CHEMICAL ENGINEERING TRANSACTIONS

VOL. 78, 2020

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

**ISBN** 978-88-95608-76-1; **ISSN** 2283-9216

DOI: 10.3303/CET2078077

# Multi-stage Carbon Emission Pinch Analysis of an Integrated Power Generation and Electric Vehicle System

Ahmad Fakrul Ramli, Ahmad Muzammil Idris, Zarina Ab Muis*, Wai Shin Ho

Process Systems Engineering Center (PROSPECT), Department of Chemical Engineering, School of Chemical and Renewable Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia
zarinamuis@utm.my

The introduction of electric vehicles to the transportation fleet has merged the power generation and transportation sectors into an integrated system. Rather than fuel sources, electricity is used to charge electric vehicles, so these vehicles play a vital role as an important green technology that could reduce carbon emissions in the transportation sector. This study aimed to extent carbon emission pinch analysis for an integrated system to optimise the energy mix for electricity generation in Malaysia. In the first stage, the minimum number of electric vehicles required to reduce transportation emissions was determined. In the second stage, the optimal energy mix for the power generation sector was determined while including the electricity demand for the electric vehicle. Four scenarios namely S1, S2, S3, and S3 were developed based on Peninsular Malaysia as a case study, to analyse the impact of different mitigation strategies based on the performance of the integrated system (number of vehicles, fuel consumption, and energy mix) and economic evaluation based on total cost and total cost per emission reduction. The emission reduction is based on the 45 % target based on 2005 level for the transportation and power generation sector. The results reveal that S1 has the lowest total cost (MYR $1.73x10^{12}$) and S4 has the highest total cost (MYR $3.13x10^{12}$) compared to other scenarios proposed. However, in term of total cost per emission reduction, S4 shows the lowest (MYR $9.36x10^{6}$) while S1 being the highest with MYR $13.1x10^{6}$. The results generated from the scenarios proposed give a clear visualisation on how the policies affect the demand growth. Pinch analysis technique is proven to be a suitable tool in targeting and planning for emission reduction target and energy demand management.

## 1. Introduction

The transportation and power generation sectors are responsible for almost half of total global carbon emissions. Lately, a rising awareness of environmental issues among the youth has increased the growth of green technologies (Bhowmik et al., 2017). The same trend in carbon emissions can be observed in Malaysia, where transportation and power generation have had a massive impact on total carbon emissions. To solve this issue, the government has set a target to achieve 45 % carbon emission reduction by the year 2035 (Ali, 2015). One of the efforts under this vision is to introduce electric vehicles (EVs) to the transportation sector. The EV is a very promising alternative, not only to reduce carbon emissions, but also to increase the efficiency of energy usage. However, large-scale EV usage on the road will increase energy demand on the power generation sector. In addition, the total carbon emissions for EV could then shift to power generation. This means that the full benefits of EV can only be reaped if clean sources of power generation such as renewable energy (RE) were used to generate electricity. Thus, this study proposes a multi-stage energy planning technique for a system integrating power generation and transportation (electric vehicle) using a Carbon Emission Pinch Analysis (CEPA). Besides, this study will provide an overview of the effect of EV implementation on the power generation sector.

Tan and Foo (2007) were the first to propose CEPA, which is now the most well-known method for optimisation based on pinch principles. Numerous studies relating to $CO_2$ emissions have been done in various countries and solutions to the emission problem have been proposed via the power generation sector (Crilly and Zhelev 2009), carbon capture and storage (Ooi et al., 2013), water footprint analysis (Tan et al., 2009), chemical processes (Tjan et al., 2010), the transportation sector (Walmsley et al., 2015), and waste

Paper Received: 15/05/2019; Revised: 05/09/2019; Accepted: 12/11/2019
Please cite this article as: Ramli A.F., Idris A.M., Ab Muis Z., Ho W.S., 2020, Multi-stage Carbon Emission Pinch Analysis of an Integrated Power Generation and Electric Vehicle System, Chemical Engineering Transactions, 78, 457-462 DOI:10.3303/CET2078077

management (Tan et al., 2015). The most recent application of CEPA was that of Ramli et al. (2018) for the transportation sector. The study proposed different mitigation strategies for the transportation sector to achieve the target of carbon emission reduction and identified the minimum amount of energy needed for the transportation sector to implement EV. Aziz et al. (2017) proposed an advanced pinch analysis framework for low carbon dioxide emissions for industrial site planning. Idris et al. (2018) developed a framework for an integrated water and energy system called the Water-Energy Nexus Cascade Analysis. CEPA has been widely used in studies aiming to reduce carbon emissions. A few models have been developed to identify optimal cost by implementing certain policy measures based on certain economic situations. However, fewer studies have focused on an integrated system, especially the integration between the transportation and power generation sectors. This study extends the work of Ramli et al. (2018) and determines the minimum required RE percentage and the number of EV units needed on the road to achieve the carbon emissions target. This study focusses on the impact of EV towards power generation sector by proposing different mitigation strategies including the utilization of public transport and the electrification of car. The minimum electricity required for EV were combined with the current electricity demand and pinch analysis technique was used to determine the best energy mix for power generation sector.

