The Potential of Monaragala, Sri Lanka for Building Integrated Photovoltaics

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Abstract— *Solar energy is available in abundance on the island of Sri Lanka. The consumption of non-renewable energy resources has significantly increased in recent years, rapidly approaching the point of exhaustion. Moreover, the vast increase in energy consumption and CO_2 emissions has become a contributing factor of great concern in the construction industry. This research has a primary objective of attempting to determine the potential of a house in Monaragala district to generate renewable energy via photovoltaic technology in order to combat climate change. The potential and compatibility of houses in Sri Lanka for the installation of PV modules are studied, and climate change policies in Sri Lanka are widely analysed.*

The research focus is mainly on the potential of building integrated photovoltaics and whether household roofs in the district of Monaragala are suitable for photovoltaic installation. This is done by collecting sample houses, analysing roofs on their orientation and area, carrying out calculations on the potential electricity that could be generated by the average dwelling, and determining whether these could meet current energy demands.

Quantitative methods are made use of in this research in order to approach the research question. Mapping methods are utilised in order to establish roof area and orientation of houses, which are then used to compute the amount of electricity that can be generated via PV. Consequently, these values help to positively answer the research question, whether the need for fossil fuel energy in the domestic sector can be completely eradicated with the utilisation of PV.

It is eventually determined that, with the right allocation of government subsidies and other modes of encouragement, the requirement for fossil fuel energy in the domestic sector may be nullified by making use of photovoltaic technology. The project eventually illuminated possible errors in data gathering and how they could be eradicated in future research.

Keywords— **Photovoltaics, Building, Integrated, Potential**

I. INTRODUCTION

This research is carried out in order to investigate the potential of building integrated photovoltaics in the district of Monaragala in Sri Lanka, within the domestic sector. Since CO_2 emissions are ever increasing, causing pollution and hence climate change, there arises a necessity to minimise and cut down on fossil fuel usage in the country. The domestic and construction sectors currently hold a large part in the increasing levels of CO_2 emissions and consumption of fossil fuel energy, and this research attempts to take a step forward in reducing this use of non-renewable energy and emissions. Current government policies on energy and emissions, available mapping methods, the existing housing stock in Monaragala, and solar radiation data calculations are also investigated and carried out.

The aim of this research was to establish whether the current domestic houses in the district of Monaragala have appropriate roofs for PV installation, and approximately how much energy can be produced by the average house in the district. These aims included reviewing current Sri Lankan government policies, reviewing mapping techniques for the integration of PV, studying the current housing stock, obtaining data regarding roof orientations, house types and areas, acquiring annual weather data, and calculating the potential of BIPV.

After determining the aims, the objectives of the research were confirmed as carrying out intensive literature review on the current energy demand and emissions policies that currently exist in Sri Lanka, reviewing available renewable energy technologies in the country, identifying mapping methods that are available for photovoltaic integration, identifying the different types of existing houses and deciding on which to use for this research, obtaining solar radiation data for the district of Monaragala by means of EcoTect and PVSyst, carrying out data collection by the selected mapping method by using AutoCAD to obtain roof areas and orientations, evaluating the PV potential by using the obtained roofing data and solar irradiation data to calculate the total energy that can be generated by the average house in Monaragala, and carrying out a cost analysis of installing PV in a typical household in the district and evaluating the cost savings that can be achieved through photovoltaics.

A. Housing Stock in Sri Lanka

According to the Department of Census and Statistics, Sri Lanka (2012), the majority of houses in the country are single storied, taking over a percentage of 85.7%, whilst 7.2% are two storied housing units. 3.6% of the total housing units are 'line rooms', and 0.7% denote huts or shanties. Further, 47.5% of the housing units have used tiles for roofing.

B. Mapping Techniques

3D and 2D mapping techniques were well analysed in order to determine an appropriate mapping technique in order to calculate roofing areas. It was deduced that the most accurate and complex methods make use of 3D data in the form of Light Detection and Ranging (LiDAR) and Geographic Information Systems (GIS). These present a 3D terrain of the site, which allows convenient calculation of roof areas, shading, and radiation, and could further help to reduce the time taken to plan effective solar panel placement (Sanderson, 2014). The main drawback of the two software, however, is the high cost of purchase.

