# Analysis of Carbon Footprint and Impact of Global Warming Potential on Aspects of Transportation, Electricity and Water Use in Istiqlal Mosque

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**Abstract.** This research assesses the carbon footprint from transportation, electricity consumption, and water usage at Istiqlal Mosque, Jakarta. The primary objectives are to quantify emissions, conduct impact analysis, and propose strategies for reducing the carbon footprint in these three aspects. The method employed involves calculating the carbon footprint using emission factors. The results indicate the carbon footprints as follows: 1,653.87 kg $CO_2$/month for transportation, 183,670 kg $CO_2$/month for electricity, and 2,710.60 kg $CO_2$/month for water consumption. These emissions have the potential to contribute to global warming, resulting in estimated impacts of 610 kg $CO_2$-eq/month for transportation, 242,000 kg $CO_2$-eq/month for electricity, and 2,560 kg $CO_2$-eq/month for water consumption. Proposed carbon footprint reduction measures include implementing Car-Free Day (CFD) initiatives, installing a 150-kilowatt-peak (KWP) solar panel system, incorporating water-saving features, and establishing a rainwater harvesting system. These recommendations can help Istiqlal Mosque reduce its carbon footprint and support environmental sustainability.

**Keywords:** Carbon footprint, transportation, electricity use, water use, Istiqlal Mosque

## 1 Introduction

Over the past few years, global warming has become an issue of international concern. Global warming is a condition in which the temperature of the atmosphere, Earth's land, and the oceans rises. The greenhouse effect is considered one of the primary factors causing global warming with significant impacts because it traps heat radiation from the sun, preventing it from reflecting back into space [14]. Greenhouse gases are components naturally present in the atmosphere. Meanwhile, the greenhouse effect refers to the term used to describe the heat trapped in the Earth's atmosphere, which cannot escape into space [19].

According to the America's Climate Choice report in 2011 [1], there has been an average surface temperature increase of 0.8°C over the past hundred years. Out of this temperature increase, about two-thirds, or approximately 0.6°C, occurred in the last three decades. In addition to

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causing an increase in the Earth's average surface temperature, global warming also has the potential to lead to various natural disasters, such as coastal flooding due to rising sea levels, droughts in some regions, environmentally damaging storms, serious health issues, food supply shortages, and various other impacts [2]. According to the book "Sains Perubahan Iklim" by [18], carbon dioxide ($CO_2$) and methane ($CH_4$) are two types of greenhouse gases that play a significant role in increasing the Earth's average surface temperature. These gases contain carbon elements and are largely produced by human activities. Data from the Intergovernmental Panel on Climate Change (IPCC) [7] show that about 76% of greenhouse gas emissions into the atmosphere are in the form of $CO_2$, 16% are $CH_4$, 6% are NOx, and 2% are fluorinated gases.

Various human activities that use energy result in $CO_2$ emissions, and one of these activities is worship in mosques. Mosques are places of worship for Muslims worldwide and often serve as centers for social activities, education, and religious events. The greenhouse gas emissions associated with mosque activities include transportation, electricity, and water use. One such activity in a mosque that requires carbon footprint calculations is worship activities at Istiqlal Mosque, as Istiqlal Mosque is the largest mosque in Southeast Asia. Based on data obtained from Istiqlal Global Fund Parking [8], it is stated that the average number of vehicles in Istiqlal Mosque is 12,211 motorcycles and 13,060 cars per month. Moreover, based on data from the Ria`yah Department of Istiqlal Mosque [3], the electricity consumption of Istiqlal Mosque averages 209,261.67 kWh per month, and the water usage averages 5,918.33 $m^3$ per month. With the significant use of transportation, electricity, and water, it is necessary to calculate the accumulation of greenhouse gas emissions resulting from worship activities in mosques over a specific period of time. This calculation is known as the carbon footprint. The carbon footprint is the total amount of carbon dioxide ($CO_2$) emissions generated by an activity, both from direct and indirect sources, accumulated over the entire life cycle of a product or activity [20].

Therefore, there is a need for calculating or analyzing the carbon footprint of worship activities at Istiqlal Mosque to determine the carbon footprint value, assess the environmental impacts generated, and as an effort to reduce carbon emissions, which is a form of better environmental management for worship activities at Istiqlal Mosque. With the obtained carbon footprint, it is possible to optimize the environmental efficiency of Istiqlal Mosque. The purpose of this research is to identify the amount of carbon footprint generated, analyze the impact of the carbon footprint generated, and recommend efforts to reduce the carbon footprint in the aspects of transportation, electricity, and water usage in the area of Istiqlal Mosque.