## 2. Methodology

### 2.1 Carbon Emission Pinch Analysis Framework for an integrated system

The CEPA flow for the integrated system proposed in this study is shown in Figure 1. The first part of the framework shows the development of CEPA for the transportation sector. It consists of data extraction, the development of a demand and supply composite curve, and the identification of the minimum electricity generation required. The second part of the framework is the CEPA for the power generation sector, which includes data extraction, the development of a demand and supply composite curve, and the identification of the optimal energy mix for the power generation sector. The CEPA method is based on Ramli et al. (2018), who first used it for the transportation sector by constructing a composite curve for demand (based on transport class) and supply (based on fuel sources) including EVs. This study proposed different mitigation strategies including fuel switching and public transport utilisation for the transportation sector to determine the minimum electricity that must be generated for the transportation sector. The results obtained were then used as input for the power generation sector combined with the residential, commercial, and industrial electricity demand to form a grand demand composite curve. The CEPA method was then reapplied to identify the minimum amount of fossil fuels that must be shifted to RE after which the optimal energy mix for the power generation sector could be determined.

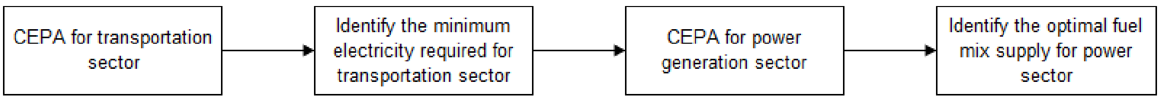


*Figure 1: CEPA flow for the integrated transportation and power generation sector*

### 2.2 Case study

Peninsular Malaysia was taken as a case study for this work whereas the data needed for the CEPA framework was obtained from MAMPU (2019). The current total transportation energy and the electricity demand growth rates are 2.0 % and 3.5 %, as shown in Figure 2. The total number of vehicles on the road in Malaysia is estimated to increase to up to 35 M units by 2035 based on a business-as-usual scenario, leading to a 33,783 ktoe increase in the energy demand for the transportation sector. The total emissions based on the 2005 level for the transportation sector and the power generation sector is 73430.00 kt-$CO_2$. The government intends to reduce the 2005-level total emissions by 45 %, which is equivalent to 33043.5 kt-$CO_2$-eq. For the transportation sector, the average travel demand is measured in passenger-km based on Eq. (1) where TD is the total travel demand, NV is the number of vehicle units, DT is the average distance traveled per year, and O is the occupancy level for each transport mode. For the power sector, the energy demand is measured in ktoe.

$$TD = NV \times DT \times O \tag{1}$$

Four scenarios were developed in this study, namely S1, S2, S3, and S4. In S1, it is assumed that 10 % of the total emissions reduction is from the transportation sector, while 90 % is from the power generation sector. Meanwhile, S2, S3, and S4 assumed a 20 %, 30 %, and 40 % reduction from the transportation sector, while the rest was allocated to the power generation sector. S1 assumed no utilization of public transportation while S2, S3, and S4 were set to low, medium, and high utilization of public transport. Table 1 summarizes all the developed scenarios. To conduct the economic evaluation, all scenarios were compared in terms of total energy cost, total maintenance cost, and total cost savings. The total cost savings were calculated by comparing the total cost (summation of energy and maintenance cost) for each scenario to that of the baseline scenario.