II. METHODOLOGY AND EXPERIMENTAL DESIGN

A. Orientation

In order to continue this project, AutoCAD was utilised as to create a compass that could be set against the maps to determine the housing and roof orientations accurately. It was established that roofs 90˚ from the North to 112.5˚ would be marked as East facing roofs. Those between 112.5˚ and 157.5˚ were classified as South-East facing roofs. Likewise, South facing roofs were denoted as those between 157.5˚ and 202.5˚, South-West as between 202.5˚ and 247.5˚, West as between 247.5˚ and 270˚. Any roofs that were North facing from the East-West line were not taken into consideration based on the rule that they are not orientated for maximum PV potential, i.e. roofs between 270˚ and 90˚. The wheel showing orientation classifications is displayed below (Figure 1).

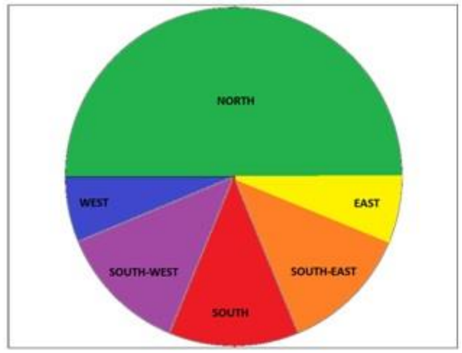


Figure 1. Orientation Wheel

B. Mapping and Samples

The district of Monaragala was used as the overall location in which to base this research. Therefore, houses in Monaragala district were sampled and analysed. Since the district was the area of residence, it was possible to personally visit and gather data that was not available via the internet or publications.

In order to obtain accurate data and results, it was decided to gather samples out of at least two cities within the district. Within these two cities, a couple of blocks of houses were chosen to be analysed. The process of analysis included determining the type of house, and roof orientations and areas. Shown below is a map showing the district of Monaragala within Sri Lanka (Figure 2).

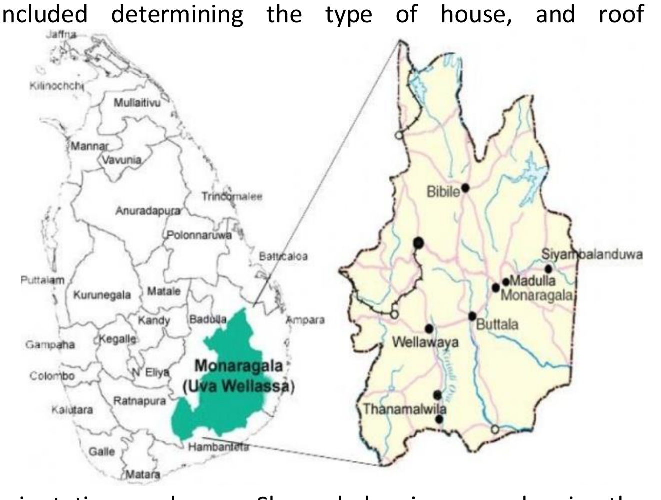


Figure 2. Map of Monaragala District

The cities selected for analysis were Nugegalaya and Monaragala. Blocks of houses were then selected from each of the two townships. The housing samples were chosen in order to make data collection and analysis more convenient, i.e. houses grouped together in an organised pattern. Skewed blocks with no directional pattern or randomly organised were not selected, since the roof orientations would be unique, and would therefore need to be analysed and accounted for individually, which would be time consuming and unfeasible. The following blocks of houses were, therefore, selected.

Town	Area (including roads)	Coordinates
Nugegalayaya	Kiribbanweva-Sooriyaweva Road (Bopale Junction)	6°20'24.6"N 81°00'04.5"E
	Hambantota-Gonnoruwa-Meegahajandura Road (Meegahajandura Junction)	6°21'34.9"N 81°02'02.0"E
Monaragala	Colombo-Batticaloa Highway	6°53'22.9"N 81°20'48.0"E
	Colombo-Batticaloa Highway	6°53'13.6"N 81°20'43.1"E

Table 1. Sample Areas

C. Obtaining Data: Case Study

This section presents how the project and its calculations were carried out. The data collection from the first block of houses, i.e. Nugegalayaya (6°20'24.6"N 81°00'04.5"E), is shown in detail so that it can be understood exactly how the data was accumulated.

