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Integrated Framework for Carbon Accounting, Mitigation, and Offsetting for Achieving Industry Carbon Neutrality in Malaysia

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The growing threat of global warming has prompted Malaysia to pledge a 45 % reduction in its greenhouse gas emissions intensity of gross domestic product (GPD) by 2030. The industrial sector is a critical area for mitigation, and carbon accounting, mitigation, and trading are crucial steps towards reducing emissions. While previous studies have focused on individual accounting, mitigation and offset assessment, a comprehensive and integrated approach is needed to guide Malaysian industries towards carbon neutrality. This paper proposes such a framework, which combines carbon accounting, mitigation, and offsetting measures. The paper also introduces the Carbon Mitigation Measures Index (CMI), which assesses carbon mitigation measures based on both their environmental and economic impacts. The proposed framework and CMI can serve as a guide for Malaysian industries to achieve their carbon neutrality goals and contribute to global efforts to mitigate climate change. By adopting this integrated approach, Malaysian industries can reduce their carbon footprint, meet national emissions reduction targets, and contribute to global efforts to combat climate change.

1. Introduction

Rapid growth in economy, technology, and lifestyles around the world results in increasing amount of global greenhouse gases (GHG) emissions. Based on a report published by PBL Netherlands Environmental Assessment Agency in 2022, the total global greenhouse gas emissions in 2020 reach 49.8 gigatonnes CO_2 equivalent (Gt CO_2-eq) (Olivier, 2022). In 2018, the highest contributors of carbon emissions are China, United States, India, Russia and Japan which are 29 %, 15 %, 7 %, 5 % and 3 % of the total global carbon emissions respectively (International Energy Agency, 2021). According to the Fourth Biennial Update report, 2022, greenhouse gas emissions in Malaysia increase from 253,156,64 Gg CO_2-eq in 2016 to 259,326.11 Gg CO_2-eq in 2019.

In order to reduce the global GHG emissions, many countries had participated in Paris Agreement and pledged to reduce their greenhouse gas emissions in order to achieve the aims of the Paris Agreement. Malaysia has pledged to reduce its greenhouse gas emissions intensity of gross domestic product (GPD) by 45 % relative to its 2005 level by 2030 (International Energy Agency, 2020). 35 % reduction is on unconditional basis and a further 10 % reduction will be from receipt of climate financing, technology transfer as well as capacity building from developed countries. Malaysia also committed to become a carbon-neutral nation by 2050 (TheStar, 2021). According to Fourth Biennial Update report, the energy, transportation, industrial process and product use (IPPU), agriculture, land use, land-use change and forestry (LULUCF), and waste sectors are the main sectors emitted the highest GHG emission. In the business-as-usual (BAU) scenario for 2019, the sectoral GHG emission is 78.5 % from the energy sector, 9.9 % from the IPPU sector, 3.0 % from the agricultural sector, and 8.6 % from the waste sector. 12.95 % of the emissions in energy sector are from manufacturing industries and construction and 51.18 % of the emissions in waste sector are from industrial wastewater treatment and discharge. This shows that industrial sector also contributes direct and indirectly to the total emissions in energy

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and waste sectors. Identifying mitigation opportunity along industrial sector value chain may results in significant reduction of emissions in energy and waste sectors too. Hashim et al. (2015) presented an Integrated carbon accounting and mitigation (INCAM) framework to monitor emissions reduction strategy implementation, however this method does not address how the emission reduction changed over time and how many years is needed to reach carbon neutrality. The objective of this paper is to propose a systematic and integrated framework as a guide for Malaysian industries towards achieving net-zero emissions. The paper is organized as follows. Section 2 proposed an integrated carbon accounting, mitigation, and offsetting framework as well as carbon mitigation measures index. The effectiveness of the proposed framework and index are demonstrated using a refining plant case study in Section 3 while Section 4 concludes the research finding.

2. Integrated carbon accounting, mitigation, and trading framework

The integrated framework comprises of 3 main steps, (i) carbon accounting, (ii) carbon mitigation, (iii) carbon trading. Firstly, the input data such as production data, reduction target, emissions baseline, activity data (fuel consumption, electricity consumption, waste generation, water consumption, transportation, etc.), and emission factors will be collected. The company will then be divided into several carbon accounting centres (CACs) and activity data for each CACs will be sorted based on the scopes so that an in-depth analysis of the emission hotspots can be done.