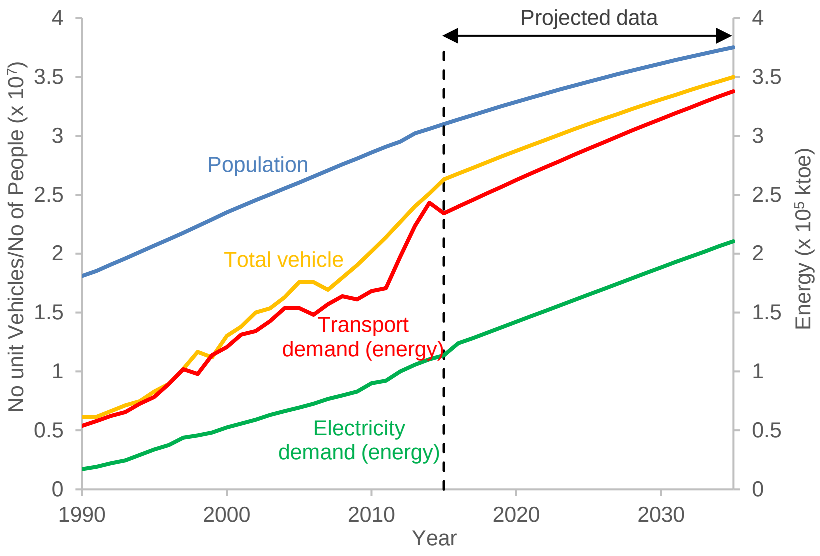


*Figure 2: Population and energy growth in Malaysia (MAMPU, 2019)*

*Table 1: Economic evaluation for different scenarios proposed*

| Description | S1 | S2 | S3 | S4 |
|---|---|---|---|---|
| Emission reduction for transportation sector | 10 % | 20 % | 30 % | 40 % |
| Emission reduction for power sector | 90 % | 80 % | 70 % | 60 % |
| Utilization of public transport | none | Low | medium | High |

## 3. Results and discussion

Figure 3 shows an example of the CEPA results for both the transportation and power generation sectors. Further analysis of each scenario is discussed in Section 3.1, 3.2, and 3.3 based on three main findings; i) the CEPA results for the transportation sector; ii) the CEPA results for the power sector; and iii) the economic evaluation outcome for an integrated system.

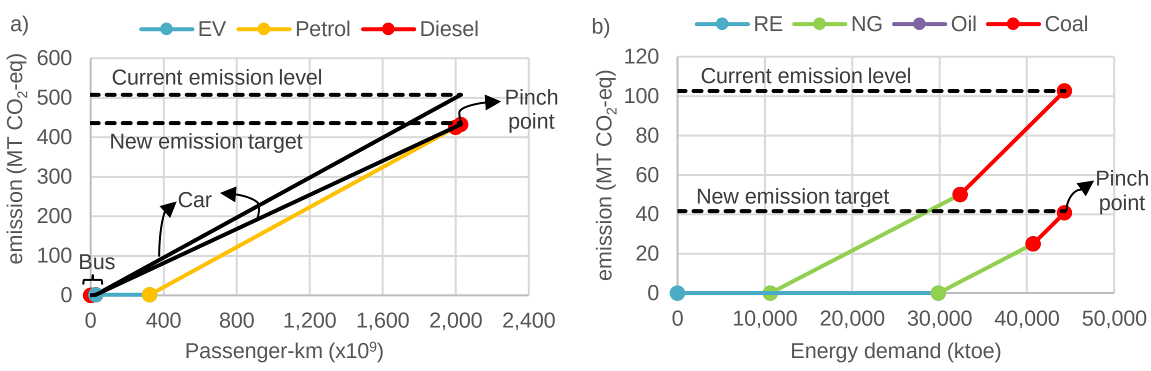


*Figure 3: Example of CEPA results for S1 (a) transportation sector (b) power sector*

### 3.1 Transportation management in 2035

Figure 4 shows the total number of vehicles and total fuel consumption for the transportation sector for all scenarios. The results show that S1 had the highest number of vehicles and S4 had the lowest. This result is due to the increase in the percentage utilization of public transportation. The number of EV units increased linearly from S1 to S4 due to the increasing percentage of emission reduction for the transportation sector. In terms of fuel consumption, petrol still dominates the fuel mix for the transportation sector. The number of diesel cars is very low due to the limitation of this car variant in the market. Also, this type of fuel is mostly used for heavy transportation such as lorries, buses, and trucks. Hence, consumers prefer to purchase petrol cars compared to diesel cars.

The government targets to achieve 100,000 units of electric cars and 10,000 units of electric buses on the road by the year 2020. They also target this number to keep increasing until the year 2035. Not only that, but Malaysia also intends to become an electric mobility marketplace (Ali, 2015). Using the pinch technique as a targeting tool, this study found that these targets could be achieved.

