SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

An Environment Perceptive on Solar Installation for University Campus: A Case of Universiti Utara Malaysia

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ARTICLE INFO

Article history:
Received 23 October 2022
Received in revised form 29 November 2022
Accepted23 December 2022
Available online 16 January 2023

Keywords:
Solar energy; University campus; Installation; Economic; UUM

ABSTRACT

Sustainable energy has become the main agenda globally. Among the renewable energy (RE) sources, solar provides huge potential in electricity production due to the abundance of sun radiation. As tropical country Malaysia enriched with solar radiation the whole year. This paper aimed to study the environmental perspective towards solar installation in the UUM campus building. Climate change sharply decreased by implementing the solar photovoltaic (PV) system up to 91.2 % compared to the conventional source of electricity supply. The global warming impact of solar panel installation was in the range of 44.74 to 178.99 g CO2EQ / kWh. The most contributing process towards this impact was transportation. Installation PV in UUM campus, could avoided carbon dioxide emissions equivalent to 996 ton of waste recycled instead of landfilled or 47583 tree seedlings grown for ten years. Hopefully, the result encourages stakeholders to consume solar power as the primary source of renewable energy components on the way to achieving the Malaysia government's target of 50% RE in electricity generation.

1. Introduction

A substantial number of universities worldwide are scheduling appropriate investments to expand their sustainability in short and medium terms [1]. Related to this, universities consuming clean energy in their campus. Highers top three rank in SDG 7 (Affordable and Clean Energy) for Time Higher Education (THE) consuming renewable energy in campus operation. King Mongkut's University of Technology Thonburi target to install 2MW solar rooftop by 2024. Nevertheless, universities' contributions towards environmental impacts and resource efficiency cannot be disregarded as there are over 13,000 universities worldwide, and the amount is still increasing, especially in developing countries with more prominent environmental hitches. As a complicated

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https://doi.org/10.37934/araset.29.2.223235

ecosystem, universities can be recognised as 'small towns' because of their exhaustive community and establishment of multiplex services, including education, commercial, medical, and outdoor activities. All these processes significantly employ natural resources and cause substantial impacts on the environment [2]. This issue is consistent with the Sustainable Development Agenda 2030 and the Sustainable Development Goals (SDGs) since it helps to ensure that everybody has access to sustainable energy sources (SDG7), ensure fair, comprehensive, and continuous decent education (SDG4), and effective information and communication technologies (a component from SDG9) [3]. The installation of solar energy is right in confirming that the effort is effective [4,5]. As of today, many universities have executed solar power on their campus. The same applies to the University of Utah, where it implemented solar panels that would bring up to 71% of the electric generation from renewable sources to their university campus. This initiative reduces local pollution significantly and increases air quality.

Throughout the adoption of new technology, higher education institutions such as colleges and universities play a significant role in society. Solar energy has been implemented widely in many buildings, and it includes university buildings as well. As for now, universities in Malaysia have played their roles and have been listed in the UI GreenMetric World University Rankings in the year 2020, including Universiti Putra Malaysia in the 28th place and Universiti Utara Malaysia in the 77th place. In 2019, UiTM Holdings Sdn. Bhd. was granted a 50 MW capacity solar project located in Gambang, Pahang, making it the earliest campus throughout the world to invest in a green scheme through the issue of ASEAN Green SRI Sukuk. Furthermore, the assistance from the Green SRI Sukuk scheme ultimately fosters greater investor access and prioritises environmental and social effects [6]. This shows that universities in Malaysia have an enormous potential to develop solar energy in their university campuses and are currently supported by the government of Malaysia in many ways [7].

To address the environment, the best solution available is using the life cycle assessment (LCA), an established method applied in many studies. Prior research [8] reviewed existing studies about LCA applied to buildings and identified two classifications, which were the building industry (e.g., construction) and building sector (e.g., residential and commercial). Table 1 summarises similar studies that use LCA for building-integrated solar photovoltaic (PV) systems. Most of the research assessed regular environmental matters, mostly CO_2 emissions. LCA studies based on other diverse impact categories are scarce [9].

