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Rooftop Solar Photovoltaic-based Clean Development Mechanism for Sri Lanka

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Abstract

Solar energy is the most abundant energy source in the world. It can play a vital role in meeting our energy needs. Sri Lanka being a country that is located near the equator has a Global Horizontal Irradiance (GHI) of 1,247 kWh/m^2 to 2106 kWh/m^2 creates an excellent photovoltaic power potential. Implementation of rooftop solar PV installation projects can contribute towards reducing the carbon footprint. CO_2 (e) emission savings could be traded according to the Kyoto GHG protocol bringing financial benefits to the country. This paper presents a Clean Development Mechanism (CDM) for Sri Lanka through a rooftop solar PV installation project in the Western Province. The results show that 68.83 km^2 of an effective area for 14.92 GW of installed capacity generating 26.15 TWh annually. This could result in reducing around 20.4 MtCO_2e of carbon dioxide emissions, earning US$ 78 million of foreign currency per annum.

Key words: Solar PV, Carbon Footprint, CDM, Energy Security, Sustainable Development

Introduction

The photovoltaic effect generates voltage and electric current when the photovoltaics (PV) are exposed to light [1]. The solar PV based electricity generation is one of the options that could ensure energy security and sustainability. Solar PV accounted approximately 3.7% of the total global electricity production in 2020. Out of the renewable energy sources used in electricity generation this corresponds to 42%. There is 760.4 GW of total installed capacity saving around 877 MtCO_2(e) emissions [2]. There has been continuous advancements in PV technology making solar panels efficient and cheaper [3]. Rooftop solar has significant advantages over other types of solar options. Use of unused roof space, cheaper to mount, saving land for other uses, giving additional protection to the roof and being easy to install are some of the advantages [4]–[8].

In recent times burning fossil fuels for electrification has become a burden for the Sri Lankan economy. Having to import fuels affect energy insecurity having an impact in their social lives as well. Therefore, Sri Lanka requires more renewable based electricity generation to ensure the country's energy security [9], [10]. Being a country near the equator Sri Lanka has great photovoltaic power potential with a GHI of between 1,247 kWh/m^2 to 2106 kWh/m^2 [11]. By the end of 2020, an estimated 414 MW of solar PV capacity was connected to the grid [12]. Hence, the solar potential of the country is yet to be exploited. Given the limited land availability, rooftop mounting will provide additional benefits [13]. Therefore, it's critical to investigate the rooftop area that could be used to mount solar panels and thus achieve the generation capacity.

The Clean Development Mechanism (CDM) [14] was introduced through Kyoto Protocol under the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 and has been in force since 2005 [15]. It allows carbon trading to encourage reducing the Greenhouse Gas (GHG) since 2005. According to the State and Trends of Carbon Pricing 2020 [16], there are 8142 registered CDM activities globally involving 111 counties in 2020. It covers 10 sectors which includes energy efficiency, forestry, fuel switch, fugitive emissions, industrial emissions, manufacturing, wastage, transportation, renewable energy and Carbon Capture and Storage (CCS)/ Carbon Capture Utilization (CCU).

It was estimated that Sri Lanka received 6.2 million potential Certified Emission Reductions (CERs) through CDMs by 2013 [17]. Moreover, CDM projects can help developing counties to meet United Nations (UN) defined Sustainable Development Goals (SDGs) [18]. It is through technology transfer, financial resource transfer, sustainable energy production, improving energy efficiency and conservation, earning foreign currency and creation of job opportunities towards poverty alleviation, and preserving local natural environment [19].

The study was initiated with the identification of the timely importance of the rooftop solar PV projects for the country to overcome the existing energy crisis and to alleviate the potential risks in future energy supply while giving some incentives for the development of CDM programs wherever possible. Given the potential for solar power generation, this research study aims to demonstrate a renewable energy electricity generation based CDM for Sri Lanka that replaces conventional fossil fuels in that reduces carbon footprint through rooftop solar PV installation in the Western province of Sri Lanka. Nevertheless it will help the country to overcome the energy problems while contributing to the country's energy trilemma balance [20]. This will also help to earn foreign currency and mitigate undesirable environmental impacts.