## 2 Method and materials

### 2.1 Data collection techniques

In this research, the required data is categorized into two types: primary data and secondary data. Primary data required includes data on the types of vehicles and the fuel used by visitors. The data collection method for primary data in this research is the questionnaire method using Google Forms, which will be distributed to visitors who use cars and motorcycles. The sample size required for the questionnaire is calculated using the Slovin method, with an error tolerance of 10%. The Slovin method is represented by the following equation:

$$n = \frac{N}{1 + N.e^2} \quad (1)$$

Where:
n = Sample size
N = Total population
e = Error tolerance

The vehicle population data used to determine the sample size is the average daily number of vehicles at the Istiqlal mosque. The following are the results of determining the sample size.

**Table 1.** Sample size for each vehicle type

| Vehicle type | Population | Sampel size |
|---|---|---|
| Cars | 401 | 80 |
| Motorcycles | 429 | 81 |

Secondary data required includes the number of vehicles entering the Istiqlal Mosque area over the course of a year. This data is obtained from parking ticket records. Additionally, data on electricity and water usage per month for one year is collected from the monthly bills of Istiqlal Mosque. Specific data on emission factors for gasoline and diesel, electricity generation emission factors, and clean water emission factors for Indonesia are also required. The emission factor for cars depends on the type of fuel used, such as pertalite, pertamax, and pertamax turbo. The use of gas oil or diesel also has emission factors regulated according to the Minister of Environment and Forestry Regulation (Permen LHK). The emission factors for car transportation are presented in Table 2.

**Table 2.** Emission factors for car transportation

| Fuel type | Emission factor | Unit | Source |
|---|---|---|---|
| Pertalite | 2408 | g $CO_2$/kg BBM | [15] |
| Pertamax | 2604 | g $CO_2$/kg BBM | [15] |
| Pertamax Turbo | 2949 | g $CO_2$/kg BBM | [15] |
| Solar | 3172 | g $CO_2$/kg BBM | [10] |

For motorcycles, the emission factor varies with the type of fuel used for each motorcycle category: automatic, moped, and sport. The emission factors for motorcycle transportation are shown in Table 3.

**Table 3.** Emission factors for motorcycle transportation

| Fuel type | Emission factor based on motorcycle type | | | Unit | Source |
|---|---|---|---|---|---|
| | Automatic | Moped | Sport | | |
| Pertalite | 2576 | 2099 | 2190 | g $CO_2$/kg BBM | [15] |
| Pertamax | 2680 | 2390 | 2231 | g $CO_2$/kg BBM | [15] |
| Pertamax Turbo | 3000 | 2800 | 2410 | g $CO_2$/kg BBM | [15] |

The emission factor for calculating electricity usage emissions is derived from the emission factor for the Jawa-Madura-Bali (Jamali) interconnected electricity system, as shown in Table 4.

**Table 4.** Electricity generation emission factor [4]

| System | Emission factor | Unit |
|---|---|---|
| Jawa-Madura-Bali (Jamali) Interconnected System | 0,8777 | Ton $CO_2$/mWh |

The emission factor used for calculating water usage emissions is based on Indonesian- specific emission factors obtained from the research by [16], as shown in Table 5.

**Table 5.** Water usage emission factors [16]

| Country | Emission factor | Unit |
|---|---|---|
| Indonesia | 0,458 | Kg $CO_2/m^3$ |

### 2.2 Data Processing and Analysis Technique

To ensure that the collected data represents all the vehicles at Istiqlal Mosque, a ratio of the types of fuel usage for each category of respondent's vehicle is determined. This ratio is calculated by dividing the number of users of each type of fuel for each vehicle by the total number of respondents. The resulting ratio data is then multiplied by the average daily number of vehicles at Istiqlal Mosque, thereby obtaining data on the number of fuel users for each type of fuel for each vehicle category on a daily basis. In the carbon footprint calculation, the data used is the amount of fuel usage (vehicles/day). The carbon footprint calculation uses the Greenhouse Gas (GHG) emission calculation methodology from the Technical Guidelines for Urban Air Pollution Emission Inventory by the Ministry of Environment and Forestry in 2013 [11], represented by the following equation:

$$\text{GHG Emission} = \text{Activity Data} \times \text{Emission Factor} \quad (2)$$

Where:
GHG Emission = Emission generated
Activity Data = Energy consumption during the activity Emission Factor
= Factor specified by IPCC Guidelines 2006

The calculation in the transportation aspect involves the distance traveled and the average fuel consumption for each type of transportation. The fuel consumption for cars is considered based on vehicle categories. The distance is measured from the entrance gate to the parking area and back. The distance covered by vehicles when parked at Masjid Istiqlal is 0.41 km.