Table 1
Summary of similar previous studies

University	Country	Objective	Result	Reference
King Mongkut's University of Technology Thonburi	Bangkok, Thailand	52.7 kWp solar installation	Projected to avoid ~1.00E+06 kg CO_2-eq over its lifetime	Eskew *et al.,* (2018)
National University of Colombia	Bogota, Colombia	1 kWh produced with a PV system	The environmental impact was reproduced in the process of extraction, transport, and disposal of PV panels	Sierra *et al.,* (2020)
Autonomous University of Barcelona	Barcelona city centre	Compare type of rooftop	Impacts produced by BAPV on climate change equivalent to -430 kg CO_2 eq/m^2	Corcelli *et al.,* (2019)

This paper aims to

I. Evaluate the life cycle assessment (LCA) impact on the solar PV system
II. Compare the LCA of solar PV and conventional resources' electricity supply at Universiti Utara Malaysia (UUM), Sintok, Kedah, Malaysia.

2. Methodology

The life cycle assessment (LCA) is a method that intends to interpret the environmental impacts of electricity generation based on the solar installation's entire life cycle. In this study, the boundary involved extraction, transportation, and installation during its process. Figure 2 and Figure 3 show the system boundaries for solar and coal-based electricity generation in Malaysia, respectively.
For the assessment of the installation of the PV system at Universiti Utara Malaysia (UUM), Kedah Malaysia, the ISO 14040 and ISO 14041 standards were employed based on the OPENLCA software application. This software application has a graphical interface that permits input of the flows of resources according to the model to be examined. Furthermore, this software has associated major global databases with the inputs and outputs for many processes throughout their life cycle, including Ecoinvent, NEEDS, AGRIFOODPRINT, and other more established database [13]. The environmental impact study was developed with the CML2001 methodology [14].

Universiti Utara Malaysia's (UUM) location in the northern region of Malaysia is enriched with radiation up to 633 W/m^2, the most suitable for on-campus solar installation. Figure 1 shows the average solar irradiance for Malaysia in 2021.

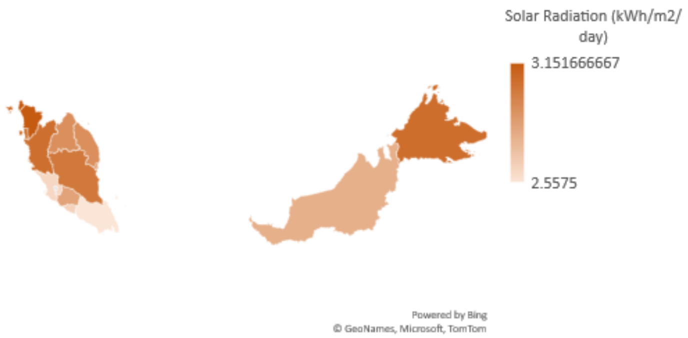


Fig. 1. Malaysia solar radiation in 2021

2.1 Research Scope

The study aimed to compare the environmental impacts under the CML2001 methodology, between 1 kWh generated with an installation of a photovoltaic system and 1 kWh of the conventional type of electricity generation using coal. The assessed impact categories presented a systems-oriented approach, grouped into 11 damage categories, such as climate change and acidification, which determine their highest impact during the entire life cycle, as indicated in Figure 2.

