Estimating Rooftop Surface Area for Solar Energy Generation: The Case of the University of Zimbabwe

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Abstract

This article is based on a study that sought to determine the approximate rooftop surface area required for the integration of solar electricity generation at the University of Zimbabwe (UZ) campus. The study promotes the use of renewable sources of energy as a measure of improving urban resilience and addressing the power supply problem currently being faced nationwide. It is observed that the national grid for electricity generation has become less reliable and has caused challenges of power supply in Zimbabwe since time immemorial. Little has been done to solve this problem, resulting in various challenges, such as, hiking power charges, poor service delivery and electricity power-cuts. The article proposes a more reliable source of energy - solar energy — which can be more efficient to the UZ. To achieve the objectives of this study, various methodologies were used, such as the case study approach from a global, regional and local context, thematic context analysis and Google Earth. Calculations were also made to measure the area required for the installation of solar panels and the required panels. Four tenets can be noted from this study, that are affordability of solar energy plant, technical knowledge, space required for the solar plant and benefits of adopting this strategy.

Keywords: *renewable energy, photovoltaic, energy efficiency, sustainability*

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INTRODUCTION

The need for sustainable electrical energy has increased, due to the advancement in technology. Solar energy has received global acceptance and use as an efficient renewable energy source. The aim of this article is to discuss measures to integrate solutions of solar energy into existing buildings of the UZ. This was achieved through identifying suitable buildings and the surface area required for the installation of solar panels. Observations have shown that existing buildings have potential for solar integration on both rooftops and facades. Solar energy is generally defined as energy from the sun. Charkraboty *et al.* (2016) define solar energy as a source of energy that is directly from sunlight or the heat that the sun produces. Solar energy can be converted into electricity by way of photovoltaics (PV). PV consist of the Greek word *phos*, meaning light and *volt*, which refers to electricity (EPIA and Greenpeace, 2006). A PV system consists of a solar panel, a battery and an inverter. Solar panels contain solar cells that collect heat energy from the sun. Once this is trapped by an inverter, it is converted to energy so that it is usable to power electrical appliances. It has been observed that 12% of the world's secondary energy can be easily and cheaply transported with relatively small losses through an electric grid. To integrate solar capture elements on existing buildings, there is need for knowledge in historical, architectural, energetic, technical and economical fields (Meinel *et al.*, 1977).

BACKGROUND AND CONTEXT

Most governments do not have a clear-cut policy on development and promotion of renewable energy technologies (such as, solar energy). Efforts continue to be undertaken within an energy planning and policy vacuum (Karekezi, 2002). This scenario can also be identified in Zimbabwe. As a result, development of renewable energy technologies follows an *ad hoc* path, with no clear national power master plan, that is rarely available or out of date.

Various policies guide the use of renewable energy in Zimbabwe. The Environmental Management (EMA) Act is one piece of legislation that has direct and indirect implications on renewable energy. Its objectives include the provision of sustainable management of natural resources, protecting the environment and preventing pollution and environmental degradation.

Provisions under environmental rights and the principles of environmental management also have positive implications for turning to renewable energy. These include the right to a clean environment that is not harmful to health and the protection of the environment for the benefit of present and future generations through the prevention of pollution and environmental degradation. The principles also call for development that is socially, environmentally and economically sustainable. EMA mandates the undertaking of an Environmental Impact Assessment (EIA) before certain projects are implemented. Energy projects are among such projects and include renewable/green energy projects such as the development of hydropower plants (GoZ, 2012).

The National Energy Policy (NEP) is another framework that has direct and indirect implications on renewable energy production. It seeks to promote the optimal supply and utilisation of energy for socio-economic development in a safe, sustainable and environment-friendly manner. Renewable energy meets these criteria. The NEP further calls for the development of the use of other renewable sources of energy to complement conventional sources of energy. Its main objective is: "to create and promote a conducive environment for energy sector players to be able to identify and develop opportunities for energy supply that promote sustainable development". Renewable energy production is an alternative way. The vision behind the National Environmental Policy and Strategies (NEPS) is to alleviate poverty and improve the quality of life for Zimbabweans and to avoid irreversible environmental damage, has implications for renewable energy (GoZ, 2012).