Shown below is the map of Nugegalaya, offBopale Junction (Figure 3). There are very few domestic houses available in the area, compared to other urban and suburban residential sectors in Sri Lanka.

Figure 3. Location 1

A block of three (3) houses was selected at the Junction, a bit North ofMahamevnawa Monastery. Next, it had to be determined in which direction the separate roofs faced. By layering the orientation wheel against the map, it can be seen that two of the houses have West and North facing roofs, and the house on the left has a South and North facing roof. Since North facing roofs were determined to be unfeasible for PV installation, they were disregarded, and only the South and West facing roofs were taken into consideration for the collection of data.

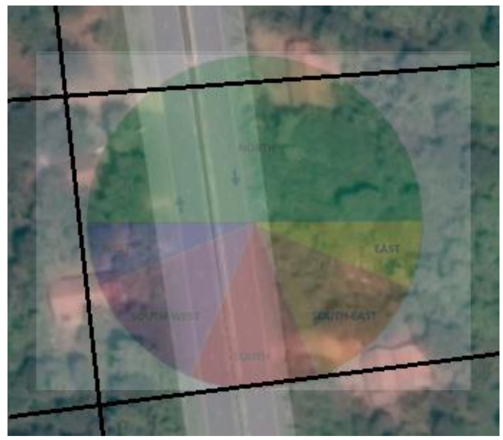
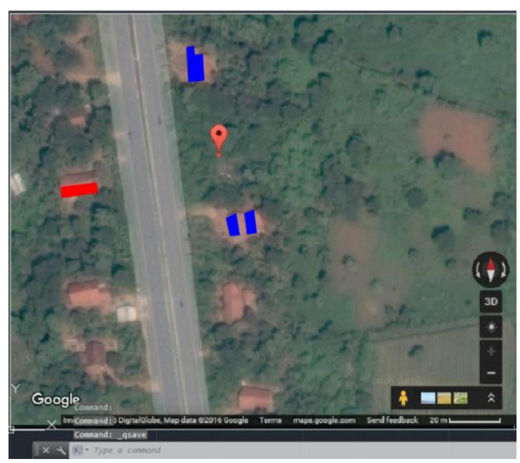


Figure 4. Location 1 Orientations

AutoCAD was then used to separate the roofs into their respective orientations. This would prove useful later on



when calculating total roof areas. The roof colours were allocated according to those on the orientation compass. The results are shown below (Figure 5):

Figure 5. Location 1 Mapped

It can be seen from the image that there is one South facing roof (hatched in red on AutoCAD), and three West facing roofs (hatched in blue on AutoCAD), where one of the houses has two West facing roofs. The data was organised by counting the number of houses analysed, and the number of roofs and their orientations. Then the area of the roofs was calculated using AutoCAD, and converted to metres by using the scale provided on the map (i.e. 20m:17.4791).

No. of Houses	Orientation	No. of Roofs	AutoCAD Roof Area (m^2)	Actual Roof Area (m^2)
3	West	3	97.8561	128.118
	South	1	41.0576	53.7546

Table 2. Location 1 Data

Using the same method, data collection was carried out for houses near Hambantota-Gonnoruwa-Meegahajandura Road (6°21'34.9"N 81°02'02.0"E). The roofs were then mapped as follows (Figure 6):

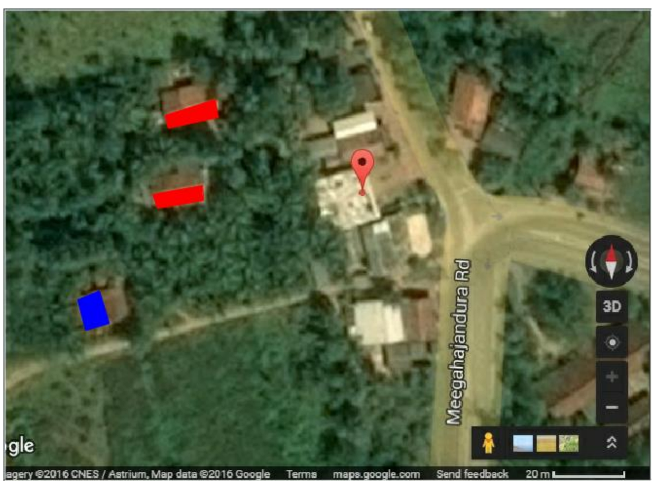


Figure 6. Location 2

No. of Houses	Orientation	No. of Roofs	AutoCAD Roof Area (m^2)	Actual Roof Area (m^2)
3	West	1	44.5225	59.62059
	South	2	88.0097	117.8548