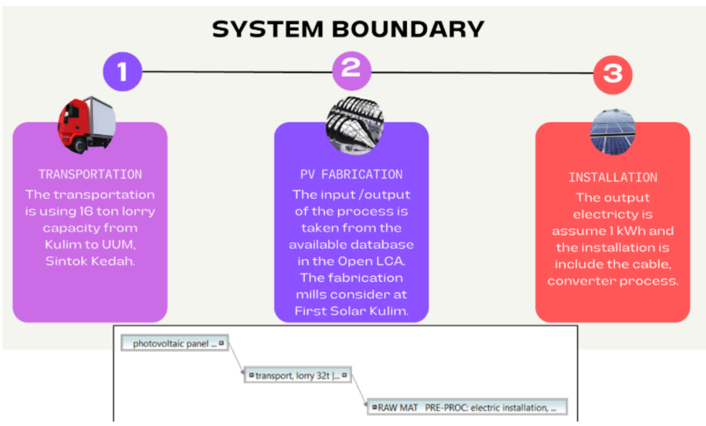


Fig. 2. System boundary of solar-based electricity generation

2.1.1 Rooftop PV panel and installation process

The UUM campus is fully furnished with contemporary facilities. The focal buildings on the campus are the academic buildings, the library, the administrative buildings, University Health Centre, and the Sports Centre. Figure 3 illustrates the UUM campus map. The academic buildings comprise three colleges: the College of Business (COB), College of Arts and Sciences (CAS), and College of Law, Government, and International Studies (COLGIS). This study only focused on the academic buildings and selected schools due to the available data from the Development and Maintenance Department (JPP). The selected schools were the School of Technology Management and Logistics (STML), School of Economics, Finance, and Banking (SEFB), and School of Business Management (SBM) under COB; and the School of Quantitative Sciences (SQS) and School of Multimedia Technology and Communication (SMMTC) under CAS. Lastly, Lecture Halls DKG 1–6 were also chosen in this study. The structure of the case study is shown in Figure 3. Rooftop PV systems are frequently the ideal installation sites for most residential and several non-residential selections [15].

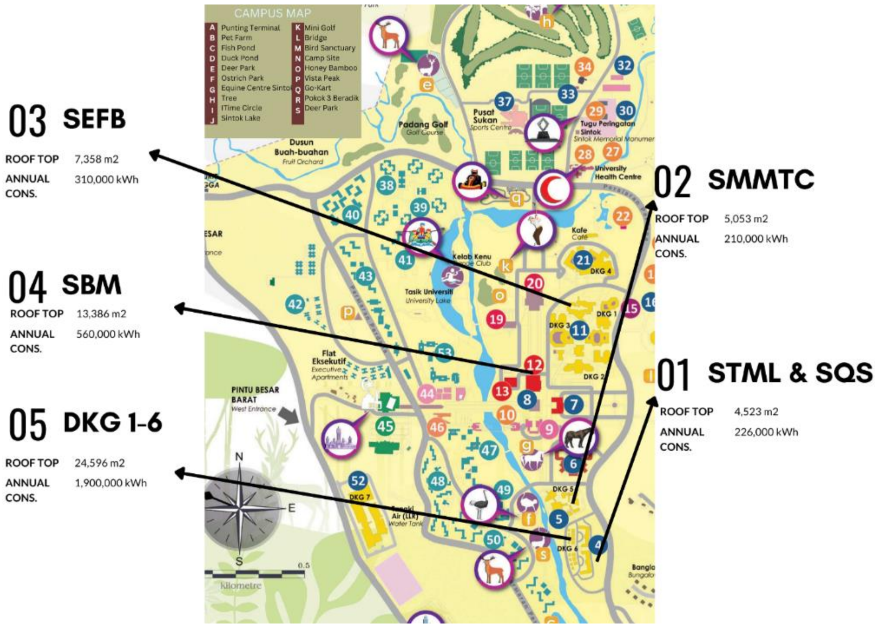


Fig.3. UUM campus map

The potential of solar power generation was estimated using the PWWatt Calculator [16]. The steps involved: (1) Resource Data Map - Lat, Lng: 6.45, 100.46; (2) Detailed information system – i. DC system size, ii. Module type, iii. Array type [17], iv. System loss [18], v. Tilt [19], vi. Azimuth [20], and (3) Drawing of the exact location. The DC system size was calculated using Eq. (1), with 16% module efficiency [16]. Figure 4 summarises the steps to obtain the system capacity.

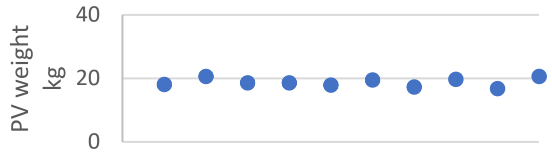
$$\text{Size (kW)} = \text{Array Area (m}^2\text{)} \times 1\ \text{kW/m}^2 \times \text{Module Efficiency (\%)} \quad (1)$$

Fig. 4. Summary of steps to obtain the system capacity

2.1.2 Transportation process

The transportation process comprised transporting the PV panels from the manufacturer to the site location, i.e., UUM. The input data to the system are indicated in Table 2. The PV panels were transported from First Solar (M) Sdn. Bhd. to UUM, Sintok using a lorry. A detailed assumption is indicated in Table 2.