Clean renewable energy does not lead to the emission of greenhouse gases (GHG). Renewable energy also prevents irreversible environmental damage and maintains essential environmental processes, thus, contributing to sustainable development. NEPS objectives and key policy principles have clear synergies with renewable energy and the green economy. These include optimising the use of resources and energy, whilst minimising waste production and pollution, its main goal is to fulfil the nation's right to a clean and healthy environment. The guiding principle of the NEPS provides that: "The people of Zimbabwe have a right to safe and affordable energy produced at minimum environmental cost" (GoZ, 2012).

Furthermore, the NEP strategic directions call for the Government of Zimbabwe, in collaboration with stakeholders, to promote economic policies that encourage efficient use of energy and discourage the over-exploitation of non-renewable energy sources. It also promotes, through the introduction of appropriate incentives, investment in and use of renewable sources of energy. It encourages greater extraction and the use of methane as a cleaner source of energy (GoZ, 2012).

The Electricity Act (Chapter 13.05) also has implications for renewable energy. It allows for the participation of independent power producers (IPPs) in the energy sector, some of whom are focusing on the production of renewable energy. Moreover, the NEP has direct and indirect implications on renewable energy production. It seeks to promote the optimal supply and utilisation of energy for socio-economic development in a safe, sustainable and environment-friendly manner. The NEP further calls for the development of the use of other renewable sources of energy to complement conventional sources of energy (GoZ, 2012).

Climate change mitigation policies also help in supporting renewable energy development, including solar energy (Hoseini *et al.*, 2013). Various incentives and mandates designed to trigger GHGs have helped promote solar energy in industrialised countries. In the case of developing countries, the Kyoto Protocol has played a leading role in promoting solar energy under the climate change regime.

THEORETICAL FRAMEWORK

Theories of metabolic rift, ecological modernisation and sustainability were examined to better understand the phenomenon of solar energy adoption at the UZ. The theory of metabolic rift was derived from the biological term 'metabolism' which refers to the exchange between and within nature and humans (Shama, 1982). In this theory, Karl Marx argued that industrial capitalism creates conditions that inevitably cause an irreparable rift in human-nature metabolism (Foster, 1999). Marx further argued that this rift results in the pollution of air, water and land. He recognised the importance of a balanced energy exchange between human societies and nature and acknowledged the disruption of this exchange resulting from industrialisation.

Since the concept of the rift is based on the concept of metabolism, healing the human-nature metabolic relationship is a way of addressing the rift. Solar energy technology could offer one way to eliminate the metabolic rift and restoring a balance in human-nature metabolic relations.

The concept of sustainability was discussed in the Bruntland Report (1987). Though there are various definitions of the term 'sustainability', this study defined the concept as improving the quality of human life, while living within the carrying capacity of supporting ecosystems (Munro and Holdgate, 1991). From this definition, it can be argued that sustainability encourages the use of renewable resources. It is widely recognised that there are three dimensions of sustainable development, that is, economic, social and environmental sustainability. In line with environmental sustainability, the use of fossil fuels is resulting in a devastating state of the environment and consequences, such as global warming for both humans and non-human species (Berardi, 2013). Solar energy, therefore, is sustainable as a long-term energy resource and results in a sustainable environment.

The third theory engaged in this article is the ecological modernisation theory that was developed by sociological theorists who conceptualise the use of solar energy technology in a different manner. Ecological modernisation theory argues that advanced states of industrialisation result in the potential for environmental values to be adopted into production practices and policy stances (Buttel, 2000). Countries that reach a state of modern industrialisation can and will develop industrial policies that promote environmental responsibility. The theory provides a practical theoretical framework for policy development and takes into account the production input necessary for solar technology. It is also able to explain the increased adoption of solar energy systems, particularly at a national scale and in advanced industrialised economies.

LITERATURE REVIEW

Solar energy has been internationally recognised to promote innovative approaches for the mitigation of carbon dioxide emissions, due to energy consumption associated with building construction and operation. It is accepted worldwide as the largest renewable energy supply (Mills *et al.*, 2008).

In the case of China, the overwhelming pollution issues and devastation of coastal cities, due to rising sea levels, forced Beijing to launch a campaign in search of green solutions (Chang *et al.*, 2017). The programme "Made in China 2025" was introduced as a central axis of the internal industrial policy of Beijing which foresees investment in research and development of clean energies to meet climate aims. In this regard, China produces two thirds of the solar panels and almost half of the wind turbines in the world. One of the studied emerging technologies consist of the installation of floating PV solar panels, capable of supplying light and air-conditioning to nearby cities.