To estimate the potential for solar PV, estimating the available area for panel installation is critical. This study calculated the available rooftop area in the Western province of Sri Lanka that could possibly use for the installation of solar panels using two different methods for the estimation of net effective rooftop area and validation of results. These are namely the constant value method and the Arc GIS-based method. Using the estimated rooftop area, solar PV installation capacity and annual electricity generation potential were calculated. Using the value for annual electricity generation, the CO_2 (e) emission reduction was estimated under GHG protocol scopes [21], [22] to propose a CDM.

Past studies have used several methods for estimating the rooftop area suitable for solar PV installation. Melius et al. [23] have reported a novel method called the "NREL method." Other studies that have used the constant value method include Chaudhari et al. [24], Denholm [25], Paidipati et al. [26], Vardimon et al. [27], Lehmann et al. [28], and Wiginton et al. [29], whereas Compagnon et al. [30], Kodysh et al. [31], Anders et al. [32], and Santo et al. [33] have adopted GIS-based method. Once the effective rooftop area is determined, solar PV capacity and electricity generation can be estimated using equations that include insolation, module efficiency and area available for PV per capita as parameters [29] or solar panel efficiency, average solar radiation absorbed by the panels and performance ratio in major for given solar PV system as parameters [34] or using solar radiation map in a GIS software [35].

Gagnon et al. [36] used GIS-based methods and lidar data to estimate rooftop solar potential in cities across the United States. A similar study was conducted in India, which used GIS data for potential rooftop mapping and PVSyst for PV system design [37]. Jamal et al. [38] analysed potential total electricity production using ArcGIS software and the HOMER optimization tool. Another project in India designed a 6.4 kWp grid-connected rooftop solar PV system using simulation power generation. In addition to the benefits mentioned above, this study demonstrates a CDM software such as PV*SOL, PVGIS, SolarGIS, and SISIFO to analyse the performance of a grid-connected rooftop solar photovoltaic system [39]. Another study conducted by the Rajasthan Technical University in India used the PV*SOL software to implement a solar PV system for one of their buildings [40]. Once the solar PV electricity generation has been identified, the carbon footprint can be calculated using the Sri Lanka Sustainable Energy Authority's (SLSEA) published contribution factors-based method [41] or the factors presented in Awanthi et al. [42] and Loyarte-López et al. [43].

Study Area - Provincial Details

The details of land area, demographics and number of buildings with respect to the Western province is given in Table 1. Due to the lack of building data available for recent years, this study used the 2012 census data published by the Department of Census and Statistics [44], [45] for the interpolation of details for the year 2020 assuming a linear correlation with the population growth rate.

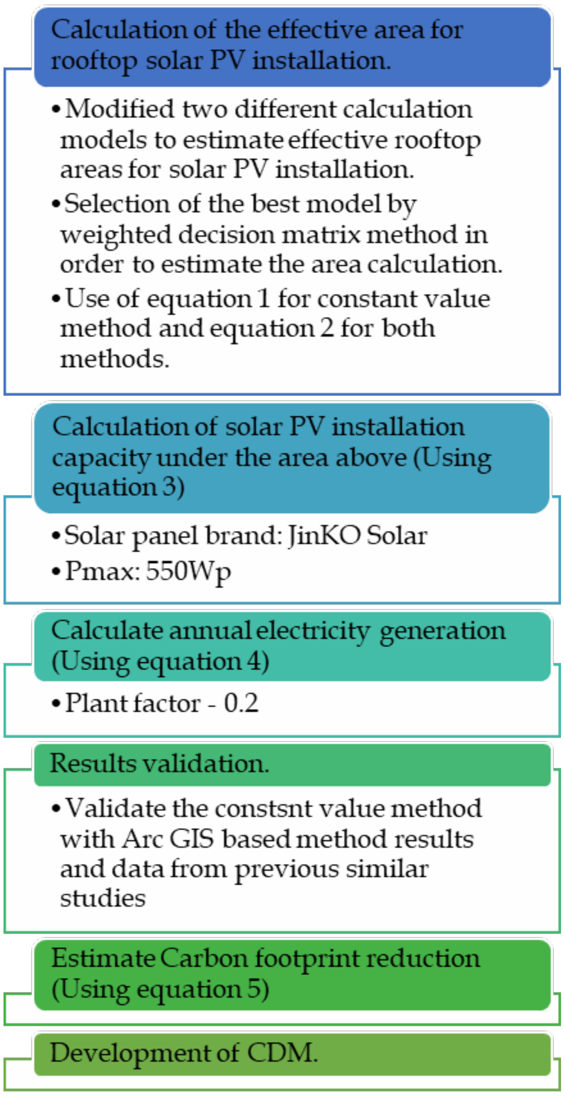
Table 1: Details of the Western Province