Table 2
Input data to the transportation process

Parameter	Amount	Details
Distance	160 km	First Solar (M) Sdn. Bhd., Kulim – Most established company with the largest solar installations in Malaysia since 2008 [21]
Lorry	32 tonnes	Most optimised capacity [22]
PV panel weight	18.78 kg/ panel	 Taken the average weight of PV panels [23] Axitec:17.69 - 18.59 kg Canadian Solar: 18.14 – 23.13 kg Hanwha Q CELLS: 18.59 kg Hanwha SolarOne: 18.14- 19.05 kg Hyundai: 17.24 – 18.59 kg Kyocera : 19.05 – 19.96 kg LG: 17.24 kg SolarWorld: 18.14 – 21.32 kg SunPower: 14.97 -– 18.59 kg Trina: 18.59 – 22.68 kg

2.1.3 Conventional electricity generation

Conventional-based electricity generation considers coal as a resource. In 2019, the highest electricity generation consumed coal at 42.8% [24]. A detailed parameter input was taken from a previous study [25]. Figure 5 indicates the system boundary for coal-based electricity generation.

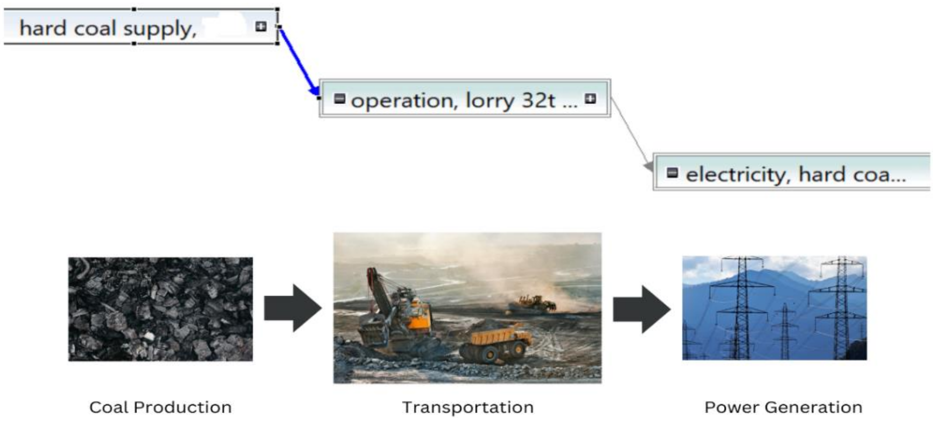


Fig.5. System boundary for coal-based electricity generation

2.2 Inventory Analysis and Impact Assessment

The life cycle impact assessment (LCIA) is a stage for estimating the possible environmental impacts by translating the life cycle impact results into specific impact indicators. The categories included: acidification potential, climate change, depletion of abiotic resources, depletion of abiotic resources – fossil fuel, eutrophication – generic, freshwater aquatic ecotoxicity, human toxicity, marine aquatic ecotoxicity, photochemical oxidation, and terrestrial ecotoxicity. Acidification potential considers acids emitted to the atmosphere and then deposited in surface waters and soils.

These impact contributions are mainly from emissions of SO_2, NO_x, HCl, NH_3, and HF, and are stated as SO_2 equivalents. Climate change is expressed as a carbon dioxide equivalent ($CO2_{EQ}$) and contains greenhouse gases (GHG) such as carbon dioxide, methane, and nitrous oxide. Eutrophication is referred to aquatic pollution mainly due to phosphorus derivatives.

The greenhouse gas equivalent emissions avoided for selected parameters were calculated using the Greenhouse Gas Equivalencies Calculator [26]. The energy data for particular kWh avoided were employed for the Greenhouse Gas Equivalencies Calculator.

