CHEMICAL ENGINEERING TRANSACTIONS

VOL. 39, 2014

A publication of AIDIC

The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editors: Petar Sabev Varbanov, Jiří Jaromír Klemeš, Peng Yen Liew, Jun Yow Yong

**ISBN** 978-88-95608-30-3; **ISSN** 2283-9216 DOI:10.3303/CET1439035

# A Graphical Approach for the Planning and Design of a Low Carbon Product

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$CO_2$ is being emitted throughout a product's life cycle, i.e., during the material acquisition and extraction, materials transportation, product manufacturing and disposal. Strategies such as product path selection, supply chain planning, product reuse and recycling, fuel switching, conversion of waste to energy and carbon sequestration can contribute to carbon emission minimisation at the different stages of a product's life cycle. A Carbon Supply Chain Product Curve (CSCPC), and an extended Systematic Hierarchical Approach for Resilient Process Screening (SHARPS) are proposed to evaluate a product $CO_2$ emission throughout its supply chain and to select the suitable, and economically viable $CO_2$ minimisation strategies. The proposed method has been tested to plan and design a low carbon palm cooking oil. Palm oil milling is determined as the major emission contributor in the palm cooking oil life cycle. High $CO_2$ reduction technologies require more investment and are less profitable. By using the CSCPC-SHARPS tool, $CO_2$ reduction can be a cost-effective, and result in low carbon emission. Application of the approach on a case study shows a potential reduction of 70.8 % carbon emissions as compared to the conventional palm oil supply chain carbon emission.

## 1. Introduction

The shift towards green economy has encouraged manufacturers worldwide to reduce $CO_2$ emissions and increase energy efficiency. Numerous projects around the world have been branded as 'low carbon' such as 'low carbon city', 'low carbon process', 'low carbon economy', 'low carbon vehicle' etc. Government, industries, businesses and consumers are becoming increasingly aware of the importance of environmental conservation. A policy to cut energy consumption has been proposed in order to reduce the greenhouse gas emissions - e.g. $CO_2$ (Khan et al., 2014). The rising demand for low carbon products has motivated in this work. The aim is to develop a new tool to aid the development and planning a low carbon product, from the material acquisition until it reaches the customer. This new tool is to help in the planning, decision making and the labelling of low carbon products.

$CO_2$ is being emitted throughout a product life cycle from cradle to grave. $CO_2$ emission minimisation initiatives are however mostly focused on the manufacturing stage where various initiatives are implemented including efficient housekeeping, increasing energy efficiency and saving, use of energy efficient product and renewable energy, or at the end of pipe stage i.e. carbon capture and storage. Results from previous studies show that the efficient utilisation of feedstock, byproducts recycling and waste minimisation tend to lower the global warming potential (GWP) and energy resource impacts (Chinnawornrungsee et al., 2013). Numerous studies on $CO_2$ minimisation have been published dealing with various methods for planning purposes. Many of the existing tools have focused on electricity sector regional planning (Tan, 2007), power generation planning of electric system (Mirzaesmaeeli et al., 2010), carbon capture and storage planning with pinch analysis (Ooi et al., 2013), carbon footprint reduction in chemical processes (Tjan et al., 2010), buildings (Lawal et al., 2012) and industrial site $CO_2$ reduction

Please cite this article as: Mohd Nawi W.N.R., Wan Alwi S.R., Manan Z.A., Klemeš J.J., 2014, A graphical approach for the planning and design of a low carbon product, Chemical Engineering Transactions, 39, 205-210 DOI:10.3303/CET1439035

