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Energy Emissions Profile and Floating Solar Mitigation Potential for a Malaysia's State

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ABSTRACT

The establishment of the National Low Carbon City Master Plan (NLCCM) by Malaysia's government presents a significant opportunity to minimize carbon emissions at the subnational or local scales, while simultaneously fostering remarkable economic potential. However, the lack of data management and understanding of emissions at the subnational level are hindering effective climate policies and planning to achieve the nationally determined contribution and carbon neutrality goal. There is an urgent need for a subnational emission inventory to understand and manage subnational emissions, particularly that of the energy sector which contribute the biggest to Malaysia's emission. This research aims to estimate carbon emissions for Selangor state in accordance with the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), for stationary energy activities. The study also evaluates the mitigation potential of Floating Solar Photovoltaic (FSPV) proposed for Selangor. It was found that the total stationary energy emission for Selangor for the year 2019 was 18,070.16 ktCO$_2$e, contributed the most by the Manufacturing sub-sector (40%), followed by the Commercial and Institutional sub-sector; with 82% contribution coming from the Scope 2 emission. The highest sub-sector of Scope 1 emissions was contributed by Manufacturing while Scope 2 emissions from the Commercial and Institutional. Additionally, the highest fuel consumed was natural gas, which amounted to 1404.32 ktCO$_2$e (44%) of total emissions. The FSPV assessment showed the potential generation of 2.213 TWh per year, by only utilizing 10% of the identified available ponds and dams in Selangor, equivalent to an emission reduction of 1726.02 ktCO$_2$e, offsetting 11.6% Scope 2 electricity emission. The results from the study can be used to better evaluate existing policies at the sub-national level, discover mitigation opportunities, and guide the creation of future policies.

Keywords: Greenhouse gas emission; Floating solar; GPC protocol; Stationary energy; Low carbon state

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1. Introduction

Over time, rapid urbanization, industrialization, and relatively high carbon intensity dependence on fossil fuels make cities and their populations more at risk of the effect of climate change that led to extreme weather conditions such as flash floods, droughts, and heat waves. The Intergovernmental Panel on Climate Change (IPCC) reported in February 2022 that the result of climate change is putting our planet and those within it at grave risk and how our actions shall influence the adaptation to increasing climate risk. According to experts, the rising greenhouse gas emissions are threatening the existence of our civilization [1,2]. The absolute amount of greenhouse gases that have been released into the atmosphere has increased significantly during the last decade. If the efforts to reduce these emissions are not made soon, the chances of achieving low-term emissions become more difficult. According to the IPCC special report on the impacts of global warming, the world must limit its temperature increase from 1.5 °C to 2 °C (degrees Celsius) to avoid dangerous climate change [3,4]. The reduction of greenhouse gas emissions should be dramatically implemented to avoid dangerous climate change. This can only be achieved through the establishment of a zero-emission economy which assumes that the decline in emissions begins immediately and progresses gradually to 2050. Even slightly exceeding the warming level temporarily will result in a severe impact of which some will be irreversible, especially in the low-lying coastal settlement [5].

Malaysia pledges to contribute to the implementation and achievement of the goals of the Paris Agreement through its Nationally Determined Contributions, NDCs in reducing as much as 45% of carbon intensity by 2030 across the economy (based on the Gross Domestic Product) and aspire to achieve Net-Zero GHG emission by 2050 in which the National Low Carbon Cities Master Plan (NLCCM) will be one of its urban strategies [3,4]. Taking urgent action to combat climate change and its devastating impacts is therefore an imperative to save lives and livelihood. Previously, Malaysian government introduced the Low Carbon City Framework as an opportunity to reduce carbon emissions while offering incredible economic opportunities that align with Sustainable Development Goals 2030 (SDG2030) of its 17 Goals and New Urban Agenda Blueprint [6].