3. Results and Discussion

The UUM campus is located in the northern region of Malaysia (6.461991, 100.506042) with 1,061 hectares [27] and enriched with plenty of solar radiance with an average irradiance of 633 W/m^2 [28]. PV output is calculated from irradiance of PV module [29]. Table 3 shows the result of the PV system size and the carbon dioxide emission by installation accordingly. Lecture Halls DKG 1–6 provided the most potential in installing solar PV panels due to flat rooftop conditions and direct solar radiation with minimal shadows. While other building such as SEFB and SBM are consist of gable roof shape. The factors that affected the output were the differing solar radiation intensity with latitude, season, atmospheric conditions (such as rain and humidity), air quality, and smog [30]. The average carbon dioxide equivalent emission was between 44.74 and 178.99 g CO_{2EQ} / kWh. In contrast, a study in Italy obtained 120 kgCO_{2EQ} / kWh [31]. A review from a previous study [32] estimated the range of 78–188 gCO_{2EQ}/kWh for LCA of the solar PV system. The different results of GHG emission were due to the installation location, weather, module type [33], solar irradiations, and lifetime of PV technologies [34]. These parameters aimed to estimate the effectiveness of PV towards global warming by using CO_2 equivalent (CO_{2EQ}) units.

Table 3
Result of PV system and $CO2_{EQ}$ emissions at Universiti Utara Malaysia

Building Name	Rooftop Area (m^2)	Number of Panels	System Size (kWh)	CO_{2EQ} Emissions
SQS & STML	4,523	1071	1,411,492	126,329.00
SMMTC	5,053	831	1,094,444	49,010.00
SEFB	7,358	228	299,383.4	13,446.80
SBM	13,386	209	275,522.4	12,326.20
DKG 1–6	24,596	2952	3,890,642	696,403.00

Table 4 and Figure 6 indicate the detailed impact categories for each selected building in UUM. Acidification reflect to the potential of acid release to form sulphur dioxide (SO_2). Climate change impact related to change in rainfall, floods, change in temperature, rising sea level and others. These climate changes are due to carbon emissions. In Table 4, the main impact that was significant to assess when dealing with the PV system was implied [35]. The output capacity and rooftop area size affected the amount of impact. Most of the impact categories were contributed from DKG 1–6. Most of the impact was still low compared to conventional energy resources such as coal and natural gas. Transportation was highly significant in the climate change impact compared to other processes in the system boundary (refer to Figure 7). Figure 7 signifies the impact categories for each process, purposely for the STML and SQS buildings.

Table 4
Detailed main impact categories for PV system

Impact category	SQS & STML	SMMTC	SEFB	SBM	DKG 1–6
Acidification potential - average Europe kg SO2 eq.	1.25E+10	3.78E+09	2.84E+08	2.39E+08	1.91E+11
Climate change - GWP100 kg CO2 eq.	1.26E+05	4.90E+04	1.34E+04	1.23E+04	6.96E+05
Eutrophication – generic kg PO4 eq.	3.30E+09	9.94E+08	7.48E+07	6.29E+07	5.02E+10