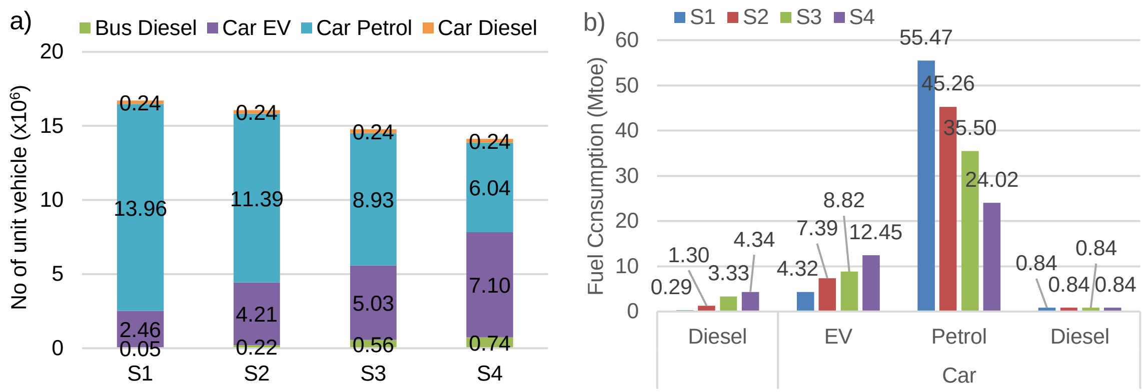


*Figure 4: (a) Total number of vehicle (b) Total fuel consumption for transportation sector*

### 3.2 Energy management for power sector in 2035

Based on the above results, the introduction of public transport alone will not be able to fulfill the emissions target. Therefore, the focus should be on EV as an alternative option, as it clearly provides better efficiency since it has zero tailpipe emissions compared to conventional vehicles. The main issue arises from the electricity generation used to cater to EV demand. Based on the power sector, the results are presented in terms of energy mix, the increase in energy demand due to EV, and the increase in RE share. Figure 5(a) shows the energy mix for all scenarios. The innermost circle is for S1 while the outermost circle is for S4. The RE share is a combination of hydro, biomass, biogas, and solar. Figure 5(b) shows the increase in energy demand and the RE share for all scenarios. S1 had the most RE share for the power sector compared to the other scenarios. This is because S1 has a higher percentage emission reduction (90 %) and S4 has the lowest percentage emission reduction (60 %) for the power sector, as mentioned in Section 2.2. The increase in energy demand due to EV depends on the total EV units involved, as shown in Figure 4. Hydro is not considered a RE source; however, for CEPA targeting, this study treated hydro as a RE source together with solar, biomass, and biogas to form a single RE curve.

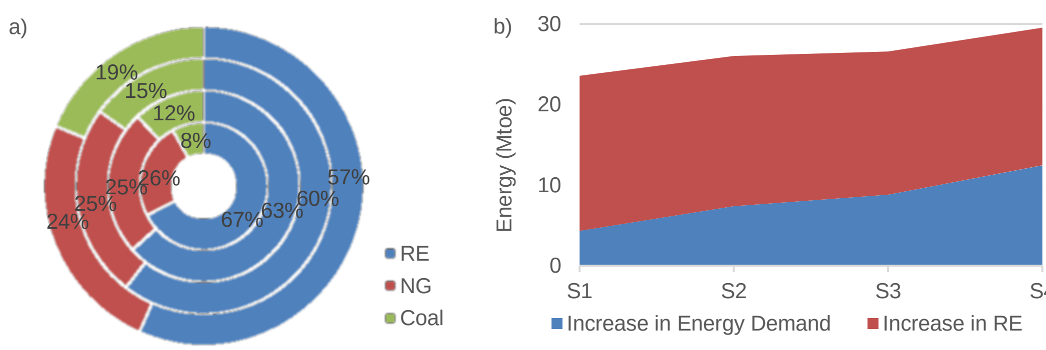


*Figure 5: (a) Energy mix (b) increase in energy demand and RE share for power generation sector*

### 3.3 Economic analysis for proposed scenario

Figure 6 shows the economic evaluation results of the integrated system (transportation sector and power sector). The total cost of the system includes capital cost and fuel costs for the transportation and power sectors. The results show that S1 had the lowest total cost (MYR $1.73 \times 10^{12}$) while S4 had the highest (MYR $3.13 \times 10^{12}$). S4 had the highest cost because it also has the highest number of EV units compared to the other scenarios. However, in terms of total cost per emission reduction, the results show that S4 had the lowest total cost per emission reduction (MYR $9.36 \times 10^{6}$) while S1 had the highest (MYR $13.1 \times 10^{6}$). Despite the higher cost of S4, the total emissions reduced were also high, resulting in the lowest total cost per emission reduction. Of all the scenarios proposed, S4 clearly provides the best results for EV implementation and RE utilization for the proposed integrated system.