Next, the carbon emissions of each CACs and scopes will be calculated using Eq(1) and Eq(2) which is the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Tier 1 and Tier 2 equation respectively. These equations are chosen as it is important to use carbon accounting method that follows National GHG Inventory methodology since it is one of the key requirements for carbon trading in Malaysia (KASA, 2022). Tier 1 equation will be used to calculate carbon emissions where country-specific emission factors are not available and Tier 2 equation will be used otherwise.

$$E = \mathrm{AD} \times \mathrm{EF} \tag{1}$$

$$E = AD \times EF_{CS} \tag{2}$$

In Eq(1) and Eq(2), E is the emission, AD is the activity data, EF is the emission factor, and EF_{CS} is the country-specific emission factor. The categorization of emissions will follow GHG Protocol Standard which is by scopes and will be further divided based on carbon accounting centre (CAC). Dividing emissions by CAC and calculating the carbon emission index (CEI) of each CAC as proposed by Hashim et al. (2015) enable the emission hotspots to be identified. The total carbon emissions of the company and the total emission reduction from baseline will be calculated.

Next, emission reduction target will be set based on the carbon benchmarking result or carbon cap if domestic carbon emission trading system is implemented in Malaysia. Current emissions reduction will be compared to emissions reduction target and if there is any excess emissions reduction with respect to target, company can consider selling their emission allowance to gain profit. If the emission reduction target is still not met, emission hotspots will be identified, and possible mitigation measures will be proposed accordingly.

To identify emissions hotspots, CEI of CACs and scopes will be calculated using Eq(3) as proposed by Hashim et al. (2015). Pie charts of CEI for CACs and scopes will be developed to ease the process of identifying emission hotspots. Higher CEI value means higher emission intensity. Scopes and CACs with highest CEI value will be identified as the emission hotspots. The mitigation measures proposed based on the identified hotspots will then be ranked based on the economic, and environmental aspects using carbon mitigation measures index (CMI).

$$CEI = \frac{E}{Total\ product\ produced} \tag{3}$$

Emission reduction and payback period are the two variables that will be used to calculate carbon mitigation measures index. Firstly, the type of variables must be identified. There are two types of variables which are beneficial and non-beneficial variables. Beneficial variables are the one that are better the larger the value is. Non-beneficial variables are the one that are better the smaller the value is. In this case, emissions reduction are the beneficial variables while payback period are the non-beneficial variables. Once the type of variables has been determined, each variable will be normalized.

For beneficial variables, the normal value will be divided by the largest number from the set to obtain the normalized value. For non-beneficial variables, the smallest number from the set will be divided by the normal value. Next, carbon mitigation measures index (CMI) for each mitigation option will be calculated using Eq(4).

$$\mathrm{CMI} = \omega_{ER} \times \mathrm{Normalized\ Emission\ Reduction} + \omega_{PP} \times \mathrm{Normalized\ Payback\ Period} \tag{4}$$

ω_{ER} and ω_{PP} is the weightage for emission reduction and payback period respectively. ω_{ER} and ω_{PP} are both set to be 0.5 if it is equally important. The weightage of emission reduction and payback period can be changed depending on the priority of a company. The total of both weightages must be equal to 1. For example, if Company X prioritize payback period more than the emission reduction, the company might set ω_{ER} and ω_{PP} to be 0.3 and 0.7 respectively. A higher value of CMI means that the options have better trade-off between the emissions reduction and payback period, giving it a higher priority ranking. The emission reduction and payback period is calculated using Eq (5) and Eg (6)

$$\%\, Emission\ reduction = \frac{Emission\ (current) - Emission\ (baseline)}{Emission\ (baseline)} \tag{5}$$

$$Payback\ period\ (yr) = \frac{Energy\ savings\ (\frac{RM}{yr})}{Investment\ cost\ (RM)} \tag{6}$$

The selected mitigation measures will be implemented based on the priority ranking and carbon emissions after implementing mitigation measures will be calculated. The new emissions reduction will be compared to the reduction target to see whether the target is met or not. If the target is still not met, mitigation measures that are next in ranking will be implemented. This loop continues until the reduction target is met or if there are no other mitigation measures to be implemented. If the target is met, carbon trading potential will be evaluated, and company can consider selling their excess emissions to gain profit. If the target is still not met after implementing all proposed mitigation measures, buying carbon credit to offset the remaining carbon emissions to achieve the target is highly recommended. By doing this, it is possible for the company to achieve the emissions reduction targets, and companies with extra emissions reduction can gain profit by selling their emissions allowance.