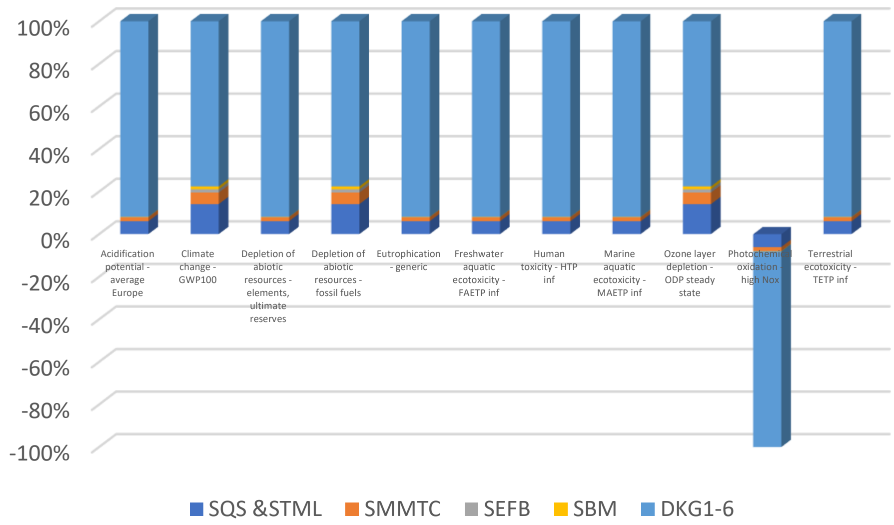


Fig.6. Impact categories for each selected building in UUM

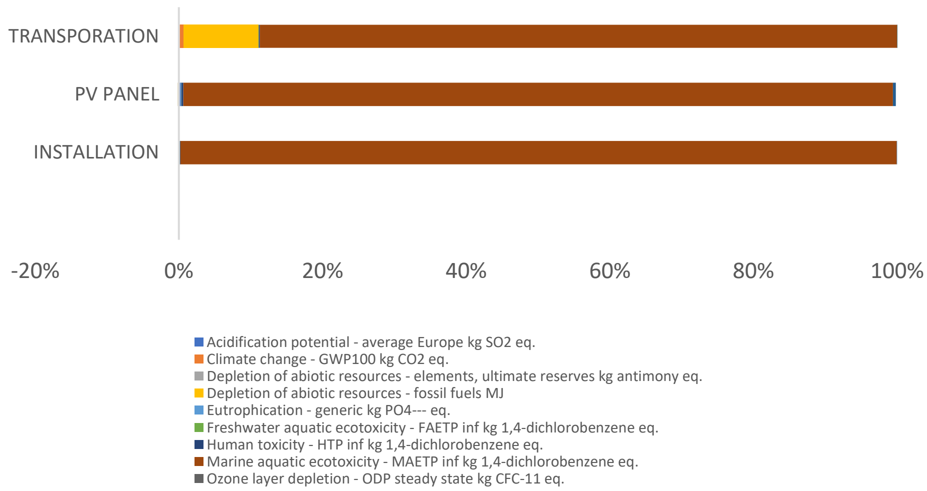


Fig.7. Impact categories for each process in STML and SQS buildings

Table 5 lists the impact categories for coal-based electricity generation. The result showed that the GHG emission for coal was about 882.64 g CO_{2EQ}/kWh. Meanwhile, a previous study obtained 1,138.8 gCO_{2EQ}/kWh for coal-based electricity generation and 35 g CO_{2EQ}/kWh [36]. Figure 8 illustrates the impact categories for solar PV and coal-based electricity generation. Most of the impact parameters were contributed from coal-based electricity generation. In this case, climate change was significantly affected by coal compared to the PV system, with almost a 91.2% reduction.

Table 5
Impact categories for coal-based electricity generation

Acidification potential - average Europe	kg SO_2 eq.	0.003605
Climate change - GWP100	kg CO_2 eq.	0.882637
Depletion of abiotic resources - elements, ultimate reserves	kg antimony eq.	3.41E-07
Depletion of abiotic resources - fossil fuels	MJ	19.83561
Eutrophication - generic	kg PO_4 eq.	0.000627
Freshwater aquatic ecotoxicity - FAETP inf	kg 1,4-dichlorobenzene eq.	0.02102
Human toxicity - HTP inf	kg 1,4-dichlorobenzene eq.	0.188849
Marine aquatic ecotoxicity - MAETP inf	kg 1,4-dichlorobenzene eq.	550.9191
Ozone layer depletion - ODP steady state	kg CFC-11 eq.	1.02E-07
Photochemical oxidation - high Nox	kg ethylene eq.	0.000182
Terrestrial ecotoxicity - TETP inf	kg 1,4-dichlorobenzene eq.	0.003506