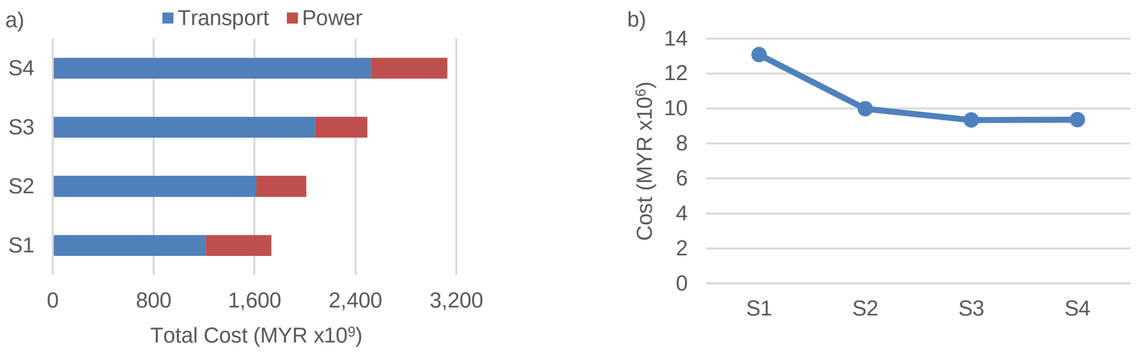


*Figure 6: (a) Total Cost (b) Total cost per emission for the integrated transportation and power generation sector*

### 3.4 Limitation towards current policies

The main issue with EV is its higher price compared to conventional vehicles. Therefore, the government must draw up a transportation policy to balance out the EV price and make it comparable to the conventional vehicle. For example, by introducing subsidies such as tax-free incentives for EV or free charging schemes, more people would be attracted to purchase EVs. Currently, the road tax for fully electric vehicles in Malaysia is between MYR 10 and MYR 50 depending on the type of vehicle. The road tax for hybrid vehicles, on the other hand, is charged based on the vehicle's engine capacity. Recently, the government has been considering implementing road tax charges based on the power output of the EV. Based on the current electricity rates, it may be likely that EV owners might have to pay a lot more for the road tax. There has been very little development on new incentives for car buyers to go fully electric or hybrid other than savings in petrol cost and a lesser impact on the environment. In Malaysia, it is very costly to own fully electric vehicles because almost all fully electric vehicles are imported and the import tax on cars in Malaysia is between 65 % and 105 %. Another limitation of EV implementation in Malaysia is the lack of charging facilities. Up until now, there are only 251 charging stations installed across Peninsular Malaysia. Of these recorded numbers, current charging stations are mostly built in urban areas such as Kuala Lumpur, Melaka, and Johor Bahru (GreenTech, 2019).

As for the power sector, the two main energy security issues in Malaysia are an 'over-dependence on fossil fuel' and 'increasing dependency on energy import', both of which threaten the country's future development. The government has been introducing various initiatives over the years including, for example, the National Energy Policy of 1979, the Four Fuel Diversification Policy of 1981, the Fifth Fuel Policy in the 8th and 9th Malaysia Plans (2001–2005 and 2006–2010) and the setting up of a new energy model in the 10th Malaysia Plan (2011–2015). The most recent initiative is the 11th Malaysia Plan (2016–2020), under which achieving sustainability through cleaner energy sources is prioritized. Additionally, Malaysia has included RE as its fifth fuel in the 'Fifth Fuel Policy'; but still the policy is not being utilized as planned. To tackle these issues, Malaysian policymakers will need to revise existing policies to expand upon the supply and generation of natural gas (to replace coal) and drastically incentivize low-carbon sources of energy such as solar to de-carbonize the energy matrix and reach the target of 20 % renewable energy by 2025. The increasingly lower cost of renewables is bringing competitive alternatives to energy generation. The electrification of the economy, including the transportation sector, can reduce the demand for liquid fuels. Finally, policy and consumer pressures can accelerate the shift towards a lower carbon footprint in the economy.