3. Case study

A physical refining plant located in Johor has been chosen as a case study to show the effectiveness of this framework. This plant processes 302,400 tonne crude palm oil (CPO) into refined, bleached, and deodorized palm oil (RBDPO) annually. Available activity data has been collected and carbon emissions of the refining plant have been calculated by multiplying each activity data with its emission factor. The activity data and carbon emissions calculated are shown in Table 1. The emission factors used in this paper are taken from Malaysia's Fourth Biennial Update Report. Carbon emissions for direct combustion of LPG uses Tier 1 equation while emissions for Scope 2- Electricity uses Tier 2 equation since the emission factor used is the region-specific emission factor for Peninsular Malaysia.

Table 1: Summary of Activity Data and Carbon Emissions

Source of Emissions	Activity Data	Unit	Emission Factor (t CO_2-eq/unit)	Emissions (t CO_2-eq/y)
Scope 1- Direct Combustion (LPG)	46,208,311.55	GJ	0.0630724	2,914,469.11
Scope 2- Electricity	1,862,214.60	MWh	0.78	1,452,527.39
	Total Emissions			4,366,996.50

The next step is to set emissions reduction target. Two scenarios with two different emissions reduction targets will be done for this case study. For the first scenario, the emissions reduction target is set to be 32 % from the baseline. For the second scenario, the refining plant will be aiming for carbon neutral in 15 y. The current carbon emissions performance of the refining plant is illustrated in Figure 1a. Based on the graph, a lot of reductions are needed to achieve targets that have been set.

The next step is to identify hotspots and proposed mitigation measures accordingly. A pie chart of carbon emissions by scopes is made to find the emissions hotspots. Figure 1b shows the carbon emissions profile of the refining plant. Based on carbon emissions profile, majority (67 %) of the carbon emissions of the refining plant comes from direct combustion of LPG to fuel boiler. Therefore, the carbon mitigation measures proposed should focus on reducing LPG consumption. Table 2 shows the summary of the mitigation measures proposed for the refining plant.

There are eight carbon mitigation measures proposed for refining plant A, where changing heat exchanger and solar thermal integration focuses on reducing emissions from direct combustion and solar PV to reduce electricity. There are six designs proposed for solar thermal integration; Option 1- 1 PFAD storage tank with available water storage tank, Option 2- 1 PFAD storage tank with new water storage tank, Option 3- 3 PFAD storage tank with available storage tank, Option 4- 3PFAD storage tank with new water storage tank and bigger

collector area, Option 5- 7 PFAD storage tank with available water storage tank, and Option 6- 7 PFAD storage tank with new water storage tank and bigger collector area.
Based on the GHG calculation, it was found that Option 6 of solar thermal integration can give the highest GHG reduction out of all options proposed. Based on the analysis, solar thermal integration using 7 PFAD storage tanks with new water storage tank and bigger collector area can reduce 15.08 % of the emissions from direct combustion of LPG by reducing its thermal energy usage. The second highest emissions reduction can be obtained through installation of solar PV which reduces 7 % of the electricity usage. Based on the emissions reduction alone, mitigation measures with highest priority will be solar thermal integration, followed by installing solar PV, and change heat exchanger.

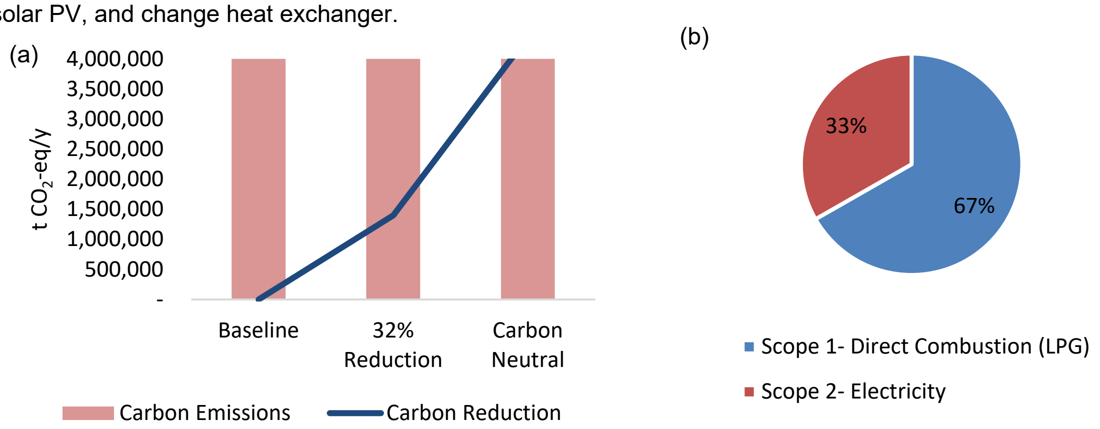

Figure 1: (a) Carbon Emissions Performance, and (b) Carbon Emissions Profile of Refining Plant A