Monitoring and reporting are crucial in tracking the progress and path towards the goals and targets set for low carbon emissions. Malaysia has recently submitted its greenhouse gas (GHG) inventory through the fourth Biennial Update Report (BUR3) as part of Malaysia's obligations as a Party to the United Nations Framework Convention on Climate Change (UNFCCC). At the local level, cities in Malaysia are using the Low Carbon City Framework and Assessment System (LCCF) formulated by the government in 2011. However, NLCCM reported that the LCCF was not inclusive and did not consider the inclusion of forest and agriculture. It is also not aligned with the GPC standard. Thus, NLCCM explicitly stipulated that cities adopt Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) in their GHG inventory [7]. The GPC standard is an internationally accepted framework for reporting emissions at the community scale which is also applicable at the subnational level. It was established through the partnership of the World Resources Institute, C40 Cities Climate Leadership Group and Local Governments for Sustainability (ICLEI). In 2011, a group of professionals with the aim of making Iskandar City Malaysia's first low-carbon city developed a blueprint consisting of GHG emissions analysis and GHG reduction targets for 2025, which also included action plans to achieve these targets. The study also highlighted the effectiveness of the city's mitigation measures due to the lack of understanding of the city's emissions profile and addressed this by conducting a GHG inventory based on GPC [8,9].

Although the government has established the LCCF reporting framework for Malaysian cities, there is no reporting framework requirement at the state level. Currently, there is no GHG emissions inventory and reporting framework for Malaysia's state due to the lack of data availability and limited

resources to conduct a bottom-up approach inventory analysis. An estimation of GHG Inventory through scaling down of the national data using appropriate scaling factors, would be a great starting point for the establishment of a state inventory. This is crucial in identifying the sources of emissions and their trends, for the identification and implementation of effective subnational climate mitigation measures to reduce greenhouse gas (GHG) emissions.

At the present time, although the specific GHG emissions from renewable energy sources are extremely low, a large portion of energy sources are still utilising the conventional energy system. Within the context of solar photovoltaic (PV) technologies, traditionally, they have been regarded as the most expensive choice for generating electricity [10]. A recent finding reported that with increased investment in research and development as well as advances in technology and materials, FSPV technology is likely to become more accessible at a lower cost in the future [11]. A report by PV Insights, a leading international solar PV research business informed of the most recent significant drop in PV pricing from 2.36 USD/watt peak (Wp) in 2010 to 0.35 USD/Wp in 2020 and predicted to decrease much more by half by 2030 [12]. Over the past few decades, installed photovoltaic (PV) capacity has increased significantly as PV has improved its competitiveness against other renewables and conventional power systems.

This study proposes a floating solar or floating photovoltaics (FSPV) system placed on top of a body of water as a mitigation measure as it is yet to be explored widely in Malaysia. Malaysia possesses a strategic advantage in the deployment of FSPV, attributed to its favourable geographical location and abundant water bodies. The Southeast Asia region enjoys constant exposure to the sun, and solar power has been identified as one of the most promising forms of renewable energy in this region [13]. Malaysia lies in the equatorial region, with an average monthly solar radiation of 4000-5000 Wh/m_2 that receives abundant sunshine of about 2200 h in a year [14]. Thus, it has the potential to establish large-scale solar power installations in the country. The study will estimate the prospective electricity output, using local irradiance data and utilising 1%, 5% and 10% of the total water body surface area for emission reduction calculation potential.

The importance of this study lies in its attempt to compile and analyse a subnational GHG emission inventory for Malaysia's state using the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) with Selangor as the first case study, providing a standardized and replicable framework for data gathering, calculation, and reporting. Another significant contribution is the investigation into floating solar potential as a mitigation measure. This research would help in resolving data limitation issues, promoting uniform reporting, and providing novel energy alternatives, in fostering Malaysia's sustainable development.