(Munir et al., 2012). However, the product life cycle $CO_2$ emissions are also contributed by the feedstock, material acquisition and transportation, product manufacturing, recycling, reuse and product disposal stages. In plantation operations, electric vehicles charges using a solar photovoltaic (PV) system can reduce up to 750 t of $CO_2$-eq/y from the total emission of 211 M kg of $CO_2$-eq/y (Ludin et al., 2014). Aivazidou et al. (2013) proposed the framework for carbon footprint management to achieve the economic sustainability across the supply chain. Strategies including product path selection, supply chain planning, product reuse and recycling, fuel switching, converting waste to energy and carbon sequestration can contribute to carbon emission minimisation in the different stages of life cycle. There is a need to develop a tool to systematically plan and prioritise $CO_2$ minimisation strategies for a low carbon product planning. Although a product planner may want to reduce $CO_2$ emission in all parts of the product lifecycle, it may not be always economically feasible. In this work, CSCPC with an extended SHARPS method by Wan Alwi and Manan (2006) was used to evaluate the $CO_2$ minimisation strategies. The low carbon product planning only considers the $CO_2$ emission reduction from the material acquisition up to the customer whereby the product producer has a say in the supply chain planning. In developing countries in particular, the mechanism to track, monitor and control the product waste after it is sold to a customer is yet to be established. Used cooking oil, for example is typically flushed down the sink. This practice tend to overload the sewage system and adversely affect the waste water treatment plants (Abdullah et al., 2013)**.** This paper demonstrates the generic methodology to plan a low carbon palm cooking oil product up to the customer, which is applicable in the context of developing, as well as developed countries. It is noted that, in developed countries, businesses are liable to pay the excess penalty of € 100 per excess t of $CO_2$ produced under the regulatory intervention of Emissions Trading Scheme - ETS (Mallidis et al., 2013).

## 2. Methodology with Illustrative Case Study

Following is the proposed step-wise procedure to plan a low carbon product. Palm cooking oil is used as an illustration**.**

Step 1: Set the product basis, identify the product supply chain phases, and extract carbon emission data throughout the phases from material acquisition to the customer.

In the first step, a product basis needs to be set e.g. 1 t of palm cooking oil. The product supply chain phases up to customer need to be identified. For palm cooking oil, the supply chain can be divided into six phases i.e. (1) palm plantation, (2) transportation from plantation to palm oil mill, (3) palm oil mill, (4) transportation from palm oil mill to palm oil refinery, (5) palm oil refinery and (6) transportation from palm oil refinery to a customer. The equivalent amount of raw material used in each phase to produce the product basis was identified. According to Kasivisvanathan et al. (2012), 1 t of palm cooking oil requires 6.58 t of fresh fruit bunch (FFB) from the plantation. The 6.58 t of FFB produces about 1.32 t of crude palm oil in the palm oil mill. This crude palm oil is further processed in the palm oil refinery to produce the 1 t of palm cooking oil. Table 1 shows the $CO_2$ emission for a 1 t palm cooking oil life cycle. It is assumed that the palm cooking oil production is only transported within 200 km radius (estimated from palm plantation to the customer).

From Table 1, the total $CO_2$ emission throughout palm cooking oil production lifecycle is estimated at 11.59 t of $CO_2$/t of palm cooking oil. Assuming 8,000 operating h/y, the $CO_2$ emission to the atmosphere is about 92.709 x $10^3$ t of $CO_2$/y.

Step 2: Generate the carbon supply chain product curve (CSCPC) plot.

After determining the carbon emission contributed by each supply chain phases, the carbon supply chain product curve (CSCPC) is plotted. The CSCPC is a plot of cumulative amount of $CO_2$ emission from material acquisition phase to customer. A negative value indicates $CO_2$ is being absorbed. For example, in a plantation, $CO_2$ is absorbed by the palm oil trees. A positive value indicates $CO_2$ is being emitted. For example, a truck transporting the materials from one location to another, uses fuel that emits $CO_2$. Figure 1 is a sample of CSCPC for 1 t of palm cooking oil.

This CSCPC can also be used as a carbon product supply chain label. If a product producer would like to inform the customer on the carbon emission of their product and compare it with their competitor, then they can use this curve. A lower carbon emission shown in the CSCPC may persuade the customer to buy their product as compared to a competitor's product. Hence, a product planner's goal is to reduce the CSCPC. This can be done by carefully planning their carbon emission reduction strategies based on the current CSCPC.

Step 3: Identify the main contributor to high CSCPC.

Looking at Figure 1, which is the current $CO_2$ emission produced throughout the supply chain based on the conventional technologies, it can be observed that Phase 3 (palm oil mill) contributes the highest $CO_2$ emission, followed by Phase 5 (palm oil refinery). Hence, this is where the product planner should first focus their effort. For example, if there are a few palm oil mills with various technologies to be chosen to supply the CPO, the one with the lowest $CO_2$ emission should be chosen.

If, on the other hand, the product planner is the owner of the palm oil mill, then the product planner can identify what are the changes that need to be employed in this phase. For the latter, the product planner can utilise the extended SHARPS technique as described in the next step.