To make environmental and economic friendly decision, the proposed mitigation measures are then ranked based on its emissions reduction potential and payback period using the carbon mitigation measures index (CMI). Normalized emissions reduction is first obtained by dividing the emissions reduction by 439,475 which is the largest number in the set. Normalized payback period is obtained by dividing the smallest value of payback period, 0.3, by the normal payback period.Carbon mitigation measures index (CMI) for each option are then calculated using Eqn. 4. ω_{ER} and ω_{PP} are both set to be 0.5 for this case study as it is equally important. The summary of the carbon mitigation measures ranking for refining plant A are shown in Table 3. Based on the results, it shows that solar thermal integration (Option 6) should first be done, followed by changing heat exchanger, and installation of solar PV. These results also showed that CMI are able to choose the best design of solar thermal integration which is Option 6.

Table 2: Summary of Carbon Mitigation Measures Proposed for Refining Plant A

No.	Mitigation Measures		Baseline ($t CO_2$-eq/y)	GHG Emission Reduction Respect to Baseline ($t CO_2$-eq /y)	% Emission Reduction	Payback Period (y)
1	Change HEX			0.00314	0.00 %	0.3 (Smallest value)
2	Solar Thermal Integration	Option 1	4,366,996.50	40,287	0.92 %	14.9
		Option 2		67,370	1.54 %	24.5
		Option 3		88,990	2.04 %	18
		Option 4		198,469	4.54 %	16.6
		Option 5		114,800	2.63 %	13.9
		Option 6		439,475 (Largest value)	10.06 %	15.7
3	Solar PV			1,013.92	0.02 %	6.68

The implementation of carbon mitigation measures can be done in phases as shown in Table 4. The total carbon reduction that can be achieved through carbon mitigation measures is 440,488.92 t CO_2-eq. The carbon emissions after implementation of proposed carbon mitigation measures have been projected and shown in Figure 2. Based on the figure, the target of 32 % reduction from baseline cannot be achieved by implementing carbon mitigation measures alone. More effort needs to be made to achieve the set target.

Table 3: Summary of Carbon Mitigation Measures Ranking

No.	Mitigation Measures		Normalized Emission Reduction	Normalized Payback Period	Carbon Mitigation Measures Index	Priority Ranking
1	Change HEX		0.000	1.000	0.500	2
2	Solar Thermal Integration	Option 1	0.092	0.020	0.056	7
		Option 2	0.153	0.012	0.083	6
		Option 3	0.202	0.017	0.110	5
		Option 4	0.452	0.018	0.235	3
		Option 5	0.261	0.022	0.142	4
		Option 6	1.000	0.019	0.510	1
3	Solar PV		0.002	0.046	0.024	8

Table 4: Reduction from Implementation of Carbon Mitigation Measures

Mitigation Measures	CO_2 Reduction (t CO_2-eq/y)			
	Baseline	Year 1	Year 2	Year 3
Solar Thermal Integration Option 6		439,475.00		
Change HEX			0.0031	
Solar PV				1,013.92
Total CO_2 Reduction (t CO_2-eq/y)	-	439,475.00	0.0031	1,013.92