2. Methodology

The methodology used in the study was structured according to the two objectives, shown in the research process flow in **Figure 1**.
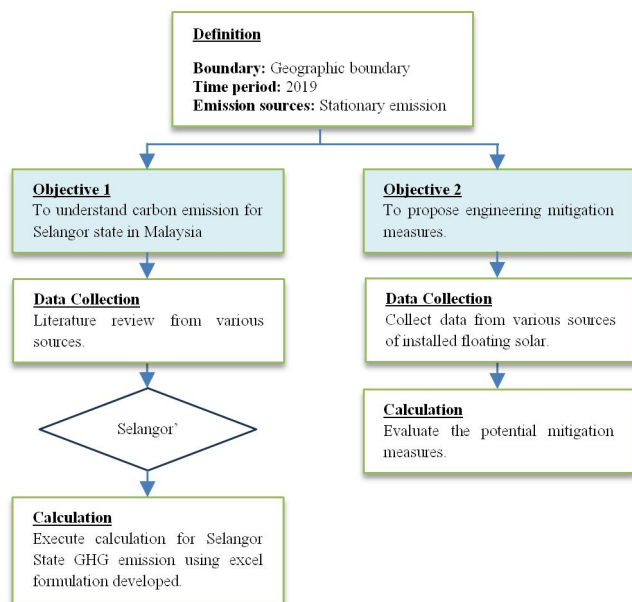

Figure 1. Research process flow.

There were three scopes of emissions sources that accounted for GPC Basic reporting [15]. However, due to data limitations, this study estimated GHG inventory limited to Scope 1 (fugitive emissions and

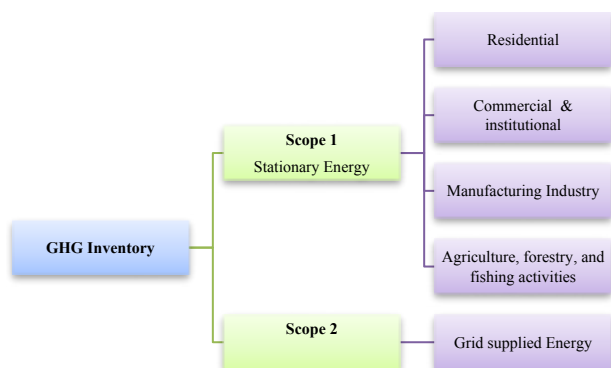energy industries were not included) and Scope 2 as shown in **Figure 2**.

Figure 2. GHG inventory coverage.

In the GPC, the city-induced reporting framework sought to account for emissions because of activities in the city or subnationally [15]. The scope framework referred to stationary energy emissions from sources within the geographic boundary of the Selangor state in Malaysia. The research scope was to employ GPC standards and benchmark carbon emission limited to Stationary Energy emissions that were accounted for carbon emissions from **Figure 3**.
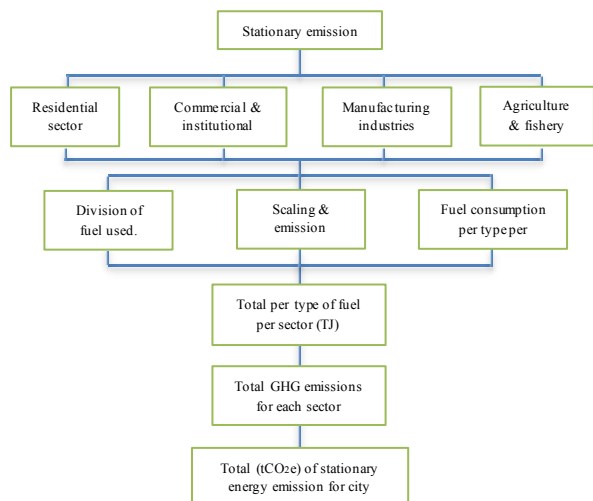

Figure 3. Breakdown of the emission inventory.

The first objective incorporated the details of data collection and GHG estimation calculation. The approach used was based on the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC).

Secondary data collection

The present study conducted a comprehensive analysis of quantifiable data by conducting a sys-

tematic literature review, which included city-scale greenhouse gas (GHG) inventory methodologies presented in scholarly journal articles, Malaysian government policies, official publications, census data, and various reports [16,17].