To ensure that the data obtained represents all vehicles in Masjid Istiqlal, the determination of the fuel usage ratio is carried out for each respondent's vehicle category. The ratio is calculated by dividing the usage of each type of fuel for each vehicle by the total number of respondents. The obtained ratio data is then multiplied by the average daily vehicles at Masjid Istiqlal. Thus, data on the amount of fuel usage for each fuel type in each vehicle category per day is obtained. In the carbon footprint calculation, the data used is the amount of fuel usage (vehicles/day).

## 3 Results and discussion

### 3.1 General overview of the research location

The research was conducted at Istiqlal Mosque, located at Jl. Taman Wijaya Kusuma, Pasar Baru, Sawah Besar District, Central Jakarta, Special Capital Region of Jakarta 10710. Its strategic location is adjacent to the Ministry of Religious Affairs of the Republic of Indonesia, PT Pertamina Persero, and the Cathedral Church. It is also close to the National Monument (Monas), Merdeka Palace, and other government ministries. The building covers an area of 24,200 square meters on a land area of 98,247 square meters. Istiqlal Mosque is equipped with basement parking facilities, ATMs, a children's play area, and a food court.

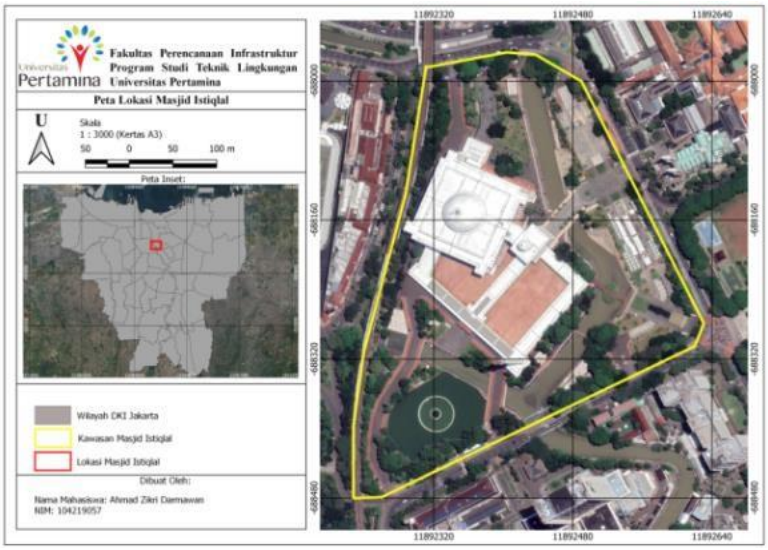


**Fig. 1**. Istiqlal Mosque, Central Jakarta

### 3.2 Carbon footprint calculation

Based on the primary and secondary data obtained, the carbon footprint was calculated in terms of transportation, electricity usage, and water usage. The following are the results of the carbon footprint.

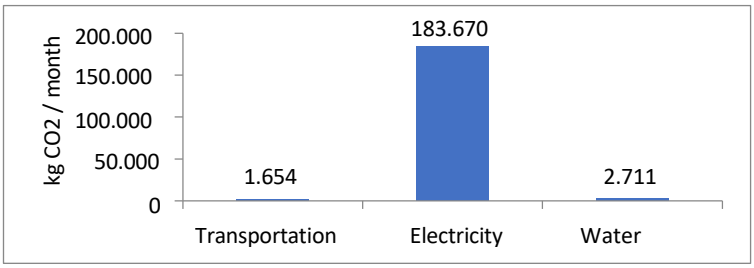


**Fig. 2.** Carbon footprint of activities at Istiqlal Mosque

Based on **Figure 2**, it is evident that the use of electricity generates the largest carbon footprint, amounting to 183,670 kg $CO_2$ per month, followed by water usage at 2,711 kg $CO_2$ per month. Meanwhile, the use of fossil fuels in transportation results in the lowest carbon footprint, at 1,654 kg $CO_2$ per month. Environmental impact analysis was then conducted using a Life Cycle Assessment (LCA) approach with SimaPro version 9.5.0.1, with the environmental impact assessed in terms of potential global warming. The following are the results of the environmental impact:

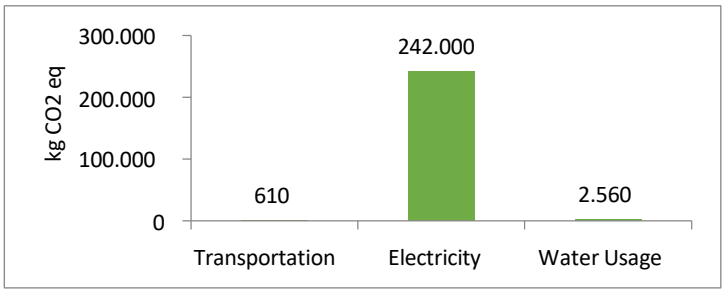


**Fig. 3.** Potential global warming impact of activities at Istiqlal Mosque

Based on **Figure 3**, it is evident that the use of electricity generates the largest potential global warming impact at 242,000 kg $CO_2$ equivalent, followed by water usage at 2,560 kg $CO_2$ equivalent. On the other hand, fossil fuel usage in transportation results in the lowest carbon footprint at 610 kg $CO_2$ equivalent. Based on the carbon footprint calculation and impact analysis using SimaPro, it is clear that the use of electricity generates the most emissions and the largest potential global warming impact. This is primarily due to the substantial electricity consumption at Istiqlal Mosque, which is used for lighting, air conditioning, water pumps, sound systems, and other building utilities.

In a study conducted by [6] on Carbon Footprint Analysis in the Transportation Sector, LPG Usage, Electricity, and Assets at Pertamina University Towards Carbon Emission Reduction Efforts, it was found that the transportation aspect at Pertamina University results in a carbon footprint of 87,951.65 kg $CO_2$ per year or 7,329.30 kg $CO_2$ per month. When compared to the carbon footprint of activities at Istiqlal Mosque, Pertamina University generates a carbon footprint 77% greater. This indicates that there are fewer vehicles at Istiqlal Mosque. Additionally, the presence of Juanda Station and Juanda Bus Stop near Istiqlal Mosque, located approximately 1 km away, provides an alternative for public transportation.

In terms of electricity consumption, Pertamina University generates a carbon footprint of 3,370.099 tons of $CO_2$ per year or 280,841.58 kg $CO_2$ per month. Compared to Istiqlal Mosque, Pertamina University produces a 34% larger carbon footprint. This is due to energy- saving efforts implemented by Istiqlal Mosque's management, such as the use of solar panels that can save 15% of the mosque's electricity consumption.

On the other hand, in a study conducted by [5] on Carbon Footprint Inventory at Pertamina University in Terms of Water Usage and Waste Management in Efforts to Reduce Carbon Emissions, it was found that the water usage aspect at Pertamina University generates a carbon footprint of 5,676.323 kg $CO_2$ per year or 473.026 kg $CO_2$ per month. When compared to the carbon footprint of activities at Istiqlal Mosque, Istiqlal Mosque has a larger carbon footprint

for water usage. This indicates that water usage at Istiqlal Mosque is higher, with water being used for ablution, toilets, plant irrigation, fountains, and other purposes.

Furthermore, in a study by [22] on Carbon Footprint Inventory of Activities at Sami Laris Supermarket in Cilacap Regency, it was found that the supermarket generates a carbon footprint of 25,544 kg $CO_2$ per month in terms of transportation. In terms of electricity usage, Sami Laris Supermarket generates a carbon footprint of 23,648.305 kg $CO_2$ per month. The water usage aspect results in a carbon footprint of 1,085 kg $CO_2$ per month. When compared to the carbon footprint of activities at Istiqlal Mosque, Istiqlal Mosque has a larger carbon footprint in terms of transportation, electricity usage, and water usage.