## 4. Conclusion

In summary, the CEPA framework for an integrated transportation and power generation system was developed in this study. The method provides insight into how energy planning can be performed in both sectors simultaneously. In this study, several mitigation strategies for the transportation sector were proposed to achieve the carbon reduction target. Besides, there are still numerous aspects that need to be considered by researching on reducing emissions and energy planning for the transportation sector. For instance, emission factors also depend on the driver's age, utilisation pattern, and driving style. Thus, further study is needed to explore the effect of these factors on the emissions and in different modes. However, CEPA is only a technique that illustrates simple energy planning as a preliminary study. It illustrates only the surface-level action on how the target can be achieved. For a complex optimisation problem that contains various constraints, mathematical models need to be developed for better and accurate results that can comply with all the constraints simultaneously. In general, CEPA can still be used to develop a baseline model and as a preliminary study to solve problems related to supply and demand.

**Acknowledgements**

The authors would like to acknowledge the funding received from Universiti Teknologi Malaysia regarding project process improvement and scheduling of biomass to bioenergy for centralised utility facilities (CUF), vote number, Q.J130000.2546.17H86; and optimally integrated power generation and impact of electric vehicle application on power generation, vote number, Q.J130000.2546.19H05

**References**

Ahmad, S., Tahar, R.M., 2014, Selection of Renewable Energy Sources for Sustainable Development of Electricity Generation System Using Analytic Hierarchy Process: A Case of Malaysia, Renewable Energy, 63, 458–486.

Ali, M.A.M., 2015, GreenTech Malaysia. National Electric Mobility Blueprint, Malaysian Green Technology Corporation Report, Bangi, Malaysia.

Aziz, E.A., Wan Alwi, S.R., Lim, J.S., Manan, Z.A., Klemes, J.J., 2017, An Integrated Pinch Analysis Framework for Low $CO_2$ Emissions Industrial Site Planning, Journal of Cleaner Production, 146, 125–138.

Bhowmik, C., Bhowmik, S., Ray, A., Pandey, K.M., 2017, Optimal Green Energy Planning for Sustainable Development. A Review, Renewable and Sustainable Energy Reviews, 71, 796–813.

Crilly, D., Zhelev, T., 2009, Expanded Emissions and Energy Targeting: A Further Application of CO2 Emissions Pinch Analysis (CEPA) to The Irish Electricity Generation Sector, Chemical Engineering Transaction, 18, 75–80.

Idris, A.M., Ho W.S., Liu, W. H., Ramli, A.F., Mohtar, A., Hashim, H., Muis, Z.A., Lim, J.S., Liew, P.Y., 2018, Water-Energy Nexus Cascade Analysis (WENCA) for Simultaneous Water-Energy System Optimisation, Chemical Engineering Transactions, 63, 271-276

Malaysian Administrative Modernization and Management Planning Unit (MAMPU), 2019, Malaysia's Open Data Portal. <https://www.data.gov.my/> accessed 04.09.2019.

Malaysian Green Technology Corporation (GreenTech), 2019, Empowering Electric Mobility, <https://www.chargev.my/> accessed 04.09.2019.

Ooi, R.E.H., Foo, D.C.Y., Ng, D.K.S., Tan, R.R., 2013, Planning of Carbon Capture and Storage with Pinch Analysis Techniques, Chemical Engineering Research and Design, 91(12), 2721–2731.

Ramli A., Muis Z., Ho W., 2017, Carbon Emission Pinch Analysis: An Application to Transportation Sector in Iskandar Malaysia 2025, Chemical Engineering Transactions, 56, 343–348.

Tan, R.R., Foo, D.C.Y., 2007, Pinch Analysis Approach to Carbon-constrained Energy Sector Planning, Energy, 32(8), 1422-1429.

Tan, R.R., Foo, D.C.Y., Aviso, K.B., Ng, D.K.S., 2009, The Use of Graphical Pinch Analysis for Visualizing Water Footprint Constraints in Biofuel Production, Applied Energy, 86(5), 605–609.

Tan, S.T., Ho, W.S., Hashim, H., Lim, J.S., Lee, C.T., 2015, Waste Management Pinch Analysis (WAMPA) with Economic Assessment, Chemical Engineering Transaction, 45, 145–150.

Tjan, W., Tan, R.R., Foo, D.C.Y., 2010, A Graphical Representation of Carbon Footprint Reduction for Chemical Processes, Journal of Cleaner Production, 18(9), 848–856.

Walmsley, M.R.W., Walmsley, T.G., Atkins, M.J., Kamp, P.J.J., Neale, J.R., Chand, A., 2015, Carbon Emissions Pinch Analysis for Emissions Reduction in The New Zealand Transport Sector Through to 2050, Energy, 92, 569–576.