Chichiri	9.10	7.96	7.44	6.96	5.96	5.66	5.48	6.04	7.17	7.74	8.21	8.31	7.16
Chitedze	8.09	8.16	7.92	6.26	5.76	5.83	5.74	6.23	6.81	7.48	7.67	7.12	6.92
Kasungu	8.73	7.93	7.43	6.94	6.53	5.74	5.88	-1.29	6.82	7.17	8.20	8.12	6.51
Ngabu	8.35	8.12	7.46	6.57	6.30	6.44	5.86	6.69	7.74	7.00	8.19	8.47	7.26
Mzimba	8.16	6.99	7.63	6.72	6.43	5.93	6.32	6.37	6.98	7.00	7.80	7.17	6.95
Mangochi	8.19	7.97	7.56	6.95	6.07	5.80	5.56	5.81	9.19	7.60	7.96	8.29	7.24
Makhanga	8.29	7.40	7.10	6.69	6.15	5.66	5.57	6.22	6.68	7.52	7.86	8.35	6.95
Karonga	8.26	8.22	8.03	7.31	6.50	6.08	6.11	6.10	6.80	7.81	8.17	6.40	7.14
Bvumbwe	9.32	7.66	7.64	6.87	6.03	5.38	5.92	6.33	7.35	7.66	7.87	8.48	7.21
Nkhotakota	7.80	7.81	7.35	5.74	5.50	5.19	5.20	5.33	6.47	7.17	7.57	8.04	6.59

The predictions for the 2019 saw Kasungu registering the lowest average value of 6.51 kWh/m²/day and Ngabu registering the highest average value of 7.26 kWh/m²/day,

MAPE on the other hand had 4 locations having a predicted value higher than the actual value and 12 locations having lower predicted values than the actual values.



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Table 5. Mean Absolute Percentage Error for the year 2019

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Mzuzu	0.42	0.17	0.24	0.45	0.77	0.31	1.06	0.49	0.25	0.42	1.53	0.55	0.01
Salima	0.26	0.85	0.22	0.92	3.17	2.54	1.66	0.44	0.19	0.44	0.26	0.39	0.75
Mimosa	0.28	0.11	0.63	0.49	1.06	0.36	2.35	0.52	0.47	0.43	0.25	0.38	0.45
Chikwawa	0.11	0.19	0.22	0.52	0.82	2.13	1.05	1.31	0.09	0.53	0.17	0.15	0.46
Chintheche	0.19	0.66	0.55	0.11	1.00	0.83	1.01	0.34	0.46	0.98	0.11	1.00	0.20
Chileka	0.42	0.48	1.42	0.82	0.34	0.38	1.29	0.08	0.38	0.25	0.14	0.02	0.40
Chichiri	0.47	0.09	1.18	0.83	0.37	0.80	0.05	0.11	0.21	0.34	0.16	0.07	0.34
Chitedze	0.28	0.47	0.94	0.67	0.49	0.99	0.01	0.07	0.74	0.36	0.51	2.24	0.08
Kasungu	0.14	0.11	0.45	0.48	1.31	0.05	0.15	22.53	0.69	0.53	0.17	0.00	1.76
Ngabu	0.13	0.20	0.20	0.55	0.95	1.87	1.20	1.11	2.24	0.95	0.03	0.15	0.61
Mzimba	0.48	1.62	0.57	0.25	0.98	0.27	1.13	0.10	0.36	0.92	0.60	0.50	0.28
Mangochi	0.08	0.05	0.13	1.07	1.24	1.09	0.71	1.29	0.07	0.08	0.48	0.09	0.43
Makhanga	0.01	0.16	0.21	0.67	1.79	1.97	0.90	0.64	0.05	0.43	0.42	0.37	0.42
Karonga	0.53	0.83	0.72	0.55	0.47	0.86	0.57	0.41	0.64	0.15	0.26	1.76	0.28
Bvumbwe	0.53	0.08	0.51	1.18	1.21	1.14	2.28	0.69	0.73	0.06	0.44	0.04	0.66
Nkhotakota	0.12	0.41	0.26	0.75	0.66	1.30	1.67	1.74	0.70	0.38	0.63	0.17	0.56