### 3.3 Recommendations

In the strategy planning for reducing the carbon footprint at Istiqlal Mosque, the focus will be on reducing the use of transportation, electricity, and water by both visitors and the mosque's management. Regarding transportation, one approach is for the mosque's management to implement a Car Free Day (CFD) policy on specific days and times. This policy encourages visitors to use public transportation or environmentally friendly vehicles, such as bicycles, when coming to Istiqlal Mosque. The implementation of CFD is in line with local regulations, including Regulation No. 2 of 2005 on Air Pollution Control and Governor Regulation No. 12 of 2016 on the Implementation of Car Free Day.

Research conducted by [13] on the Evaluation of Car-Free Days in Central Jakarta showed that CFD activities in Central Jakarta tend to have lower values compared to regular working days in terms of PM10 and CO, with reduction rates of 3.29% and 35.52%, respectively. Similarly, research by [17] on the Impact of Car Free Day (CFD) in Pekanbaru for Reducing Carbon Emissions from Transportation found that CFD activities can reduce carbon emissions by approximately 236,486 kg $CO_2$. These studies suggest that CFD implementation is effective in reducing carbon footprints in transportation.

For electricity consumption, a viable approach is to increase the number of solar panels with a capacity of 150 KWP. Currently, Istiqlal Mosque already has 404 solar panels, each with a capacity of 150 KWP, connected to the grid system without using batteries. These solar panels contribute approximately 15% to the mosque's energy consumption, resulting in savings of 20 to 30 million in electricity bills. The use of solar panels aligns with the Indonesian government's policies on accelerating the development of renewable energy for electricity generation, as well as national energy policies.

A study by [21] on the Life Cycle Assessment of Greenhouse Gas Emission Profit of Solar Photovoltaic Systems found that coal-fired power plants produce emissions of 975.2 g $CO_2$eq/kWh, whereas photovoltaic power installations produce emissions of 36.75 g $CO_2$eq/kWh. This significant difference highlights the environmental advantages of solar power generation. Therefore, increasing the number of solar panels can further contribute to energy efficiency and reducing carbon emissions from electricity use. This means that the more solar panels are used, the more carbon emissions produced will be reduced, this is due to the reduced use of electrical energy originating from coal-fired power plants. So Wu's research results confirm that the use of solar panels in the Istiqlal mosque will contribute to reducing carbon emissions.

Regarding water usage, Istiqlal Mosque already incorporates water-saving features in some areas, such as low-flow faucets, water-saving urinals, and a wudhu (ablution) water treatment and recycling system. However, these features are not uniform throughout the mosque. To improve water efficiency, it is necessary to standardize water-saving features in all areas. Additionally, a Rainwater Harvesting System (RHS) can be implemented to collect and reuse rainwater for various mosque operations, such as watering plants and wudhu. Rainwater harvesting is a water conservation method used to collect and store rainwater in containers or storage tanks. The collected water can be used for various purposes [12]. The use of rainwater is regulated by the Ministry of Environment Regulation No. 12 of 2009, covering its collection, usage, and infiltration.

## 4 Conclusion

Based on the research findings, the following conclusions can be drawn:

1. Based on the emissions factor calculations, the carbon footprint generated at Istiqlal Mosque is 1,653.87 kg $CO_2$ per month from transportation, 183,670 kg $CO_2$ per month from electricity usage, and 2,710.60 kg $CO_2$ per month from water usage.
2. According to the life cycle assessment analysis using SimaPro software, the environmental impact of Istiqlal Mosque's activities results in a potential global warming impact of 610 kg $CO_2$ eq per month from transportation, 242,000 kg $CO_2$ eq per month from electricity usage, and 2,560 kg $CO_2$ eq per month from water usage. The electricity usage aspect has a larger environmental impact compared to transportation and water usage, primarily due to the significant consumption of electrical energy at Istiqlal Mosque.
3. To reduce carbon emissions at Istiqlal Mosque:
    a. Implement Car-Free Day (CFD) on specific days and times, promoting the use of public transportation and eco-friendly vehicles like bicycles.
    b. Increase the number of solar panels with a capacity of 150 KWP to further reduce electricity consumption.
    c. Standardize water-saving features throughout the mosque and implement a Rainwater Harvesting System (PAH) to recycle water for operational purposes.