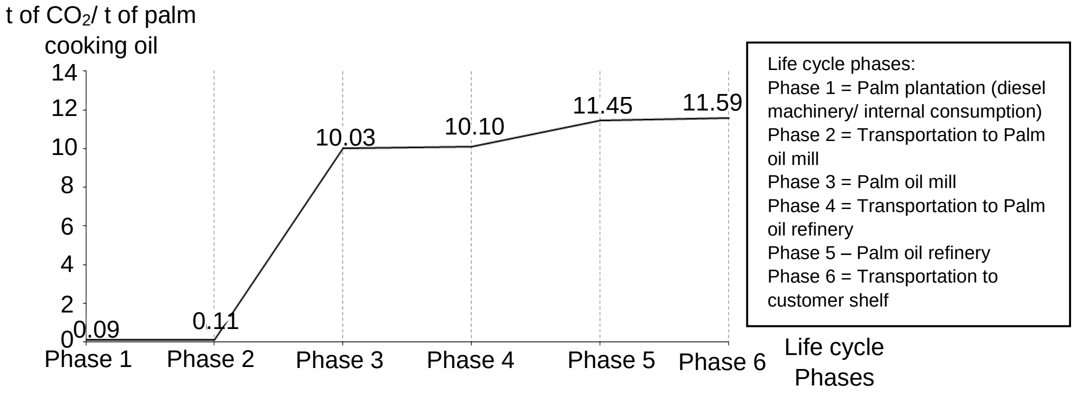


*Figure 1: A sample of CSCPC for 1 t of palm cooking oil*

*Table 1: $CO_2$ emission throughout a palm cooking oil lifecycle for a basis of 1 t of cooking palm oil*

| Lifecycle Phase | Emission ($t\ CO_2$) | References |
|---|---|---|
| Palm plantation (diesel machinery/internal consumption) | 0.085 | (Klaarenbeeksingel, 2009) |
| Transportation from palm plantation to palm oil mill (30 km) | 0.021 | (Kaewmai et al., 2012) |
| Palm oil mill (POM) | 9.924 | (Mirzaesmaeeli et al., 2010) |
| Transportation from POM to palm oil refinery (100 km) | 0.071 | (Kaewmai et al., 2012) |
| Palm oil refinery (POR) | 1.345 | (Agency, 2010) |
| Transportation from POR to customer (200 km) | 0.142 | (Kaewmai et al., 2012) |

Step 4: Employ SHARPS for the identified phase.

Systematic Hierarchical Approach for Process Screening (SHARPS) introduced by Wan Alwi and Manan (2006) is used to screen the best alternative to give the highest savings within the payback period or investment criteria set by the plant owner. The cost-effective screening technique is divided into four steps as follows:

Step i: Set level of prioritisation

Step ii: Find process improvement alternative for each process based on level of prioritisation.

Step iii: Select the process improvement option that gives the highest $CO_2$ reduction regardless of investment needed and plot cumulative investment versus saving (IAS-plot) based on the level of prioritisation. Note that the saving in this case refers to the income from changing waste to resources by using suitable technologies conversion. If there is carbon emission tax or penalties by certain countries, it can also be included. Draw the total payback period line and compute the initial payback period ($TPP_{BS}$) and investment ($INV_{BS}$).

Step iv: Compare the payback period and investment with the desired payback period ($PP_{set}$) and investment ($INV_{set}$) by designer. If it is higher, then apply SHARPS strategies are implemented. If not, then the design is proceed. Following are the two strategies:

SHARPS strategy 1- Substitution: This strategy involved replacing the equipment/process that resulted in the steepest positive gradient with an equipment/process that gave a less steep gradient.

SHARPS strategy 2- Intensification: The second strategy involves reducing the length of the steepest positive gradient until the new total payback period line ($TPP_{AS}$) and Investment ($INV_{AS}$) is equal to $PP_{set}$ and $INV_{set}$.

For the cooking oil palm example, Phase 3 which contributes to the highest $CO_2$ emission is further investigated. The $CO_2$ emitter from palm oil mill was identified as follows: 99.83 % from palm oil mill effluent (POME), with the remaining from biomass or by products produced which are palm kernel shell (PKS), palm press fiber (PPF), empty fruit bunch (EFB), palm kernel cake (PKC) and electricity used from palm oil mill (Foo et al., 2013).

POME or Palm Oil Mill Effluent is the main contributor of $CO_2$ emissions (Patthanaissaranukool et al., 2013) in a palm oil mill process due to the anaerobic digestion that produces methane (Hassan et al., 2011). One kg methane is equivalent to 24.5 kg of $CO_2$ emission (Kaewmai et al., 2012). The possible strategies adapted from Kasivisvanathan et al. (2012) to reduce the $CO_2$ emissions from POME, by products and electricity are identified and listed in Table 2.