Access to energy is critical to Africa's development and growth. Africa's energy sector is best understood as three distinct regions. These are North Africa, that is heavily dependent on oil and gas, Southern Africa, which depends on coal and the rest of Sub-Saharan Africa, that is largely reliant on biomass (Karekezi, 2002). The renewable energy resource potential in Africa has not been fully exploited, mainly due to the limited policy interest and investment levels. In addition, technical and financial barriers have contributed to the low levels of uptake of renewable energy technologies (RETs) in the region (Karekezi and Ranja, 2002). There is growing evidence that solar PV projects in the region have benefited mainly high-income segments of the population, due to the high cost of solar PV. Solar PV is unaffordable to the majority of the population in sub-Saharan Africa, given the high levels of poverty (Karekezi and Kithyoma, 2002). For example, in Botswana, by 2001, about 15,000 domestic solar water heaters (SWHs) had been installed (Fagbenle, 2001). In Kenya, by 2003, about 20,000 SWH units had been installed (Mbuthi, 2003). In Zimbabwe, by 2001, about 4,000 of these were in use (AFREPREN, 2001). The bulk of the SWHs in use are bought by high-income households, institutions and large commercial establishments, such as, hotels and game lodges.

It is argued that rural households in Africa may not be able to afford large solar home systems. Smaller systems may be more suitable; thus, solar systems are not popular in rural homes. The most popular solar intervention are the LED lanterns that are performing well in the East African market. These basically provide light and some have a charging system for phones. Energy is the sustenance of all economies and an enabler to better welfare and where there is a deficit in supply, economic growth is crippled and livelihoods destroyed (IRENA, 2012). It can, therefore, be suggested that solar energy can be the best for rural electrification to improve the welfare of the rural counterparts.

Sustainable Development Goal (SDG) 7 of 2015-2030 emphasises the imperative of achieving universal energy through increased access to renewable energy and an improvement in energy efficiency. Developing countries have started to focus on making smart cities with the implication of solar energy. India, being a fast-growing economy, has a vision of building 10 smart cities. Eight big cities have been selected to initiate the programme of making smart cities. These include Amristar, Delhi, Mumbai, Bangalore, Chennai, Vizag, Kolkata and Myanmar. According to IBM's report (2018), an average of 30% Indians will migrate from rural areas to smart cities for better livelihoods. As per prediction, the Indian government needs to create 500 new cities in the forthcoming 20 years.

The integration of solar energy at other colleges and universities around the world creates solid and successful examples of solar working in different ways at places similar to the UZ. The Harvard University has solar panel systems on eight of its buildings, the largest of which produces 590,000 kWh/year. The university also purchases renewable energy from offsite sources and has a wind turbine mounted on one of its buildings. Combined, 17% of their electricity comes from renewable sources, while saving the institution money on the use of fuel and utilities ("Sustainability", 2013). Harvard is clearly making a statement about being green and moving towards cleaner technologies. While the UZ's main objective is to create a conducive learning environment, the idea of taking on one solar project is reasonable, considering Zimbabwe's state of affairs.

The Stonehill College in the United States of America is another institution that is currently building one of the nation's largest college campus solar fields. It is a 2.7megawatt field that will contain 9,000 solar panels. The solar field is expected to save about $185,000 a year on energy costs and account for 20% of the campus' electrical usage ("One of Nation", 2014). This array produces such a large portion of the college's energy mostly because UZ is only a quarter of the size of Stonehill College, making its energy use much smaller. In addition, Stonehill's field arrays have to be built away from campus, making the use of solar less noticeable. Integrating solar energy at the UZ may also encourage other universities across the country to engage on the same project, considering its benefits.

Depending on the type of the building, two different strategies of solar panel integration have been developed (Couty and Simon, 2017). The first one is the symbiotic approach: active surfaces are placed by copying architectural existing organisation. While helping aesthetes, handrails or roofs are identified as suitable surfaces for solar integration in balance scenarios. The second strategy, by creating a new personal identity of the building, is at odds with the existing language of the context. For example, a new expression of the building is adopted through solar integration by keeping the rhythm and structure of the facade (Al-Otaibi, 2019).