The secondary data for electricity consumption and energy consumption were collected respectively from the Energy Commission (ST), using the latest National Energy Balance (NEB) 2019. The data was scaled down either using population or industrial GDP (depending on sectors) to estimate Selangor's consumption. Apart from that, relevant data was collected and referred from various sources of reports such as GHG Protocol Policy and Action Standard, Population and GDP, National Policy on Climate Change, Biennial reports, census for city, NLCCM, GPC & etc.

Activity data were identified from data provided in the National Energy Balance of the year 2019 for electricity and various fuel consumption such as natural gas, petrol, diesel, fuel oil, LPG, kerosene, ATF & AV gas, coal & coke, and biodiesel [18,19]. These data were then tabulated into GPC reporting format and converted from Kilo Tonnes of oil equivalent (ktoe) value to terajoules (TJ) using the conversion factor of 1 ktoe = 41.868 TJ.

Identification of scaling factor

The scaling factor needed to be highly correlated, as it indicated the ratio between the available data and the required inventory data. In the absence of large technical and behavioural changes, the population is a significant source of GHG emissions, particularly in the residential sector. On the other hand, data on economic activities were better suited for using other scaling factors such as gross domestic product or industrial yield or turnover. For this study scaling factor was either the population of the state or Gross domestic product (GDP) by state and type of economic activity, for the year 2019 at constant 2015 prices - RM Million. This information was obtained from the Malaysia census. Suitable scaling factors and scale data to state boundaries were identified [20-23].

Identification of emission factor

The relevant emission factors were sourced from

the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines and data provided in the Third Biennial Update Report submitted to UNFCCC [18]. Emission factors quantified the quantity of greenhouse gas (GHG) emissions released for each unit of fuel combusted. The consumed fuel scaling factors were selected from either population or Gross domestic product (GDP) retrieved from Key Summary Statistics for Local Authority Areas in Malaysia for the selected period.

The emission factor for electricity was obtained from the Grid Emission Factor (GEF) from the Malaysia Energy Commission, where GEF measures the weighted average emissions of greenhouse gases (GHGs) per unit of net electricity generated by all power plants that provided electricity for the grid, as shown in **Table 1** [24].

Table 1. Grid emission factor [24].

Grid emission factor (Gg CO_2e/GWh)			
	2017	2018	2019
Peninsular Malaysia	0.776	0.807	0.780
Sabah	0.513	0.520	0.527
Sarawak	0.213	0.193	0.222

Estimation of GHG emissions

GHG emissions of the Selangor state were estimated by multiplying activity data by an emission factor associated with the activity being measured. The degree of activity leading to greenhouse gas emissions within a specified time was quantified by the data on activities.

$$GHG\ emissions = Activity\ data \times Emission\ factor \quad (1)$$

Floating solar potential

Upon completion of the GHG estimation, the second objective followed, which was to propose a mitigation measure of floating solar photovoltaic (FSPV), by estimating the FSPV sizing and potential energy generation.

Identification of water bodies

The available water bodies in Selangor including ponds, lakes, former mines, and dams were identified and retrieved from the Selangor Water Management Authority (LUAS) website [25]. The selected water bodies for potential PV estimate had a minimum depth of not less than 3 m.

Estimation of PV sizing

Several stages and factors were considered when determining the optimal size of photovoltaic (PV) systems and the potential power generation from water bodies in Selangor. The sizing and PV generation estimation for Selangor's water bodies were done with 1%, 5%, and 10% of the area used, with an average of peak sun hours (PSH) of 4.823 kWh/m^2 per day as shown in **Figure 4** [26,27]. The calculation included a derate factor of (0.77) which encompassed all the environmental and system losses [28].
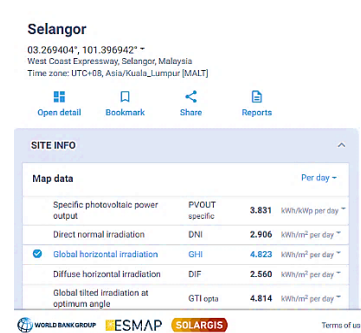

Figure 4. Selangor global horizontal irradiation.