Ground area (km^2)	3,684
Population in (2012)	5,851,130
Population in (2020)	6,165,000
Total number of building units (2012)	1,666,854
Total number of building units (2020)	1,826,207

Methodology

The details of the methodology used in this study has been given in Figure 1. The first task was to estimate the available rooftop area for solar PV installation. Accordingly, this study adopts two area calculation models developed already with some changes to match up with the Sri Lankan context.

Figure 1: The Methodology to Conduct the Research Project



Out of the proposed methods the constant value method uses census data and population data published by the government while Arc GIS-based method uses Arc Map software. Using a weighted decision matrix, the above methods were evaluated and the constant value method was selected as the most suitable way of performing the area estimation. The Arc GIS-based method was also performed to develop a data set to validate the results of the constant value method. Using the value obtained for the estimated area, the solar PV installation capacity and annual electricity generation potential were calculated with respect to a solar panel model accredited by the Sustainable Energy Authority (SEA). In the next step, the results from the constant value method was validated using the results obtained in the Arc GIS-based method.

According to the validated constant value method of annual electricity generation, the CO_2 (e) emission reduction was estimated following the GHG Protocol scopes to propose a CDM. This study was able to quantify the potential revenue earned using this CDM project in the Western Province considering the recent Carbon Credit Price in the market. All the equations used in the calculations are reported in the Calculations and Results section.

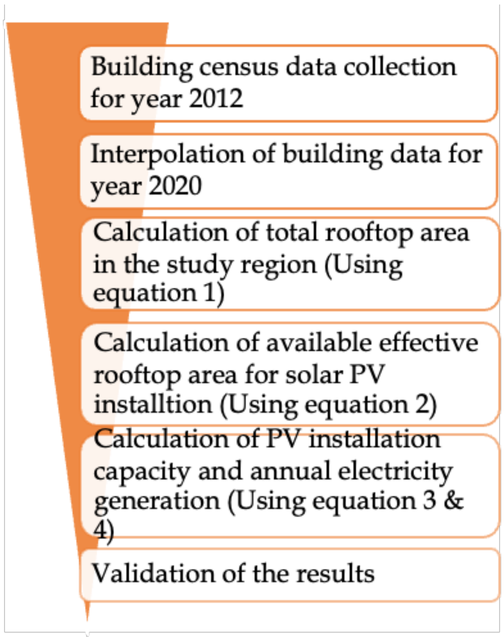
Constant Value Method

Among the two methods chosen for the study, the constant value method is the simplest and requires the least amount of time and resources.

It used published building census data, estimated average building size, and correction factors for the calculations. The most recent building census data sheet available was the "Census of Population and Housing - 2012" [44], [46], [47]. Therefore, under this method, the building census for 2020 was interpolated as a ratio of the Western province's population growth rate from 2012 to 2020. It helped to improve calculation accuracy, which could be compared to the results of the Arc GIS-based method that uses updated Google Earth images for its calculations.

The average building size was calculated using the information obtained for 3,000 houses in the study area via Google Earth and Google Maps. The available rooftop area was estimated using four validated multiplying factors (correction factors) to compensate for rooftop area reduction due to shadow, structural strength, tilt, and panel spacing. Following the estimation of available rooftop area for solar PV installation, the PV installation capacity and annual electricity generation potential were calculated and validated using the methodology shown in Figure 2.