5.3 Mean Monthly Irradiance and Mean Absolute Percentage Error for the year 2020

Table 6. Mean Monthly Irradiance (kWh/m²/day) for the year 2020

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Mzuzu	8.67	9.00	7.98	7.67	7.12	6.36	5.87	6.99	8.32	7.87	8.41	8.65	7.74
Salima	8.43	8.69	8.43	7.50	7.09	6.39	5.95	6.36	7.62	7.50	8.42	8.93	7.60
Mimosa	11.38	8.37	8.47	7.57	6.53	5.88	5.75	5.84	6.94	7.34	8.35	8.73	7.59
Chikwawa	8.70	8.52	8.49	7.95	7.29	6.15	6.53	6.70	7.26	7.53	9.29	8.85	7.77
Chintheche	8.95	9.17	7.83	7.11	6.17	5.91	5.63	6.33	7.20	7.61	8.22	8.31	7.36
Chileka	8.82	8.25	8.19	7.58	6.87	6.02	5.66	5.93	7.25	7.48	8.69	8.75	7.45
Chichiri	9.09	7.88	8.43	7.71	6.82	5.98	5.65	5.93	7.23	7.50	8.68	8.76	7.47
Chitedze	8.20	8.27	8.09	6.63	6.13	5.31	5.55	5.57	7.00	6.85	8.01	7.60	6.93
Kasungu	8.59	7.96	7.96	6.68	6.14	5.58	5.93	5.87	7.14	7.16	8.08	7.73	7.06
Ngabu	8.71	8.50	8.62	7.94	7.27	6.43	6.51	6.67	8.72	7.37	7.18	8.86	7.73
Mzimba	7.85	7.17	7.61	7.05	6.20	5.79	6.14	5.85	6.13	6.49	7.59	7.28	6.76
Mangochi	8.68	8.64	8.48	7.81	7.02	6.24	5.99	6.18	8.42	7.83	8.54	8.68	7.70
Makhanga	8.83	8.10	8.14	8.04	7.27	6.37	5.88	6.70	7.13	7.68	8.40	8.73	7.60
Karonga	8.10	8.72	8.41	7.94	7.19	6.34	5.87	6.07	6.92	7.57	8.94	8.17	7.51
Bvumbwe	9.20	8.29	8.69	8.04	7.07	5.90	6.23	6.24	7.63	7.66	8.66	8.80	7.70
Nkhotakota	8.25	8.36	8.10	7.17	6.74	5.80	5.56	6.33	7.45	7.67	8.09	8.54	7.33

The predictions for the year 2020 saw Mzimba registering the lowest average value of 6.76 kWh/m²/day and Chikwawa registering the highest value of 7.77

kWh/m²/day, as observed from MAPE, this year indicates 13 locations

having a predicted value less than the actual value, 2 values and one location having a constant value. locations having higher predicted values than the actual

Table 7. Mean Absolute Percentage Error for the year 2020

Locations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Mzuzu	1.15	2.24	1.87	2.10	0.57	3.00	1.68	2.64	3.51	1.38	1.29	1.22	1.89
Salima	1.04	0.59	1.82	1.47	1.34	1.56	0.79	0.43	1.62	1.21	1.27	0.77	1.03
Mimosa	5.80	0.70	2.20	1.74	2.11	1.73	0.99	0.36	0.86	0.70	0.41	0.05	1.28
Chikwawa	0.72	0.75	2.49	3.51	2.77	0.97	1.91	0.25	1.21	1.02	3.15	0.74	1.63
Chintheche	0.85	1.78	1.08	2.08	2.50	3.66	1.97	1.83	2.13	1.18	1.18	0.73	1.75
Chileka	0.10	1.56	2.19	1.56	2.64	0.45	0.57	0.36	0.47	0.61	0.93	0.77	0.84
Chichiri	0.02	0.17	2.21	1.79	2.41	0.95	0.52	0.31	0.15	0.52	0.96	0.91	0.74
Chitedze	0.22	0.22	0.38	0.97	1.09	1.47	0.55	1.77	0.47	1.40	0.75	1.11	0.00
Kasungu	0.27	0.06	1.19	0.62	0.98	0.46	0.15	92.45	0.78	0.03	0.25	0.80	7.81
Ngabu	0.73	0.78	2.58	3.48	2.56	0.02	1.87	0.05	2.10	0.89	2.05	0.76	1.14
Mzimba	0.62	.42	0.05	0.83	0.58	0.41	0.47	1.37	2.01	1.22	0.44	0.25	0.47
Mangochi	0.99	1.39	2.04	2.07	2.62	1.27	1.29	1.08	1.40	0.51	1.22	0.78	1.15
Makhanga	1.09	1.60	2.42	3.37	3.02	2.08	0.95	1.28	1.12	0.35	1.14	0.76	1.60
Karonga	0.34	1.01	0.78	1.42	1.77	0.72	0.66	0.08	0.29	0.51	1.58	4.59	0.88
Bvumbwe	0.22	1.36	2.29	2.84	2.87	1.61	0.86	0.23	0.63	0.00	1.67	0.62	1.19
Nkhotakota	0.97	1.18	1.71	4.15	3.77	1.95	1.15	3.13	2.54	1.17	1.14	1.04	1.99