## References


[1] America`s Climate Choices. *America`s Climate Choices Full Report*. Washington D.C: The National Academia Press (2016).
[2] Awanthi, M., & Navaratne, C.: *Carbon Footprint of an Organization: a Tool for Monitoring Impacts on Global Warming*. Procedia Engineering, 729-735 (2018).
[3] Departemen Ria`yah Masjid Istiqlal: Laporan Jumlah Penggunaan Listrik dan Air Masjid Istiqlal. Jakarta: Departemen Ria`yah Masjid Istiqlal (2023).
[4] Direktorat Jendral Ketenagalistrikan: Faktor Emisi GRK Sistem Interkoneksi Tenaga Listrik Tahun 2016 (2016).
[5] Djatmiko, T. A.: Inventarisasi Jejak Karbon di Universitas Pertamina dari Aspek Penggunaan Air dan

Pengelolaan Sampah dalam Upaya Pengurangan Emisi Karbon. Jakarta: Universitas Pertamina (2020).
[6] Harviani, S. P.: Analisis Jejak Karbon Pada Sektor Transportasi, Penggunaan LPG, Listrik, dan Aset di Universitas Pertamina Terhadap Upaya Penurunan Emisi Karbon. Jakarta: Universitas Pertamina (2020).
[7] Intergovernmental Panel on Climate Change: *Climate Change 2014:Synthesis Report, Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 151 pp. Geneva: IPCC (2014).
[8] Istiqlal Global Fund Parking: Laporan Jumlah Kendaraan Masjid Istiqlal. Jakarta: Istiqlal Global Fund (2023).
[9] Kementrian Lingkungan Hidup Republik Indonesia: Peraturan Mentri Lingkungan Hidup Nomor 12 Tahun 2009 Tentang Pemanfaatan Air Hujan (2009).
[10] Kementrian Lingkungan Hidup Republik Indonesia: Peraturan Mentri Lingkungan Hidup Nomor 12 Tahun 2010 Tentang Pelaksanaan Pengendalian Pencemaran Udara di Daerah (2010).
[11] Kementrian Lingkungan Hidup Republik Indonesia: Pedoman Teknis Penyusunan Inventarisasi Emisi Pencemaran Udara di Perkotaan (2013).
[12] Nadia. F., dan M. A. Mardyanto: Perencanaan Sistem Penampungan Air Hujan Sebagai Salah Satu Alternatif Sumber Air Bersih di Rusunawa Penjaringan Sari Surabaya. Jurnal Teknik ITS. 5(2): 2337-3539 (2016).
[13] Nugroho, S. T., Simarmata, J., Wibisono, G. I., & Arifa'i, A. M.: Kajian Evaluasi Hari Bebas Kendaraan Bermotor di Jakarta Pusat. Jurnal Teknik Transportasi, 2722-9599 (2020).
[14] Nur, Y., Lestari, P., Uttari I.: Inventori Emisi Gas Rumah Kaca ($CO_2$ dan $CH_4$) Dari Sektor Transportasi Di DKI Jakarta Berdasarkan Konsumsi Bahan Bakar. Bandung: Institut Teknologi Bandung (2008).
[15] Rusdiani, R. R.: Kajian Faktor Emisi Kendaraan Bermotor Bahan Bakar Gasolin Roda Dua Di Kota Surabaya. Surabaya: Institut Teknologi Surabaya (2018).
[16] Sari, E., Kristanto, G. A., & Pratama, M. A.: *Green House Gasses Estimation from Clean Water Production and Supply Sector in Depok City, Indonesia*. AIP Conference Proceedings, 2230 (1): 040015 (2020).
[17] Sasmita, A.: Pengaruh Kegiatan Car Free Day (CFD) Di Kota Pekanbaru Untuk Pengurangan Emisi Karbon Dari Kegiatan Transportasi. Jurnal Purifikasi, 15-20 (2015).
[18] Setiani, P.: Sains Perubahan Iklim. Dalam P. Setiani, Sains Perubahan Iklim (hal. 70-75). Jakarta: Bumi Aksara (2020).
[19] Triana, V.: Pemanasan Global. Jurnal Kesehatan Masyarakat Universitas Andalas Padang, 1 (2008).
[20] Wiedmann, T., & Minx, J.: *A definition of 'carbon footprint'*. Ecological economics research, 1-11 (2008)
[21] Wu, P., Ma, X., Ji, J., & Ma, Y.: *Review on Life Cycle Assessment of Greenhouse Gas Emission Profit of Solar Photovoltaic Systems*. Energy Procedia, 1289-1294 (2017).
[22] Yuliani, A. R.: Inventarisasi Jejak Karbon dari Aktivitas Swalayan Sami Laris Kabupaten Cilacap. Jakarta: Universitas Pertamina (2022).