The estimation varied depending on the specification of the selected module. For this purpose, Jinko Solar panel was selected, and details of its specification as shown in **Table 2**. With the selected PV, the required number of PV modules for installation could be determined according to the intended surface area of the water bodies.

Table 2. PV module specification [29].

Brand	Jinko Solar
Type	Mono-Facial Module (P-Type)
Model	Tiger Pro 72HC (530-550 Watt)
Watt/Panel (W)	550
Surface area (m^2)	2.578716

3. Results and analysis

3.1 Analysis of GHG emissions

The total GHG emissions for Selangor for the year 2019 were summarized and shown in **Figure 5**. The total emissions contributed by both consumption of fuels and electricity is 18,070.16 ktCO$_2$e, where

80% of the GHG emissions are contributed by Scope 2 source (electricity). Logically, reducing emissions from electricity use will significantly reduce the overall GHG emissions in Selangor.

Figure 6 shows both Scope 1 and Scope 2 emission contributions by each sub-sector. The total GHG emissions from residential, commercial and institutional, manufacturing and agriculture, and forestry and fishing activities are 5,261.56 $ktCO_2e$, 5,492.72 $ktCO_2e$, 7,395.84 $ktCO_2e$ and 10.03 $ktCO_2e$ respectively. The manufacturing sector contributes mostly (around 40%) to the total emissions in Selangor, followed by the commercial (30%) and residential (29%) sectors. This is attributed to Selangor being the industrialised state in Malaysia, with little agriculture, forestry, and fishery activities. In comparing the various fuel types for Scope 1 emission, natural gas is the highest emission source, consumed the most by the manufacturing industries sector of 1404.32 $ktCO_2e$ (44%), followed by diesel coal and coke, as shown in **Figure 7**. LPG was also used widely by residential, contributing quite considerably to Selangor's total emissions. Selangor's population in 2019 was around 6.51 million, signifying substantial contribution from the residential sector in addition to the other sectors in Selangor.

Breaking down the emissions by scope from different sub-sectors, it is noteworthy that Manufacturing is the highest emission contributor for Scope 1 as shown in **Figure 8**, while Commercial and Institutional is the highest contributor for Scope 2 as shown in **Figure 9**. Interestingly, the amount of emission contributions by the Manufacturing, Commercial and Residential is around 30% each.

In order to attain a carbon balance, it is necessary that strategies aimed at emission reduction prioritise the high-emitting sectors. These encompass sustainable industrial practices, a transition towards renewable energy sources, and the implementation of energy efficiency measures. Furthermore, promoting the use of sustainable energy sources such as floating solar photovoltaics (FSPV) has the potential to significantly reduce emissions and facilitate the transition towards carbon neutrality.

Figure 10 shows the breakdown of gas emissions, with carbon dioxide (CO_2) contributing the most at 18,060.83 $ktCO_2e$, representing more than 99% of emissions. Methane and nitrous oxide contribute comparatively lesser quantities, with emissions of 4.56 $ktCO_2e$ and 4.77 $ktCO_2e$, respectively. The high CO_2 emission is largely attributed to Scope 2 electricity emissions. Understanding this breakdown of emissions by specific gas types and sources yields useful insights that can influence targeted strategies for abatement. For example, mitigating carbon dioxide emissions from specific sectors has the potential to achieve significant reductions, considering its large contributions to the total emissions in Selangor.
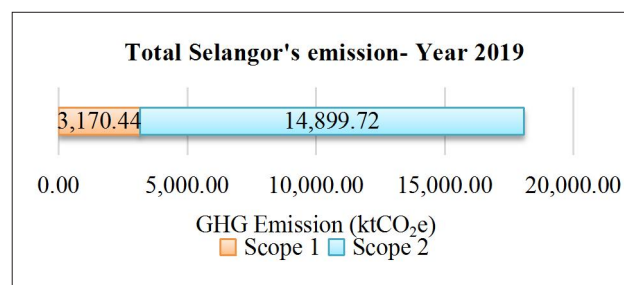