5.4 Mean Monthly Irradiance and Mean Absolute Percentage Error for the year 2021

Table 8. Mean Monthly Irradiance (kWh/m²/day) for the year 2021

Locations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Mzuzu	9.26	9.71	8.48	8.17	7.72	6.98	6.28	7.76	8.81	8.00	8.73	9.26	8.26
Salima	8.56	8.95	8.74	8.00	7.60	6.51	6.22	6.78	7.97	7.95	8.53	9.12	7.91
Mimosa	11.58	9.06	8.83	7.91	7.08	5.97	5.86	5.94	6.84	7.39	8.45	9.18	7.83
Chikwawa	8.67	9.30	8.92	8.28	7.74	6.34	6.78	6.96	7.14	7.41	8.37	9.39	7.94
Chintheche	9.34	9.56	8.23	7.49	6.53	6.44	6.18	6.59	7.34	7.59	8.36	8.71	7.69
Chileka	9.01	9.07	8.58	7.86	7.09	5.99	5.68	6.09	7.22	7.49	8.64	9.19	7.65
Chichiri	9.22	3.15	8.75	7.97	7.04	5.96	5.72	6.10	7.19	7.51	8.63	9.15	7.19
Chitedze	8.47	8.63	8.33	6.81	6.18	5.19	5.27	5.31	6.50	6.70	7.85	7.72	6.91
Kasungu	8.87	8.54	8.13	6.89	6.23	5.57	5.80	5.81	6.86	7.10	7.94	8.26	7.16
Ngabu	8.67	9.29	8.99	8.27	7.72	6.51	6.77	6.88	7.68	7.32	7.35	9.39	7.90
Mzimba	8.63	8.09	8.01	7.13	6.37	5.49	5.81	5.69	6.06	6.43	7.73	8.00	6.95
Mangochi	8.91	9.19	8.86	8.15	7.28	6.27	6.05	6.53	8.58	7.92	8.52	9.23	7.95
Makhanga	8.83	9.14	8.77	8.40	7.86	6.62	6.22	7.42	7.25	7.42	8.07	9.24	7.93
Karonga	8.83	9.05	8.94	8.36	7.34	6.10	5.67	6.15	7.16	7.65	9.35	9.44	7.83
Bvumbwe	9.16	9.13	9.03	8.23	7.45	6.25	6.39	6.58	7.57	7.67	8.60	9.32	7.94
Nkhotakota	8.70	8.84	8.34	7.41	7.10	6.52	6.34	7.01	7.63	7.83	8.25	8.41	7.69

The predictions for the year 2021 saw Mzuzu registering the lowest average value of 8.26 kWh/m²/day and Chitedze registering the highest value of 6.91 kWh/m²/day, as observed from MAPE, this year indicates 14 locations having higher predicted average values than the actual values, 2 locations having higher predicted average values than the actual values.