Solar cells and PVs were invented in 1954, after much research around photoelectric technologies (Crabtree *et al.*, 2007). Basically, solar panels contain solar cells that collect heat energy from the sun, once this energy is trapped, an inverter is used to convert energy into electricity. The inverter is usually supported by an energy storage system, such as a rechargeable battery, to provide electricity when there is no sunlight. The lifespan of the battery depends on geographic location, general maintenance and load balancing. PV technology has many applications, both for stand-alone systems and also for integration into buildings. PV may be used, for instance, in monitoring stations, radio repeater stations, telephone kiosks, street lighting etc. (Chakrobty *et al.*, 2016).

Direct solar energy can broadly be categorised into solar photovoltaic (PV) technologies, which convert the sun's energy into electrical energy and solar thermal technologies, which use the sun's energy directly for heating, cooking and drying (Karekezi and Ranja, 1997). Solar energy has, for a long time, been used for drying animal skins and clothes, preserving meat, drying crops and evaporating seawater to extract salt. Substantial research has been done over the years on exploiting the huge solar energy resource. Today, solar energy is utilised at various levels. On a small scale, it is used at the household level for lighting, cooking, water heaters and solar architecture houses; medium-scale appliances include water-heating in hotels and irrigation (Lewis, 2007).

At community level, solar energy is used for vaccine refrigeration, water-pumping, purification and rural electrification. At the industrial level, solar energy is used for pre-heating boiler water for industrial use and power generation, detoxification, municipal water-heating, telecommunications and, more recently, transportation (solar cars) (Karekezi and Ranja, 1997; *Ecosystems*, 2002). With increased efficiency and reduced cost of solar water heaters, small-scale solar water heaters now have a payback period of 3- 5 years (Karekezi and Karottki, 1989; Karekezi and Ranja, 1997). However, the diffusion of these systems has, in recent years, been slower than anticipated.

METHODOLOGY

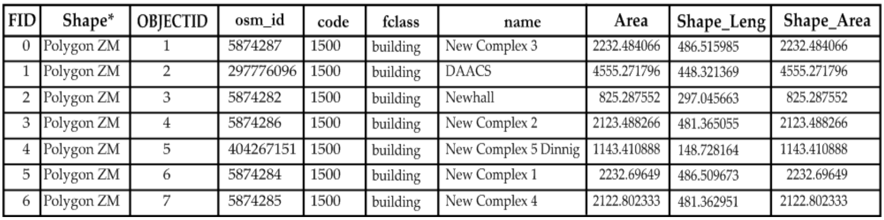
The methodology applied in this study is largely qualitative, based on the use of case studies, themes and documentary review analysis. The study made use of several case studies which were promoting the adoption of clean energy-solar, as a measure to minimise electricity cost and power-cuts at the UZ main campus. A case study is defined as an intensive study of a single unit with an aim of generalising across a larger set of units (Gerring, 2004). Thematic analysis is another method used in the study. It is a method for identifying, analysing and reporting patterns (themes) within data. It minimally organises data in rich detail (Boyatzis, 1998). The use of themes in this study managed to uncover a variety of phenomenological information for better inquiry on the topic under discussion. The study also made use of documentary analysis in analysing government statutory laws regarding green infrastructure. A number of documents were used to highlight a range of different perspectives regarding the issue of solar energy.

Roof surface area estimation was carried out using a combination of Google Earth Pro and ARCGIS in which Google Earth was used to manually digitise all the buildings at the University Campus. Google Earth was adopted because of its provision of high spatial resolution images which enables clear identification of buildings and avoids digitising errors like edge errors. The method of manually digitising all the buildings in the study area was adopted because the area was small and image classification of rooftops could not be adopted. Rottensteiner (2017) carried out a similar study and found out that manual digitising of building of roof surfaces performs well than image classification of rooftops. Figure 1 shows buildings digitised on high resolution Google Earth Pro imagery.

Figure 1: Rooftops digitised in Google Earth Pro.

After manual digitising of rooftops in Google Earth Pro, digitised polygons were opened in QGIS as vector layers and were converted to shapefile. The shapefiles were then opened in ARCGIS and they were projected as UTM coordinates from the previous geographical coordinate system for area calculation (Hari, 2019). In ARCGIS, area was calculated for each and every roof surface in square metres using the calculate geometry tool. Table 1 shows the attribute table with the area for each surface digitised.