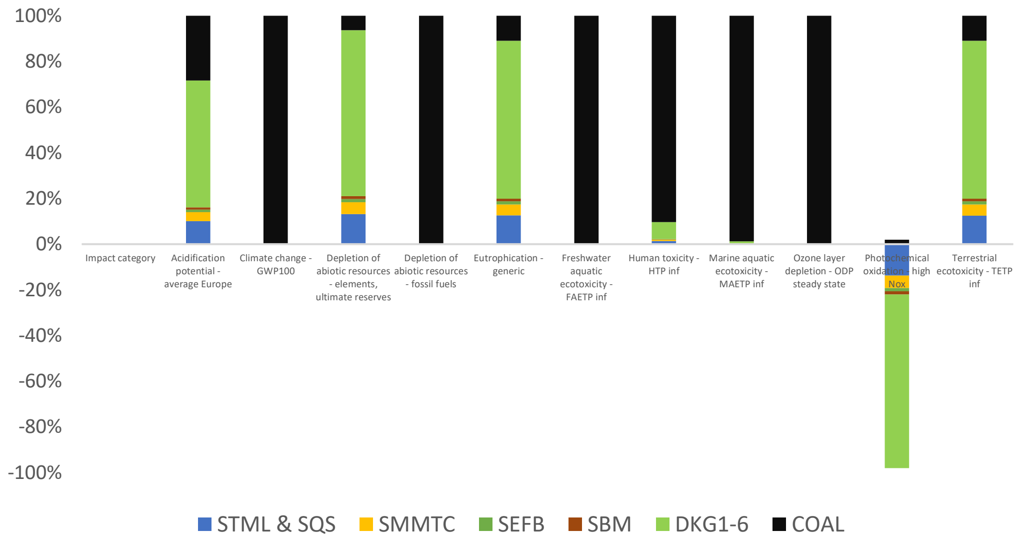


Fig.8. Impact categories for both PV system and coal-based electricity generation

Figure 9 indicates the GHG emissions for selected buildings in UUM and the overall emissions with the current pattern of electricity consumption supplied from the grid system. The trend decreased due to Malaysia's Movement Control Order implemented that year and the university policy that executed online learning for students and working from home for staff until 2021. These were the main reasons for the output data. The average $CO2_{EQ}$ emission for those three years was 28.97 million tonnes $CO2_{EQ}$. However, the data showed a sharp increase before the COVID-19 pandemic, up to 40.3 million tonnes $CO2_{EQ}$ from 2014 to 2017.

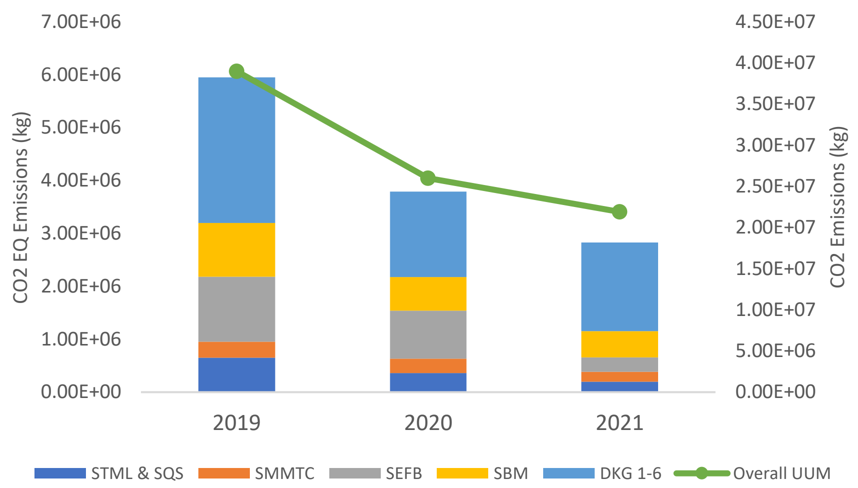


Fig.9. Pattern of carbon dioxide emissions from 2019 to 2021 in selected buildings in UUM

The installation of solar PV systems would increase the carbon dioxide avoided. Figure 10 shows the carbon dioxide equivalent emission for three parameters, namely coal-based, solar PV, and avoided emissions. The size and capacity of solar PV installation were directly proportional to CO_2 emissions avoided. Figure 11 indicates the greenhouse gas equivalent emissions avoided by selected parameters, such as tonnes of waste recycled instead of dumping at landfills, incandescent lamps switched to LEDs, wind turbines running for a year, and tree seedlings grown for ten years. The installation of solar PV systems in selected buildings in UUM corresponded to tree seedlings that have grown about 47,583 trees.