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Table 9. Mean Absolute Percentage Error for the year 2021

Locations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Mzuzu	1.14	1.31	1.04	1.09	1.41	1.63	1.15	1.82	0.98	0.29	0.63	1.19	1.07
Salima	0.27	0.49	0.61	1.11	1.19	0.32	0.75	1.10	0.77	0.99	0.23	0.35	0.68
Mimosa	0.29	1.38	0.70	0.75	1.41	0.25	0.30	0.29	0.25	0.10	0.20	.86	0.52
Chikwawa	0.07	1.53	0.83	0.70	1.04	0.53	0.64	0.64	0.26	0.26	1.64	1.03	0.39
Chintheche	0.74	0.71	0.84	0.89	0.97	1.51	1.62	0.70	0.33	0.05	0.28	0.81	0.78
Chileka	0.35	1.67	0.79	0.62	0.55	0.08	0.07	0.45	0.06	0.01	0.09	0.83	0.42
Chichiri	0.24	10.00	0.64	0.55	0.53	0.04	0.21	0.47	0.11	0.01	0.10	0.73	0.57
Chitedze	0.55	0.72	0.48	0.47	0.14	0.38	0.85	0.78	1.19	0.38	0.35	0.27	0.11
Kasungu	0.54	1.22	0.35	0.52	0.22	0.05	0.38	0.17	0.67	0.13	0.29	1.15	0.19
Ngabu	0.08	1.56	0.72	0.69	1.02	0.20	0.66	0.54	1.98	0.13	0.38	0.99	0.38
Mzimba	1.64	2.13	0.88	0.19	0.46	0.86	0.91	0.45	0.19	0.14	0.31	1.65	0.39
Mangochi	0.44	1.06	0.75	0.72	0.62	0.07	0.17	0.94	0.32	0.20	0.05	1.06	0.53
Makhanga	0.01	2.12	1.31	0.75	1.36	0.67	0.95	1.79	0.29	0.56	0.67	0.98	0.75
Karonga	1.52	0.63	1.05	0.89	0.35	0.65	0.55	0.20	0.57	0.17	0.76	2.61	0.63
Bvumbwe	0.07	1.69	0.65	0.40	0.88	0.98	0.43	0.91	0.14	0.02	0.12	0.98	0.55
Nkhotakota	0.91	0.95	0.50	0.57	0.90	2.07	2.35	1.78	0.39	0.33	0.35	0.25	0.90