Table 1: Attribute table of surfaces digitised and converted to shapefiles with area calculated



FID	Shape*	OBJECTID	osm_id	code	fclass	name	Area	Shape_Leng	Shape_Area
0	Polygon ZM	1	5874287	1500	building	New Complex 3	2232.484066	486.515985	2232.484066
1	Polygon ZM	2	297776096	1500	building	DAACS	4555.271796	448.321369	4555.271796
2	Polygon ZM	3	5874282	1500	building	Newhall	825.287552	297.045663	825.287552
3	Polygon ZM	4	5874286	1500	building	New Complex 2	2123.488266	481.365055	2123.488266
4	Polygon ZM	5	404267151	1500	building	New Complex 5 Dinnig	1143.410888	148.728164	1143.410888
5	Polygon ZM	6	5874284	1500	building	New Complex 1	2232.69649	486.509673	2232.69649
6	Polygon ZM	7	5874285	1500	building	New Complex 4	2122.802333	481.362951	2122.802333

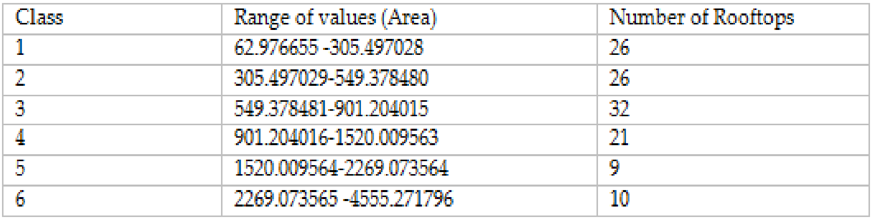
The attribute table was converted to an Excel file using the conversion tool in

ARCGIS toolbox for calculation of the total area and after this, total area of all rooftop surfaces at the UZ was found to approximate 117,389.4555 square meters.

RESULTS

The UZ campus consists of approximately 124 building structures. Most of the roofs at the university have pitched roof structures. Implementing installation of solar panels on the UZ campus is an effective and easy way to introduce clean energy with proven technology. Solar panels offer both an environmental and economic benefit, especially, at universities, where energy consumption is high. With an undergraduate population of over 9,000 students, one major sports field, seven major dining locations and over 10 dormitories, the UZ campus is always using large amounts of energy. Solar PV will reduce the UZ's electricity bill, encourage a safe and clean environment and promote sustainable initiatives at the institution. PV systems offer advantages, such as. supplying safety, free fuel, minimum maintenance cost, easy installation, modular systems, inaudible operation and no waste production. However, they also have major disadvantages, such as, requiring expensive investment as the products are of advanced technology and needing large storage spaces. The attribute table has information of all the rooftop surfaces which were put into six major classes, based on a specified range of surface area (Table 2).

Table 2: Summarised attribute table classified into six classes based on rooftop surfaces



Class	Range of values (Area)	Number of Rooftops
1	62.976655 -305.497028	26
2	305.497029-549.378480	26
3	549.378481-901.204015	32
4	901.204016-1520.009563	21
5	1520.009564-2269.073564	9
6	2269.073565 -4555.271796	10

The information in Table 1 was presented in the form of a bar graph as shown by Figure 2.

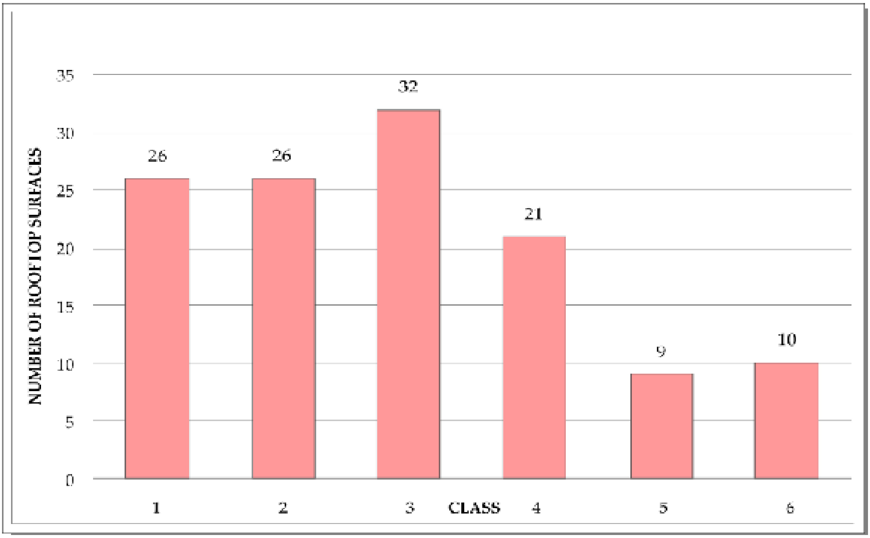


Figure 2: Surface Rooftops Available.