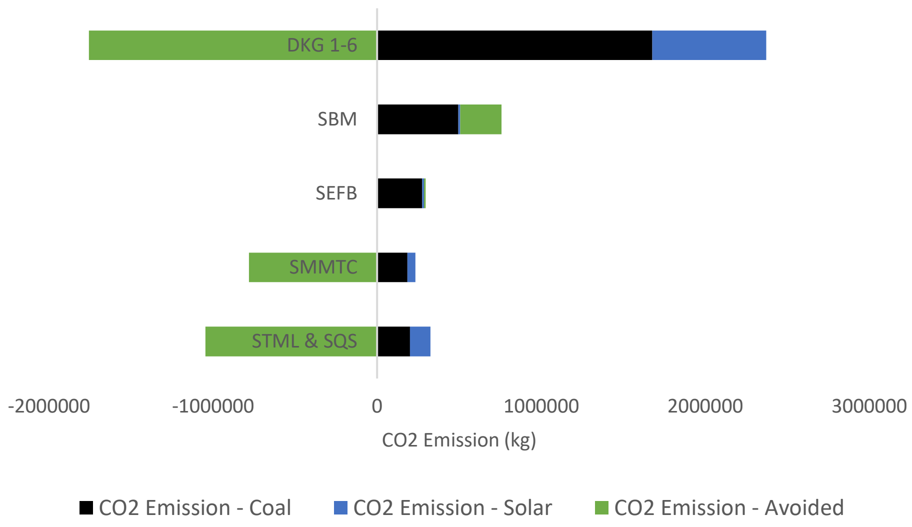


Fig.10. Carbon dioxide equivalent emissions

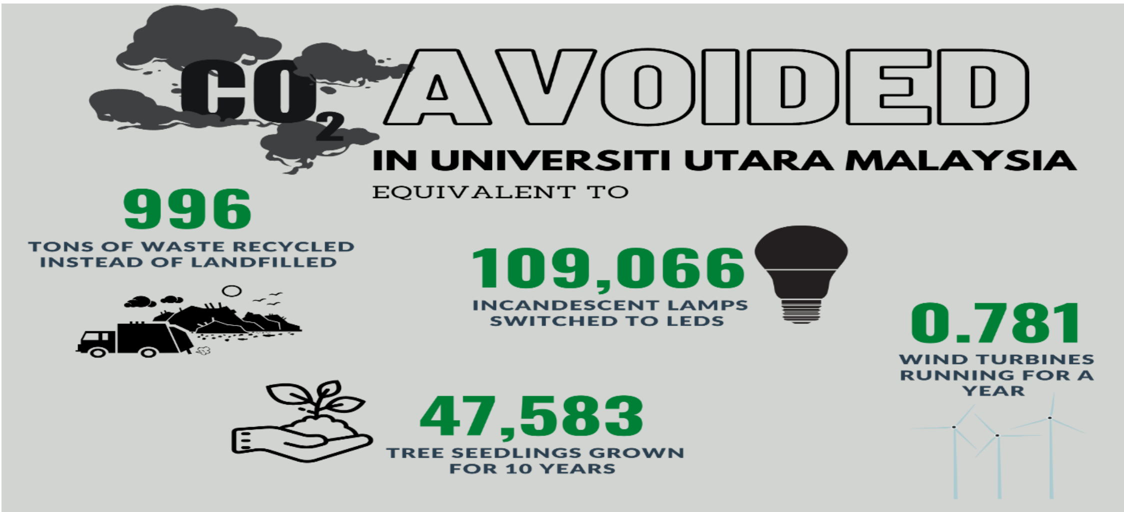


Fig.11. Infographic for greenhouse gas equivalent emissions avoided by selected parameters

4. Conclusion

The installation of a solar PV system in university buildings generated a positive impact towards environmental and economic aspects. UUM has great potential in consuming solar due to location, radiation, available technology, etc. The global warming impact on solar system installation was in the range of 44.74 to 178.99 g CO_{2EQ}/ kWh. The transportation process provided the most significant contribution towards this impact. Solar PV installation decreased by about 91.2 % compared to coal-based electricity generation. The carbon dioxide emission avoided became the interesting factor to encourage the university in making the decision process.

Moreover, installing a building-integrated solar PV system could be the solution or a means to fulfil the government's target to achieve 50% of energy generation based on renewable energy. The key parameter of carbon dioxide emission avoided can be the power factor to encourage stakeholders and society to move towards sustainable energy source.

Acknowledgements

The authors would like to express their gratitude to Universiti Utara Malaysia and the Centre for Testing, Measurement & Appraisal (CETMA) for the provision of financial aid to this research under the DEVELOPMENT AND ECOSYSTEM RESEARCH GRANT SCHEME (DEcoR- 14918/2020). The authors would also like to thank the reviewers and associate editor for their support and feedback in improving this research manuscript.

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