Table 3. Location 2 Data

Similarly, housing samples were obtained and mapped on AutoCAD for the third sample area near Colombo-Batticaloa Highway (6°53'22.9"N 81°20'48.0"E), and is shown in the image below (Figure 7).

No. of Houses	Orientation	No. of Roofs	AutoCAD Roof Area (m^2)	Actual Roof Area (m^2)
2	South West	2	296.481	420.063

Table 4. Location 3 Data

Finally, the fourth area was mapped, also near the Colombo-Batticaloa Highway (6°53'13.6"N 81°20'43.1"E) as displayed (Figure 8).

Figure 8. Location 4

No. of Houses	Orientation	No. of Roofs	AutoCAD Roof Area (m^2)	Actual Roof Area (m^2)
4	South West	1	37.7659	61.5051
	South East	2	64.6461	105.282
	South	2	100.1361	163.080

Table 5. Location 4 Data

D. Solar Radiation Data

In order to calculate the PV potential of Monaragala district, the next step that had to be taken was to obtain annual average solar radiation data that is incident upon the area. An attempt was made to calculate average values for radiation data by using EPW weather files for EnergyPlus. Due to limited resources for Sri Lanka, the nearest location available on the weather file database was for Hambantota. This weather file provides a range of weather data for the region, including wind analysis, solar position and angles, hourly radiation, temperature, and relative humidity and many other values. The most important was the monthly radiation data that was provided by the file.

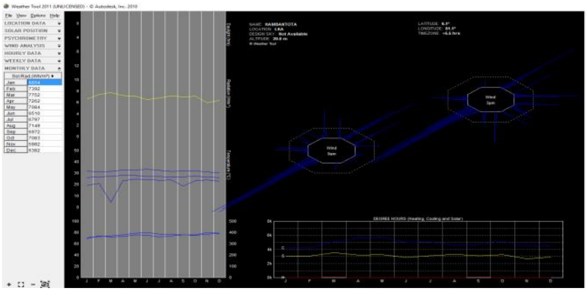


Figure 9. EcoTect Weather Data

Figure 7. Location 3

Thus, the radiation values obtained are given in the table below:

Month	Available Radiation ($kWh/m^2/day$)	Available Radiation ($kWh/m^2/yr$)
January	6.654	206.274
February	7.392	206.976
March	7.752	240.312
April	7.262	217.86
May	7.084	219.604
June	6.510	195.3
July	6.797	210.707
August	7.149	221.619
September	6.972	209.16
October	7.083	219.573
November	5.982	179.46
December	6.382	197.842
Annual Total		**2524.687**

Table 6. Weather Data

However, upon further inspection, these values appeared rather discrete, and improbable, since the average radiation data in the UK, as found by the Chartered Institution of Building Service Engineers (CIBSE - Guide J) approaches only $1000kWh/m^2$.

By comparing values obtained by the Sri Lanka Sustainable Energy Authority (2016), it was discovered that an Energy Atlas has been created to obtain annual solar radiation values for specific areas in Sri Lanka. By using this tool, a value of **$1901.8kWh/m^2/yr$** was obtained for the district of Monaragala.

III. RESULTS

A. Photovoltaic Potential in Monaragala

Since the available roof areas and solar irradiation in the district of Monaragala were obtained, it became possible to estimate how much electricity could be generated by the district in order to meet the energy demands on the average household in the domestic sector.

Next, the average electricity consumption of a rural household was assumed to be 20kWh per month. However, in order to better the standard of living, for the purposes of the calculations, the electricity consumption per month was taken as 40kWh, which is roughly the electricity consumption of a household in a semi-rural area. This means that the annual electricity consumption of an average household is 480kWh.