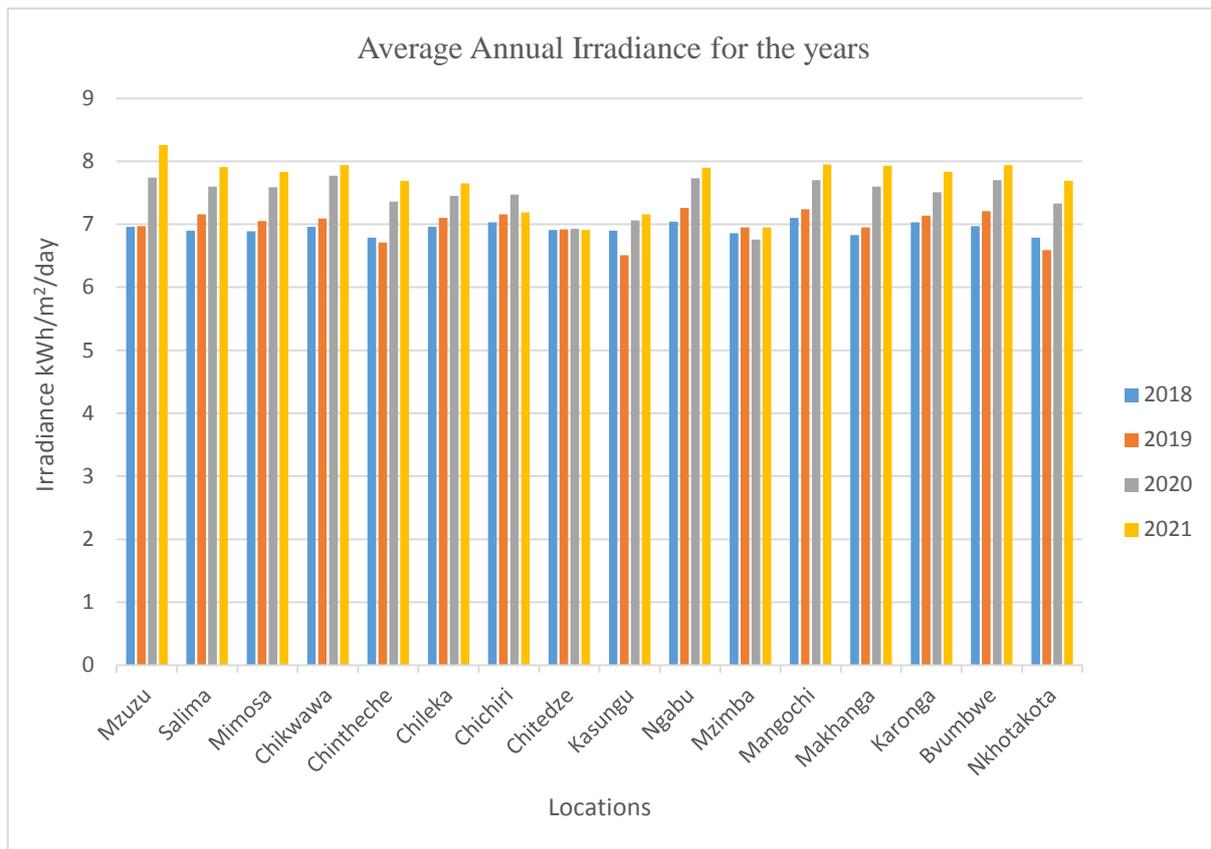


Fig. 5. Average Annual Irradiance for the years

The bar graph above is the overall predicted irradiance through the years that is from 2018 up to 2021 for all the sixteen locations, for simplification the years are colour coded. Blue bars represents the year 2018, red bars represent the year 2019, grey bars represent the year 2020 and lastly the orange bars represent the year 2021. Observations from

the graphs indicate the year 2021 having highest predicted irradiance than all the other years with Mzuzu indicating the longest bar and from the table Mzuzu has a value of 8.26 kWh/m²/day. The year 2020 comes second after 2021 registering a higher

predicted irradiance value with Chikwawa having the longest bar in the year and registering a value of 7.77 kWh/m²/day, the year 2019 comes third with higher annual averages from the locations with Ngabu having 7.26 kWh/m²/day as the highest annual average. Lastly it is the year 2018 which was used as the basis for the predictions, with Mangochi having a value of 7.10 kWh/m²/day and the longest bar for the year respectively.

Addressing objective number two Mangochi is the location with the highest predicted irradiance through all the years with a value of 7.50 kWh/m²/day and MAPE of 2.28%

VI. CONCLUSIONS

The main objective was to estimate the overall energy yield in the future years, the predictions were performed for each and every location with monthly averages as outcomes; using these values and computing their average it can be concluded that 7.265 kWh/m²/day is the expected energy yield from the locations in the years to come, the Independent Power Providers (IPPs) wishing to capitalize on the solar resource can work with this projection to align their goals as well as contributing in reducing the electrical energy deficit. This can be of great significance focusing on generation of power on a locational basis because the transmission problems because of long distances can be minimised. From the tables above the predictions were established and since the solar resource is not a stable but rather a varying resource it is seen in some locations that the predicted value of insolation is lower than the actual value and in some cases the predicted value was greater than the actual value, with this being said, the energy yield from the sun from the locations upon which this piece of paper was based is of great potential as observed it is on average exceeding 6kWh/m²/day. This is an adequate representation of irradiation to meet the electrical energy needs if it is harnessed with appropriate technology. Supply of power therefore will have to be directed to the masses with no or in need of electrical power with the IPPs directly providing directly if they have the capacity or feeding to the main grid and leaving it there for distribution, as a developing country it can be better if the power by the IPPs is fed to main grid because it is capable of distributing it to more than one location and the assumption is that most of the providers are still developed and are not yet to that level of being able to perform some of the activities and functions independently. 7.265 kWh/m²/day is the overall energy yield from this piece of work, some of the utilisation options aside from the obvious one is that it can help in shifting the reliance of biomass as a primary source of energy especially for cooking and in the long run it forestry reserves will be conserved as well as helping the country regain its lost vegetative cover hence reducing deforestation in the long run. The other utilisation option is that on a district level if this energy is harnessed it can improve the quality of by providing the very most modern basic need which is energy in terms of better health services being accessed easily, good quality education since most of the community day secondary schools have no electricity which makes education poor to some extent. Another important thing is that the health issues resulting from gases emitted by usage

fuelwood can be minimised in the rural areas if this harnessed.

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