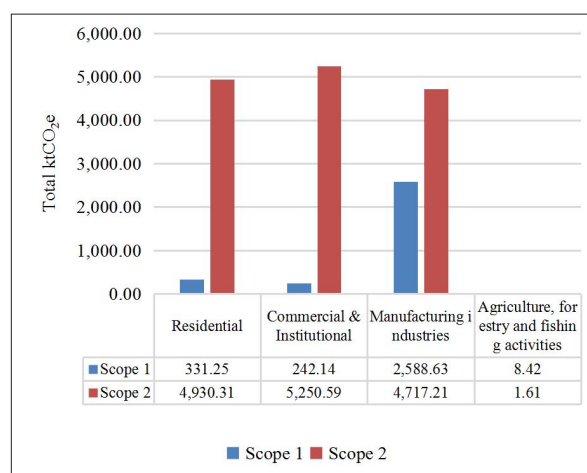**Figure 5.** Total Selangor's emissions for the year 2019.

Figure 6. Sectoral distributions of Scope 1 and Scope 2 (electricity) emissions.

3.2 Estimation of FSPV potential

In this study, 27 waterbodies including ponds (lake and former mines) and dams in Selangor were found to be suitable for floating PV installations as shown in **Tables 3 and 4**. The study proved that

floating PV installations in Selangor have great potential for generating electricity with only just 1%, 5% and 10% utilization of the water body surface area. With 10% surface coverage, the system would be capable of generating nearly 2.213 TWh for Selangor in a year, offsetting around 11.6% (1726.02 ktCO$_2$e) of the Scope 2 emissions.
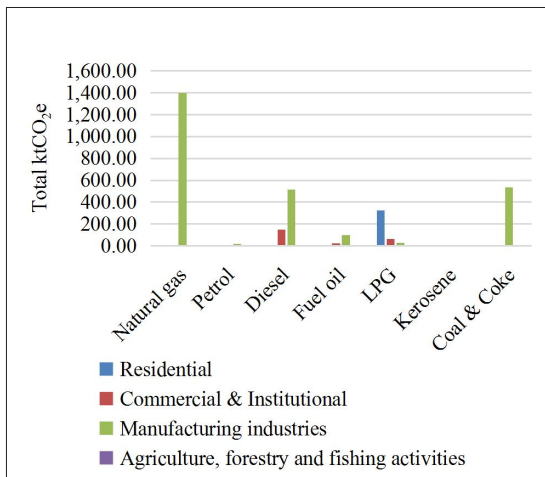

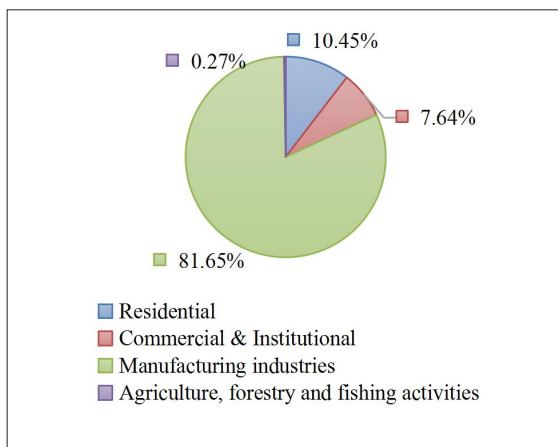**Figure 7.** Sub-sector breakdown and source of Scope 1 emission.