From the graph, it can be noted that class three, with an area ranging from 549.378481-901.204015 has the highest number of rooftop surfaces available at the UZ.

Determining the area of the rooftop surface alone was not enough since it was not showing the number of buildings that can receive direct radiation from the sun and those that cannot. So, to account for that, the aspect, that is the downslope direction of the maximum rate of change in value from each cell to its neighbours, was derived. Aspect was derived from raster data set of rooftop surface area of the UZ and it was derived mainly because it shows buildings with aspect facing different directions, which can have a bearing on the amount of radiation reaching the surface. It was observed that from a visual perspective, almost 75% of the rooftop surfaces are flat and, as such, can receive direct radiation without interference from other structures in different directions. Moreso, about 35% of the rooftop surfaces are oriented in different directions, with some lying in the east, north and southeast directions, indicating that changes in sun angle with seasons could have a direct effect to the amount of radiation received. Figure 3 shows the aspect map of rooftop surface.

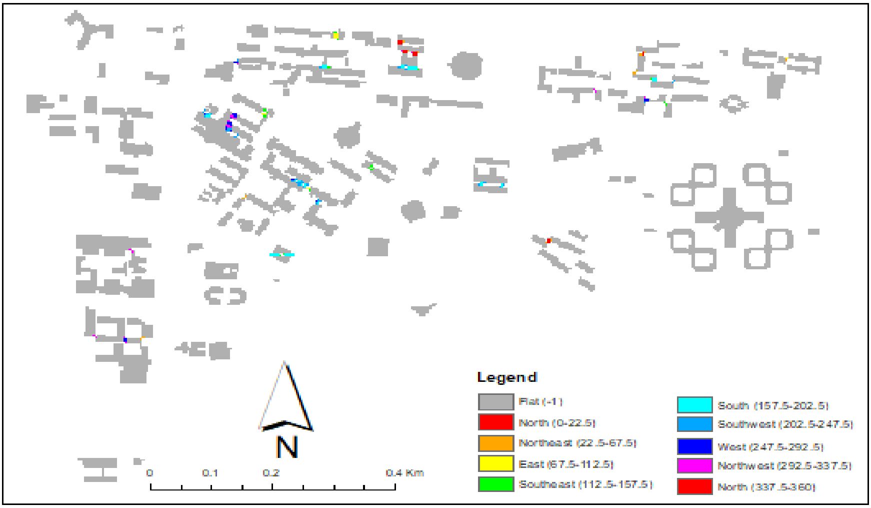


Figure 3: Aspect of UZ Rooftop Surface derived from ARCGIS

Flat surfaces are less likely to be affected by changes in illumination angles which change with seasons and this means that utilising those flat surfaces will guarantee constant supply of energy from PVs. All the surfaces on the aspect map show those surfaces with aspect (-1) that are flat and all other colours indicate any change in slope direction. This means that the University has a few of its rooftop surfaces oriented to different slope directions. Furthermore, the Area Solar Radiation (ASR) was estimated and it was found that flat surfaces have high area solar radiation and low radiation is associated with all other surfaces with different surface directions that are not flat. Figure 4 shows a map of solar radiation.