Next, the process improvement options that give the highest $CO_2$ reduction regardless of investment needed are identified for each of the $CO_2$ contributor i.e. POME (option 3), byproduct (option 4) and electricity (option 7). A plot of cumulative investment versus saving (IAS-plot) is generated as shown in Figure 2. The initial payback period ($TPP_{BS}$) and investment from the implementation of these three strategies are determined from the IAS plot, i.e. $TPP_{BS}$ is 25.27 y and investment USD21.75 M. The payback period ($TPP_{set}$) and investment ($INV_{set}$) criteria set by plant owner is 2 y and USD10 M.

*Table 2: Identified $CO_2$ reduction strategies in palm oil milling*

| Option | $CO_2$ Reduction Strategies | $CO_2$ Reduction (%) | Investment (USD) | Saving, (USD/y) |
|---|---|---|---|---|
| **A** | **POME** | | | |
| 1 | Anaerobic digestion (methane capture) + boiler + steam turbine | 97.83 | 5,106,309.70 | 6,471,967.27 |
| 2 | Anaerobic digestion - 80 % (methane capture) + boiler + steam turbine + fermentation - 20 % | 98.27 | 7,289,821.85 | 5,338,818.38 |
| 3 | Fermentation | 99.87 | 16,050,227.17 | 52,245.85 |
| **B** | **Byproducts** | | | |
| 4 | Boiler (PKS + PPF + EFB) | 99.66 | 126,662.84 | 801,262.28 |
| 5 | Boiler (PKS + EFB) + pyrolysis (PPF) + boiler (methane capture) | 91.90 | 622,490.98 | 774,960.49 |
| 6 | Pyrolysis + boiler (methane capture) | 90.75 | 1,704,377.72 | 328,963.84 |
| **C** | **Electricity generation** | | | |
| 7 | Boiler (PKS + PPF + EFB) + steam turbine | 97.29 | 134,115.51 | 806,212.23 |
| 8 | Boiler (PKS + EFB) + pyrolysis (PPF) + boiler (methane capture) + steam turbine | 90.73 | 629,697.78 | 779,747.95 |
| 9 | Pyrolysis + boiler (methane capture) + steam turbine | 90.75 | 1,707,439.32 | 330,996.08 |

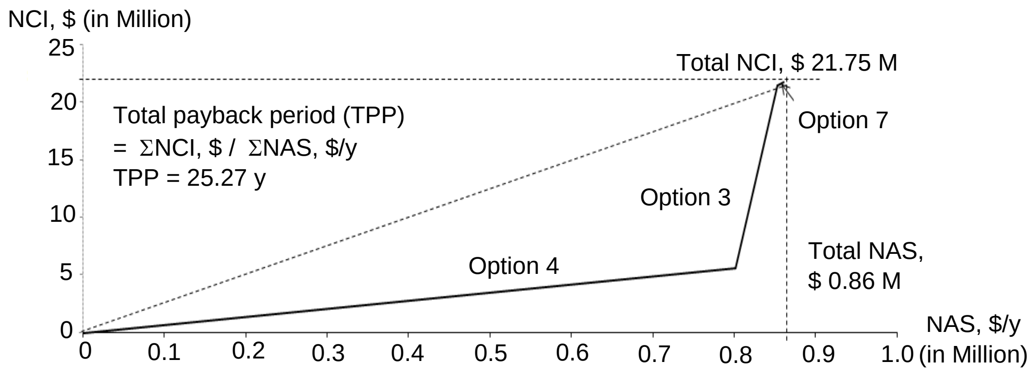


*Figure 2: IAS plot covering three $CO_2$ reduction 3 option strategies in palm oil mill*

From the IAS-plot, the strategy to reduce POME $CO_2$ emission has been identified as the most costly investment as it has the steepest gradient in the plot. SHARPS strategy is then applied. Using SHARPS

Strategy 1, it can be seen from Table 2 the next best option with a lower investment is Option 2. Applying this option instead of the previous option, yield a new IAS-plot as shown in Figure 3. The process is repeated until $TPP_{set}$ and $INV_{set}$ is achieved. The final strategies implemented are Options 1, 4 and 7 with the final $TPP_{AS}$ and $INV_{AS}$ of 1.75 y and USD9.58 M/y. After the payback period, the plant will gain additional profit of USD 5.46 M/y.