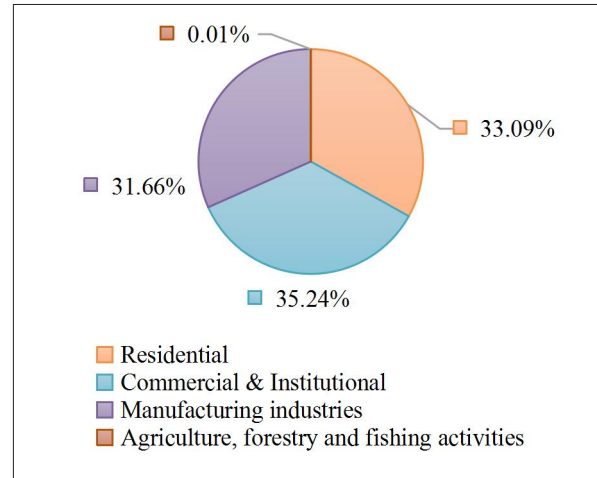**Figure 8.** Scope 1 contribution by sectors.

Figure 9. Scope 2 contribution by sectors.
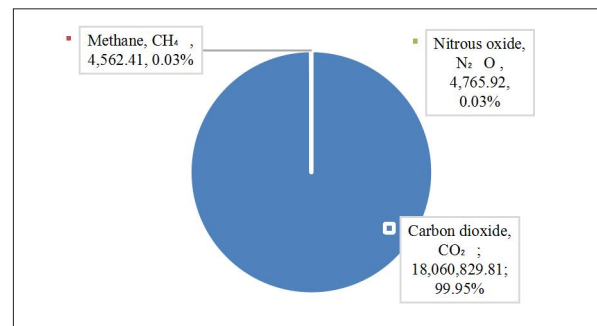
Figure 10. Gasses profile for Selangor's emission in 2019.

3.3 Policy implications

The findings of this study highlight the urgency of mitigating GHG emissions in Selangor and throughout Malaysia. This research is an effort to estimate emissions from available secondary primary data and better understand emissions in the stationary energy sector, which is crucial not just for Selangor's GHG inventory but also for demonstrating progress towards emission reduction targets considering Malaysia's commitments to Sustainable Development Goals 2030 and the Paris Agreement. For this purpose, numerous important policy implications and suggestions might be drawn:

Improvements in data management and availability

To achieve uniform reporting across states and regions, a standardised reporting structure should be created, one that is in line with international standards like the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC). In

Table 3. PV Sizing and energy generation for the available pond in Selangor.

Pond name	Area (Ha)	Area used (m^2)			No of module for % area used (nos)			Possible annual energy generation (GWh/year)		
		1%	5%	10%	1%	5%	10%	1%	5%	10%
P1	114.32	11,432	57,160	114,320	4,433	22,166	44,332	3.30	16.53	33.05
P2	99.63	9,963	49,815	99,630	3,864	19,318	38,636	2.88	14.40	28.80
P3	479.64	47,964	239,820	479,640	18,600	93,000	186,000	13.87	69.33	138.67
P4	31.27	3,127	15,633	31,266	1,212	6,062	12,125	0.90	4.52	9.04
P5	11.23	1,123	5,615	11,230	435	2,177	4,355	0.32	1.62	3.25
P6	25.50	2,550	12,750	25,500	989	4,944	9,889	0.74	3.69	7.37
P7	5.60	560	2,800	5,600	217	1,086	2,172	0.16	0.81	1.62
P8	11.80	1,180	5,900	11,800	458	2,288	4,576	0.34	1.71	3.41
P9	3.90	390	1,950	3,900	151	756	1,512	0.11	0.56	1.13
P10	106.41	10,641	53,205	106,410	4,126	20,632	41,265	3.08	15.38	30.76
P11	63.41	6,341	31,705	63,410	2,459	12,295	24,590	1.83	9.17	18.33
P12	132.60	13,260	66,300	132,600	5,142	25,710	51,421	3.83	19.17	38.34
P13	176.40	17,640	88,200	176,400	6,841	34,203	68,406	5.10	25.50	51.00
P14	65.20	6,520	32,600	65,200	2,528	12,642	25,284	1.88	9.42	18.85
P15	21.10	2,110	10,550	21,100	818	4,091	8,182	0.61	3.05	6.10
P16	182.80	18,280	91,400	182,800	7,089	35,444	70,888	5.29	26.42	52.85
P17	3,349.79	334,979	1,674,895	3,349,790	129,901	649,507	1,299,015	96.84	484.23	968.45
P18	10.00	1,000	5,000	10,000	388	1,939	3,878	0.29	1.45	2.89
P19	405.64	40,564	202,820	405,640	15,730	78,652	157,303	11.73	58.64	117.27
P20	2.83	283	1,415	2,830	110	549	1,097	0.08	0.41	0.82