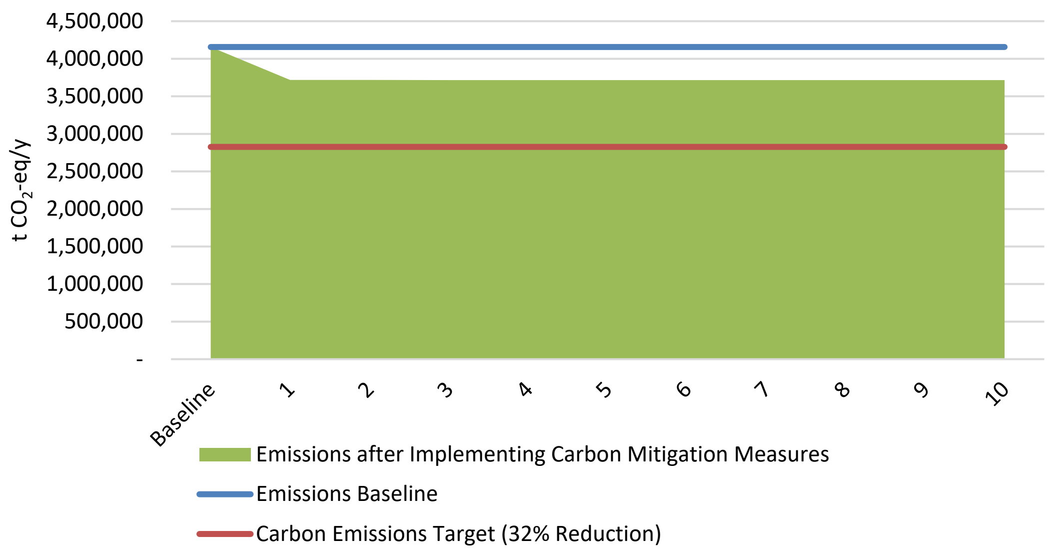

Figure 2: Carbon Emissions Projection After Implementation of Mitigation Measures

If the implementation of carbon mitigation measures cannot meet the specified emission reduction target, the next actions that should be considered are carbon removal. The most preferred method of carbon removal is through tree planting which is due to the continuous carbon removal until the end-life of the trees planted. Tree can serve as carbon sink in the environment. To further reduce carbon emissions of the refining plant, recommendations of tree planting have been made. A total of 10,000 trees are suggested to be planted in stages for 5 y. It is estimated that on Year 10, a total of 1,299,289.93 t CO_2 can be removed through tree planting alone. Carbon emissions projection for different scenarios has been made to show the effect of carbon mitigation and carbon removal through tree planting. Figure 3 shows the carbon emission projection towards carbon neutral with different scenarios. Based on the projection, the target of 32 % reduction can be achieved in the middle of Year 8 through Scenario 2 which combined carbon mitigation measures and tree. It is clear that tree planting can be really effective in reducing carbon emissions. Carbon neutral can be achieved approximately in the first half of Year 19 through Scenario 2. However, the company set the target to achieve carbon neutral on Year 15. Offsetting through carbon trading can be done to achieve the target set as shown in Scenario 3.

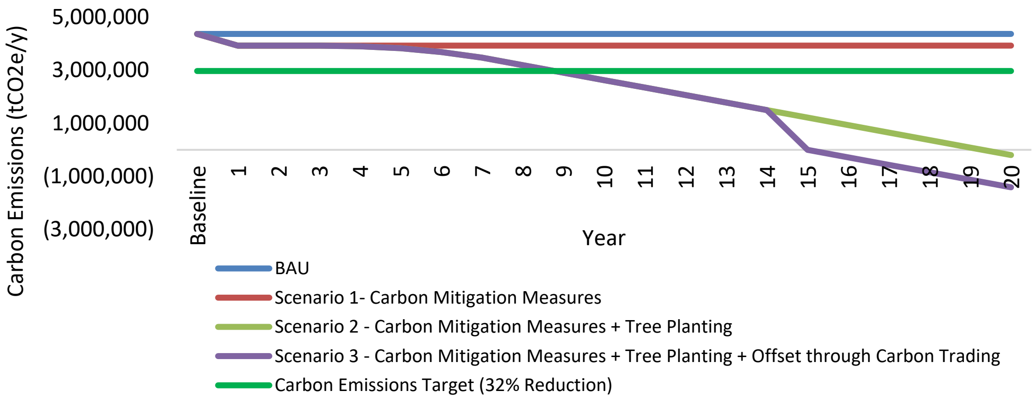

Figure 3: Carbon Emissions Projection for Different Scenarios

4. Conclusions

The integrated carbon accounting, mitigation, and offsetting framework proposed in this study are effective in guiding industries towards achieving carbon neutrality. The framework demonstrated sucessfully using the refining plant as a case study. The results indicate that the refining plant can achieved its target to reduce 32 % of its GHG emissions as well as achieve carbon neutral in 15 y. The proposed carbon mitigation measures index (CMI) is also proven to be effective in ranking carbon mitigation measures based on the emissions reduction and payback period. In conclusion, reducing greenhouse gas emissions is a global issue that requires concerted efforts from all nations. By adopting these frameworks and tools, industries can achieve their GHG emissions reduction targets and contribute to a healthier environment for future generations.

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