Step 5: Redraw the CSCPC plot.

The CSCPC plot is redrawn with the improved $CO_2$ reduction scenario as shown in Figure 4. The product planner has now managed to produce a low carbon cooking oil product which are also economically feasible.

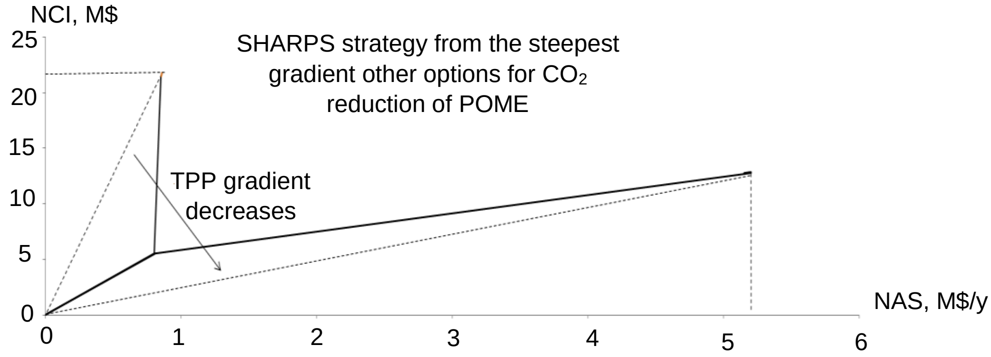


*Figure 3: IAS-plot showing the decreased investment cost and revised TPP*

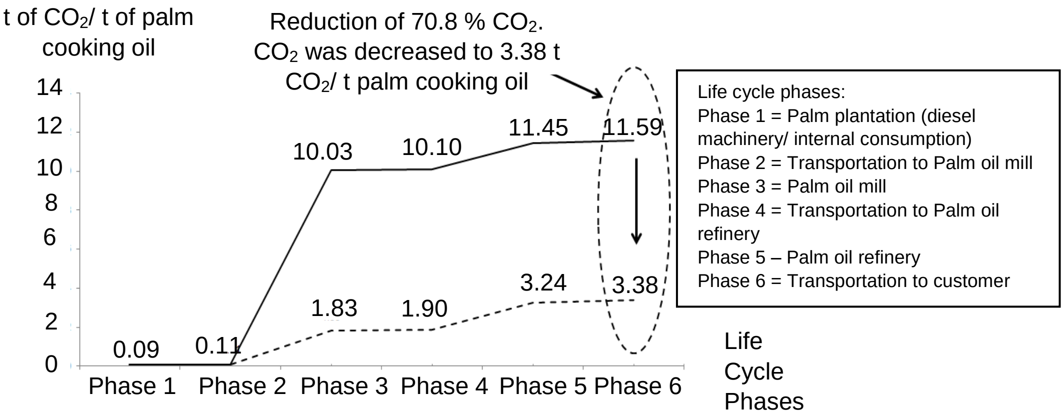


*Figure 4: CSCPC-plot after $CO_2$ Reduction using SHARPS technique.*

## 3. Conclusion

A tool to cost-effectively plan a low carbon emission in a product supply chain has been developed. The Carbon Supply Chain Product Curve as well as an extended SHARPS strategy has been introduced. The methodology has been applied to a palm cooking oil case study that resulted in a reduction of 70.8 % carbon emissions as compared to the case without carbon minimisation planning. The graphical approach planning using CSCPC-SHARPS tool has successfully reduced up to 821 t of $CO_2$ emission from the total emission of 1,159 t $CO_2$/100 t of palm cooking oil production. This can significantly aid the planning for the most suitable $CO_2$ reduction strategies to be selected within the desired payback period and total investment cost required. The CSCPC can also boost a company's image and competitiveness as it can be used to demonstrate a company's effort in carbon minimisation through means such as product labelling.

**Acknowledgements**

The authors would like to thank Process Systems Engineering Centre (PROSPECT), Faculty of Chemical Engineering, Universiti Teknologi Malaysia (UTM) (Vot: A.J090403.5368) for the financial support; and together to Universiti Malaysia Pahang (UMP) and Ministry of Education, Malaysia. The financial support from the Hungarian State and the European Union under project TAMOP-4.2.2.A-11/1/KONV-2012-0072 Design and optimisation of modernisation and efficient operation of energy supply and utilisation systems using renewable energy sources and ICTs“ has been gratefully acknowledged as well.

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