Figure 2: Methodology for the Constant Value Method



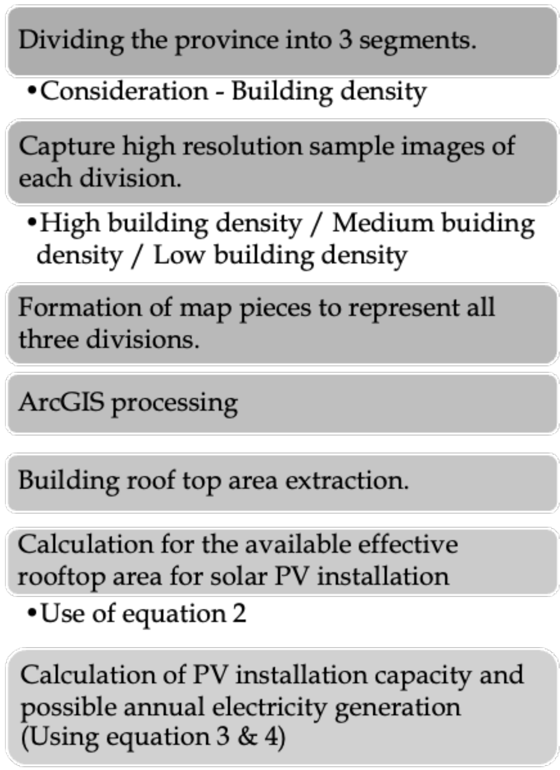
Arc GIS Based Method

The main steps involved in this method are shown in Figure 3. Compared to the previous constant value method, this method requires more time and resources. To calculate the area using this method, the Western province was divided into three distinct segments. The identification of the segments was based on the density of buildings as seen on Google Earth/Google Map. High resolution Google Earth images were captured to represent each division using Fireshot software.

The images were then merged to create three pieces of the Western provincial map that represents a significant area of each of the three divisions using the Adobe Photoshop software platform. With the help of the object-oriented image classification technique available in the Arc GIS platform, these three map pieces were processed in the Arc GIS software to identify rooftop areas in the Western province. With our experience, we would recommend supervised image classification over unsupervised image classification for higher accuracy, but at the expense of time spent on the procedure.

Once the image classification was complete, the rooftop areas that were not detected was manually added by comparing them with the original image. The resultant area values of each division were then interpolated for the entire division while taking the sample ground area to total ground area ratio into account. Then the total available rooftop area for solar PV installation was calculated using correction factors stated above. The rooftop solar PV installation capacity and annual electricity generation potential were then estimated using the method used in the constant value method. It could validate the results obtained through the constant value method.

Figure 3: Methodology of Arc GIS based Method



Assumptions for Calculation Methods

- ✓ The amount of space obstructed by building components such as heating, ventilation, and air-conditioning (HVAC) systems is assumed as 17% for the constant value method. Inclusion of such areas in the results and error in image classification is assumed as 5% for the Arc GIS-based method.
- ✓ The amount of space obstructed by indirect shadows, poor roof structural strength and material incompatibility is assumed as 10 %.
- ✓ The amount of space obstructed due to the consideration of rooftop facing (south facing, north facing, flat, etc.) was taken as 50%.
- ✓ The amount of space obstructed due to panel spacing and other potential issues is taken as 25% [23].

Calculations and Results

The estimation of the total rooftop area in the province, effective area, installation capacity and the annual electricity generation for Solar PV were calculated using equation 1, 2, 3 and 4 and the corresponding results are summarized in Table 2.

Table 2: Important Steps of Constant Value Method and Arc GIS based Method

Method	Constant Value Method	Arc GIS based Method
Total Building Units (2020)	1,826,207	
Average building size (m^2)	134[a]	
Total rooftop area in the province (km^2)	244.71	247.37
C_1	0.75	0.95
C_2	0.75	0.90
C_3	0.50[b]	0.50[b]
C_4	0.75[c]	0.75[c]
Effective area for solar PV installation (km^2)	68.83	79.31
Solar panel size (m^2) (2.278 m x 1.1134m)	2.54	
Number of panels need for the project	~ 27,135,786	~ 31,271,396
Solar panel capacity (W)	550	
Solar PV installation capacity (GW)	14.92	17.20
Plant factor	0.2[d]	0.2[d]
Annual electricity generation (TWh)	26.15	30.13