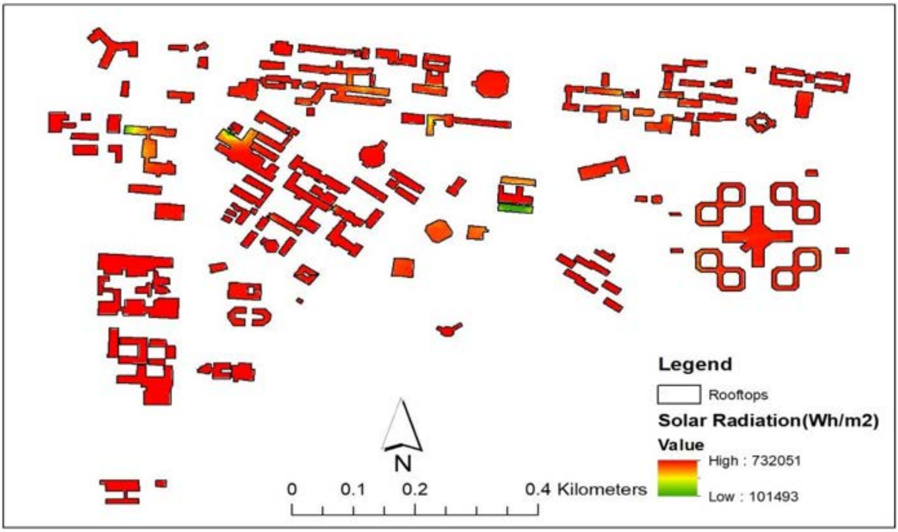


Figure 4: Area Solar Radiation of the UZ

As depicted by the area solar radiation map, the least rooftop surface can receive a significant amount of radiation of about 101.4kWh/m^2/year from the sun and a maximum radiation of 732kWh/m^2/year. This simply shows that the greater proportion of the UZ can receive a great amount of solar radiation from the sun which can be converted into PV sustainably.

DISCUSSION

From the analysis conducted, a number of important lessons in relation to solar energy utilisation and importance were noted. It was noted that solar energy offers a way to eliminate the metabolic rift while restoring a balance between human and metabolic relations. Since solar energy is a renewable resource, it can be made use of for economic and societal benefit sustainably without compromising the environment. In a bid to fight climate change, industrialised countries are switching to solar energy generation that is air pollution-free and, as such, adopting solar energy at the UZ campus is another way of fighting adverse climate change effects at a local scale. To meet the SDG7 of 2013-2030 of energy access to all by 2030, solar system development is the way to go, especially, for developing countries that are already facing challenges in electricity generation from other means like hydro power generation, due to climate change. Solar energy can be of use at various scales and, as such, the UZ solar energy can be of use in powering its daily activities, for example, water-heating, telecommunication and refrigeration of its laboratories.

Solar PV has become one of the most viable forms of electricity generation methods on a large-scale being adopted by many countries worldwide, due to its proven record of promoting sustainability with the environment (Nguyen and Pearce, 2010). To estimate the surface area, the capability of Google Earth Pro, which offers high resolution Satellite Imagery, was utilised. All of the rooftop surfaces at the UZ were digitised in Google Earth and were converted from keyhole mark-up language format (kml) to shapefiles in QGIS. The polygon shapefiles were re-projected to UTM coordinates for the calculation of area for each of the polygons and the area was determined for all the rooftop surfaces. The statistical findings of the research have been summarised in Table 3.

Table 3: Summarised statistical findings of the rooftop surface area at the UZ

Total Rooftop Surface Area	117389.45
Minimum Rooftop Surface Area	62.976
Maximum Rooftop Surface Area	4555.27
Mean Rooftop Surface Area	946.68
Median	664.7

The rooftop surface area was integrated with surface aspect to determine the direction of slope of roof surfaces available at UZ. It was found that the greater part of the UZ campus has flat rooftop surfaces, with nearly a negative (-1) aspect and this can guarantee constant reception of radiation by these surfaces without any interference from other structures around. Area solar radiation was determined and it was found out that an average UZ rooftop surface can receive a significant amount of radiation per year with the least surface receiving at least 101.4kWh/m^2/year and best larger surface receiving at least 732kWh/m^2/year. However, areas along roof edges and roof borders posed problems in digitising them, leading to an underestimation of surface area calculated.

CONCLUSION AND RECOMMENDATIONS

The article sought to estimate rooftop surface area at the UZ campus and, as such, the area was found to be approximately 117389.45 square metres which can be used efficiently to generate a significant annual PV at the UZ. The greater part of the estimated surface area was found to be concentrated at learning venues more than at student's halls of residence as evidenced by a greater number of building structures and this can make the learning environment more conducive when solar panels are pitched on its rooftops considering the noise that is produced by the university generator in the absence of electricity. The buildings at the UZ are almost of the same height so the effect of shadow from other surrounding buildings will be very minimal and also there are only a few buildings that are surrounded by trees which can pose the effect of shadow on rooftops. The central dining hall, on its own, has the largest rooftop surface area, indicating that on its own, it can sustainably produce PV energy which can be used to run some, if not all, of its operations without the need to switch to other forms of energy like gas. Having estimated the rooftop surface area of the UZ, it is, therefore, recommended that the university advances a number of options to adopt the installation and use of solar energy as:

- Installation of solar systems which promote sustainability and green energy.
- The university has to remove all trees around its administration block which can have a bearing effect on the reception of radiation by roof surface.
- Solar installation is the way to go to get rid of noise pollution at campus from main library and administration generators.

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