Table 4. PV Sizing and energy generation for available dams in Selangor.

Dam name	Area (km^2)	Area used (m^2)			No of module for % area used (nos)			Possible annual energy generation (GWh/year)		
		1%	5%	10%	1%	5%	10%	1%	5%	10%
D1	5.09	50,900	254,500	509,000	19,739	98,693	197,385	14.72	73.58	147.16
D2	8.05	80,500	402,500	805,000	31,217	156,085	312,171	23.27	116.37	232.73
D3	2.03	20,300	101,500	203,000	7,872	39,361	78,721	5.87	29.34	58.69
D4	2.55	25,500	127,500	255,000	9,889	49,443	98,886	7.37	36.86	73.72
D5	0.81	8,100	40,500	81,000	3,141	15,705	31,411	2.34	11.71	23.42
D6	2.01	20,100	100,500	201,000	7,795	38,973	77,946	5.81	29.06	58.11
D7	3.01	30,100	150,500	301,000	11,672	58,362	116,725	8.70	43.51	87.02

the absence of local data, an inventory development using national data can be first established, to kick off the inventory activities before proper local data management can be set up.

Understanding local emissions profiles

This case study of Selangor demonstrates how important it is to have detailed subnational emission inventories for identifying emissions hot spots, conducting thorough risk assessments, creating effective mitigation strategies, and assessing the effectiveness of policies. Emissions trends and patterns can be better understood if this analysis is expanded to include additional Malaysian states and extended time periods.

Reduction through Scope 2 emissions

Given that electricity consumption (Scope 2 emissions) accounted for a sizeable portion of Selangor's carbon footprint, reducing this source of emissions

requires coordinated efforts to shift to renewable energy sources and improve energy efficiency in the industry, residential and commercial sectors.

FSPV as a mitigation measure

The study demonstrates the significant potential of FSPV technology in Selangor, providing an opportunity for emission reduction. More research is needed on policies and incentives that could speed up the adoption of FSPV systems on waterways.

4. Conclusions

In conclusion, Malaysia's commitment to the Sustainable Development Goals 2030 and Paris Agreement shows that the country is serious about reducing carbon emissions while fostering long-term economic prosperity. However, effective climate policies and planning are hindered, due to issues in data management and availability, uniform reporting framework and understanding of subnational emission profiles. This study addressed those issues by estimating carbon emissions using GPC framework and assessed the emission reduction potential via FSPV (Floating Solar PV) systems, utilising available ponds and dams in Selangor. Furthermore, the study stressed the need for detailed subnational emission inventories for proper risk assessment, mitigation strategy development, and policy evaluation.

The recommendation that can be made to this study is to extend the data period, covering the remaining Malaysia states for an in-depth analysis of state inventory, to provide a more comprehensive and robust knowledge of emissions trends and patterns. Longer time periods, for instance, a decade or more, allow for a more accurate assessment of how economic fluctuations, policy moves, technology developments, and changes in energy consumption patterns affect emissions. Additional research is required to explore viable approaches in order to effectively mitigate emissions and attain carbon neutrality.

Author Contributions

A.M.A. designed the study and outlined the structure of manuscript; interpreted and discussed the result; and edited and revised the manuscript. S.N.Z processed and analysed the data and performed the proposed methods; drafted the manuscripts, interpreted, and discussed the results; and handled the submission steps. A.S.I. provided the data and documents for relevant analysis. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

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