[a] – Calculated through a survey conducted for 3000 building units over the Western province.
[b] – Estimated through the same survey.
[c] – Directly adopt from [23].
[d] – Plant factor reported in [48].
C_1, C_2, C_3 & C_4 – Correction factor 1,2,3 & 4

$$\text{Total rooftop area in the province} = \text{Total Building Units} \times \text{Average building size} \qquad \text{Eq. 1}$$

$$\text{Effective area for solar PV installation} = C_1 x\, C_2 x\, C_3 x\, C_4 x \text{ Total rooftop area in province} \qquad \text{Eq. 2}$$

Where; C_1, C_2, C_3 & C_4 are correction factors shown in Table 2.

$$\text{Solar PV installation capacity} = \frac{\text{Effective area for solar PV installation}}{\text{Solar panel size}} \times \text{PV panel capacity} \qquad \text{Eq 3}$$

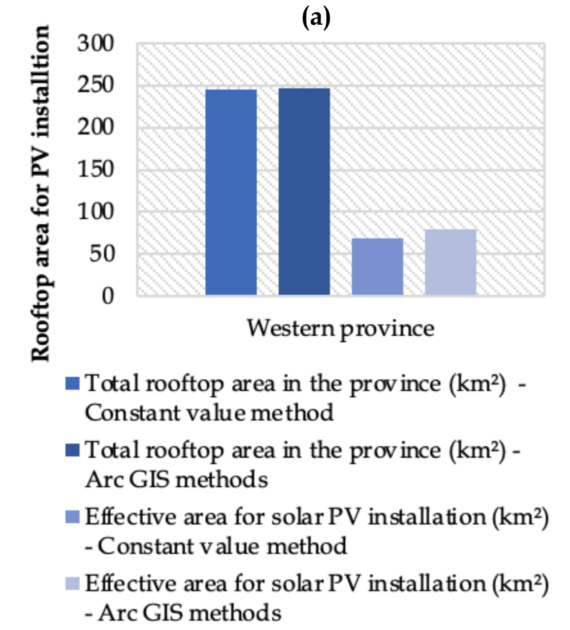
$$\text{Annual electricity generation} = \text{Solar PV installation capacity} \times \text{Plant factor} \times 8760 \qquad \text{Eq 4}$$

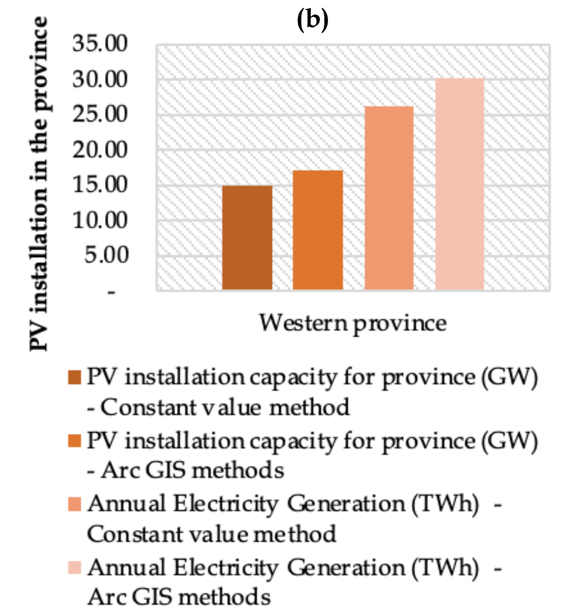
$$CO_2 \text{ Emission} = \text{Annual electricity generation} \times \text{Emission Factor} \qquad \text{Eq 5}$$

Figure 4: Graphical representation of

(a) Total and Net Effective Rooftop Area in the Western Province for Rooftop PV Installation

(b) Solar PV Installation Capacity and Annual Electricity Generation Potential from the Constant Value Method and Arc GIS Method





Results Validation

$$Total\ rooftop\ area\ in\ the\ province = Total\ Building\ Units\ x\ Average\ building\ size$$ Eq. 1

$$Effective\ area\ for\ solar\ PV\ installation = C_1 x\ C_2 x\ C_3 x\ C_4 x\ Total\ rooftop\ area\ in\ province$$ Eq. 2

Where; C1, C2, C3 & C4 are correction factors shown in Table 2.