Next, it was essential to calculate the average roof area that was available for the installation of PV per household. The roofing data obtained through the research was used to complete this, by utilising the total available roof area and dividing it by the total number of houses that were sampled.

Area	SE m^2	S m^2	SW m^2	W m^2	Total Roof Area m^2
Bopale Junction	0	54	0	128	181.9
Meegahajandura Junction	0	118	0	60	177.5
Monaragala	0	0	420	0	420.1
Monaragala Town	105	163	62	0	329.9
Total number of houses	**12**	**Total available roof area m^2**			**1109.3**
Average roof area per household m^2					**92.4**

Table 7. Final Results

Assuming the utilisation of monocrystalline silicon PV panels, which are approximately 15% efficient at a maximum annual output of 100%, it became possible to obtain the total amount of electricity that could be produced by the average household by using PV, as such:

$$1901.8\frac{kWh}{m^2} \times 92.4m^2 \times \frac{15}{100} = \mathbf{26358.948}\boldsymbol{kWh}$$

Comparing against the average yearly household energy consumption, which is 480kWh/yr, a production of 26360kWh via PV is quite a staggering amount, and could render the necessity for fossil fuel energy unnecessary in the rural domestic electricity sector.

The CO_2 emissions were also calculated as another parameter. The overall average of CO_2 emissions in Sri Lanka is 0.71kg/kWh. By the usage of PV for electricity production, the total amount of electricity required by a household is not consumed through the grid, therefore there would be an emissions savings of:

$$0.71\frac{kg}{kWh}\times 480kWh = \mathbf{340.8}\boldsymbol{kg}$$

III. DISCUSSION AND CONCLUSION

Whilst conducting this research, many errors in data collection and the final results was realised. The most significant ambiguity was the roof area as assessed and obtained through Google Maps. It was noticed that the images available via Google Maps for Sri Lanka were undefined, grainy, and of low resolution. This made it hard to determine the borders of the roofs. Since the roof boundaries could not be ascertained, accurate roof areas could not be obtained. It is believed that roof lengths could differ from as much as 0.2m. The usage of software such as GIS or LiDAR would have been more precise, save for the high cost of purchase and financial restraints.

Another significant ambiguity was the roof tilt angles, where within the research, the roofs were assumed to be on a horizontal plane, but was however, not the case in reality. Many of the roofs assessed were actually tilted, which had a significant impact on the amount of solar radiation incident upon them. In order to gather more accurate data, it would be necessary to individually examine each house. However, this is time consuming and unfeasible, and a better solution would be to develop a software that consists of detailed information regarding individual houses within its database.

The final error was the shading incident on roofs. When collecting roof areas, it was assumed that solar radiation falls upon the entire roof. However, this is not the practical case, since most of the roofs are heavily shaded by surrounding trees and structures. This would cause the photovoltaic potential to decrease drastically.

Consequently, there are many means that could be taken to increase the accuracy of the research, such as using larger sample sizes and more samples of houses, and perhaps conducting individual case studies on a couple of houses to look into details such as roof tilt angles and areas based on personalised house visits.

A measure that could be taken by the government to make photovoltaic technology seem attractive to consumers is to introduce grid feedback tariffs, like those that have been implemented in countries such as the UK and the US, where the household owner is allowed to sell electricity back to the grid, in turn earning and income, and reducing the break even period for their investment.

The aim of this research was to determine the potential of building integrated photovoltaics in the district of Monaragala, Sri Lanka, by considering how possible it is to install photovoltaic systems in existing domestic houses, calculating the amount of electricity that can be generated, and how CO_2 emissions could be decreased.

A methodology was proposed that detailed how samples were chosen out of Monaragala district, and how the roof areas were calculated and assessed, in order to calculate the photovoltaic potential of the houses.

The limited mapping methods and data available in Sri Lanka were the main limitations faced when attempting this research. A suggestion and ambition is to expand the Sri Lankan mapping database via further research by creating a software consisting of all data on houses including roof tilt areas, angles and orientations, and will act as a smart tool to select houses as required, allowing the sampling and data gathering process to be much less time consuming and much more feasible and convenient.

ACKNOWLEDGMENT

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