$$Solar\ PV\ installation\ capacity = \frac{Effective\ area\ for\ solar\ PV\ installation}{Solar\ panel\ size}\ x\ PV\ panel\ capacity$$ Eq 3

$$Annual\ electricity\ generation = Solar\ PV\ installation\ capacity\ x\ Plant\ factor\ x\ 8760$$ Eq 4

$$CO_2\ Emission = Annual\ electricity\ generation\ x\ Emission\ Factor$$ Eq 5

Figure 4: Graphical representation of

(a) Total and Net Effective Rooftop Area in the Western Province for Rooftop PV Installation

(b) Solar PV Installation Capacity and Annual Electricity Generation Potential from the Constant Value Method and Arc GIS Method

Figure 5 depicts the results obtained from the constant value method and Arc GIS-based method. With respect to these details and literature extracted from the previously published similar work, the constant value method results were validated using three authentications.

Authentication 1

The total rooftop area calculated by constant value method was 244,711,742 m^2, whereas Arc GIS provided a rooftop area of 247,374,435 m^2. The pure building area value extracted from the constant value method is approximately 98.9% of the area obtained by the Arc GIS-based method with correction factors are not taken into account. Therefore, there is a degree of confidence to accept the results of the constant value method.

Authentication 2

According to results, the effective rooftop area that considers correction factors, installation capacity and annual electricity generation potential derived from the constant value method 87% of the value obtained from the Arc GIS-based method. Therefore, after the consideration of correction factors, the constant value method results seem to be more realistic.

Authentication 3

The net effective multiplication factor considered in the constant value method is 28%. This is because the correction factors considered to compensate for the area reduction due to shading, poor roof strength, tilt, panel spacing and other non-considered factors are 17%, 10%, 50% and 25% respectively. Therefore, the net selection factor of the constant value method in this study being well below the selection factors in those similar studies, reported in Table 3. It assures the accuracy of constant value method results.

Table 3: Different Selection Factors have been Considered in Similar Previous Studies

Studied Region	Selection Factor (%)	Ref.	Remark
USA	> 58	[49]	All 2 methods
USA	51.2	[50]	
USA	27^{RB} & 60^{CB}	[25] [26]	Constant value method
Puerto Rico	50	[51]	
Israel	30	[27]	
USA	60–65^{CB} & 22–27^{RB}	[52]	
USA	57.8	[53]	
Southeastern Ontario	30	[29]	
Bardejov, Slovakia	59	[54]	Arc GIS-method
Europe	59.06	[54]	
^{RB} – Residential Building & ^{CB} – Commercial Building			

Development of a CDM

Based on the solar PV results from the Constant Value Method, the annual electricity generation potential of a project that installs rooftop solar PV in the western province is 26,148,043 MWh, with a total generation saving of approximately 28,734,084,720 MWh per year. As a result, with the implementation of this rooftop solar PV installation project in Sri

Lanka's western province, approximately 20,401,200 tCO2e of GHG emissions could be reduced each year, as shown in

Table **4**. This could be traded for a developed country under the Kyoto protocol. At the 2021 carbon credit price of US$3.82/tCO2e [55], there could be an annual earnings of approximately 77,932,585 USD as shown in Table 5.

Table 4: Carbon Footprint Reduction under the Proposed Rooftop PV Installation Project

<table>
<tr><td colspan="5">In this calculation, the SLSEA-defined emission factors are used [41].</td></tr>
<tr><td colspan="3"></td><td>Emission Factor</td><td>Units</td></tr>
<tr><td rowspan="2">Scope</td><td>2</td><td>Electricity</td><td rowspan="2">0.71</td><td rowspan="2">kg/kWh</td></tr>
<tr><td>3</td><td>Electric power transmission and distribution losses</td></tr>
<tr><td colspan="5">The electric power transmission and distribution losses factor is taken as 9% [56].</td></tr>
<tr><td colspan="5">Using equation 5</td></tr>
<tr><td colspan="3">Electricity Saving (TWh)</td><td colspan="2">CO_2 Emission (tCO_2e/ Year)</td></tr>
<tr><td colspan="2">Under Scope 2</td><td>under Scope 3</td><td>Total</td><td></td></tr>
<tr><td colspan="2">26.15</td><td>2.59</td><td>28.73</td><td>20,401,200.15</td></tr>
</table>

Table 5: Foreign Revenue from Carbon Savings

Carbon Credit (US$/$tCO_2e$)	3.82
Earning (US$/year)	77,932,585

Discussion

This study determined the rooftop solar installation capacity and annual electricity generation potential for the Western Province of Sri Lanka. It used two methodologies: Constant Value Method, which is based on building census data published by the Department of Census and Statistics, and the Arc GIS-based Method, which uses Arc Map software for rooftop identification via supervised image classification supported by other software. Both methods include correction factors to provide an accurate output result while accounting for the rooftop area availability reduction due to shading, the roof's poor structural strength, tilt (south facing, north facing, flat, etc.), and panel spacing, along with other potential minor issues. For the constant value method, correction factors of 17%, 10%, 50%, and 25% were used. For the Arc GIS method correction factors used were 5%, 10%, 50%, and 25%. Shading was considered in this case under two distinct conditions: direct shading caused by building components such as HVAC systems and indirect shading caused by building shadows.

Furthermore, the indirect shadows, along with poor structural strength of the roof and material incompatibility, constituted 10% of the correction factor for both methods. Direct shading-based correction was taken as 17% for the Constant Value Method and 5% for the Arc GIS-based method because supervised image classification does not consider directly shaded rooftop area in its proceedings because the training model defined another layer for such area. However, 5% of the correction factor was considered to compensate for errors.

Accordingly, to the results of the constant value method, out of total rooftop area of 244.7 km^2 in the province, 68.8 km^2 of effective area was identified for solar PV installation. It corresponds to 14.92 GW of solar PV installation capacity and 26.15 TWh of annual electricity generation potential for the Western province of Sri Lanka. The Arc GIS based method provided that out of total rooftop area availability of 247.4 m^2, an area of 79.3 km^2 could be used for solar PV installation. It will provide 17.20 GW of solar PV installation capacity and 30.13 TWh of annual electricity generation potential.

The average building size used in the constant value method was derived from a survey conducted through Google Earth and Google Map platforms selecting 3000 building units in the study area as a sample deriving the 3rd correction factor also (50% for tilt) in both calculation methods. The estimation of solar PV installation capacity was based on the SEA-recognized JinKO solar panel available in the Sri Lankan market [57]. The calculation of the annual electricity generation potential was based on a 20% plant factor reported in Rathnasiri et al. [48]. Furthermore, results from the Constant Value Method were validated using three authentications based on the Arc GIS-based method results and the data reported in previous studies. Accordingly, the finalized effective rooftop area of solar PV installation was estimated as 68.8 km^2. It will give a solar PV installation capacity of 14.9 GW leading to an annual electricity generation of 26.1 TWh. For this annual electricity generation, the carbon footprint reduction could be calculated using the GHG protocol and the SLSEA-defined carbon footprint calculation method. According to these results it will reduce 20.4 MtCO2e. If this is proposed as a CDM based carbon trading from Sri Lanka to a developed country at a price of 3.82 US$/tCO2e, it could generate approximately US$ 78 million per year. The calculations show that this type of project has a high potential for ensuring the sustainability of the country's energy industry. Given this opportunity, the necessary steps must be taken to capitalize on renewable energy resources available across the country.

Conclusions

This study was conducted to identify potential opportunities for renewable energy development that contributes to timely neediness and ensures the security of future energy flow in Sri Lanka. To meet this requirement, this study proposed a CDM that can save 20.4 MtCO2 (e) of carbon emissions per year while bringing in approximately US$ 78 million in foreign currency per year. The proposed CDM is the installation of rooftop solar PV panels in the country's Western province. As a result, we discovered and validated an effective rooftop area that could be used for solar PV installation and the adopted two area calculation models with small alterations. Using the constant value method, it was estimated that there is 245 km^2 of total rooftop area availability in the province and 68.8 km^2 of an effective area for solar PV installation was calculated. This was validated from Arc GIS results and literature details. Calculations using SEA-recognized solar panels show that the study area has a potential for 14.9 GW of solar PV installation capacity and 26.2 TWh of an annual electricity generation based on the availability of the area. Based on these values, we can conclude that Sri Lanka has a huge opportunity to maintain its energy supply by increasing the share of the renewable energy mix.

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