Supply chain pinch analysis to optimal planning of biogas production

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Abstract. Supply chain is essential for an organization as it helps to maximize the operations which are profitable through the production, capacity, subcontracting, inventory and stock outs optimum levels. The traditional supply chain involves high documentation cost, with data involved that are mostly inaccurate and useless. In supply chain, the system of production plays an important role. The pinch analysis concept is initially used in the approach of energy conservation, and has extended to the optimization of resources and process integration. This paper presents the application of supply chain using pinch and cascade analysis for biogas production from palm oil mill effluent (POME). Biogas falls under the renewable energy where it can be produced via anaerobic digestion of POME. POME contributes to huge environmental impact mainly due to its high organic content. Supply chain via pinch analysis is used targeting to eliminate or reduce the difficulties faced in conventional supply chain. In this biogas supply chain analysis, it aims to meet the demand in a specific time frame. Minimum production rates are determined as accordance to the demand of electricity from 2020 to 2050. The pinch points are the points where the supply and demand are at the minimum, which the optimum production rate of electricity is able to determine from supply chain via pinch analysis. Monte Carlo Simulation tool is involved in the later stage of the study. It is used in the findings of analysing the increment of more than 10% of up-scale and down-scale production demand for each year for 35 years. The simulation is done from 2016 to 2035 of every five years interval. At the end of the study, the optimization of biogas production was achieved with the application of supply chain via pinch analysis. The supply and demand of biogas to electricity projection from 2020 to 2050 is forecasted. The optimal planning of electricity production from biogas was indicated in the supply chain cascade analysis.

1. Introduction
Supply chain is a system which the people and company are involved in order to get the product from the production to customers. In a business, supply chain includes all the stages in order to fulfil the demand of customers directly or indirectly in a most economical way possible [1]. Usually, supply chain management is used to create the highest value for the whole network from supply chain inclusive of the end customer and the company for a better decision making. Effective supply chain management
Pinch analysis initially began with the approach of conservation of energy. Over the years, this technique has become a handy tool in the optimization of resources and process integration [3]. Pinch analysis is useful in goal setting like estimating the optimum performance by prioritizing the process actual schedule based on fundamental principle [2]. Pinch analysis is also known as the algebraic targeting approach or supply chain cascade analysis for SCM [4]. Pinch analysis is practical at the stage of conceptual design for the assessment of objective performance in the utilization of resources [4].

Biogas is a clean and renewable fuel resulted from the natural decomposition of organic matter like palm oil mill effluent (POME) [5]. In the production of biogas, oxygen is not present which anaerobic digestion occurs, converting organic substance into biogas [5]. Biogas is a renewable energy that generates heat and electricity from renewable sources like POME. POME is a waste that is generated in the production of palm oil. It is considered as non-hazardous waste but possesses huge environmental impact due to its high organic content that will produce greenhouse gases (GHG) like methane (CH4). It is expected to increase in quantity as there is an increase demand of palm oil [6]. More demand of palm oil means increasing production of POME. According to United Nation Sustainable Goal 12, it aims to decrease the generation of total waste in the world by 2030. It is a big challenge when the demand for palm oil increases substantially over the years as shown in Figure 1 [5]. However, this is solvable if it is utilized as fuel for power generation and cogeneration. Regardless of the impacts POME brings to the environment, POME is still considered as a useful waste which can be seen in its feasibility in biogas production.

Malaysia plays a big role in the global palm oil production, with 46% of world exports and 37% of the production of palm oil in the world [5], being one of the major exporters and manufacturers in the global. With that being said, Malaysia has abundant of POME that can be a useful feed in biogas production. As of now, Malaysia is still highly dependent on fossil fuels like coal, oil and natural gas for electricity generations [7]. Malaysia government has established plans and policies to emphasis the usage of renewable energy [8]. Policies like Five-Fuel Diversification Energy 2001 and National Renewable Energy Policy and Action Plan 2010 were introduced due to the depletion of oil and gas significantly. Thus, besides oil, gas, coal and hydro, renewable energy is considered as an important source of energy [7]. Biogas industry can be developed to a larger scale and is feasible to replace the limiting supply of natural gas in the future. The accessible to renewable energy resources with sufficient supply of POME in Malaysia has driven Malaysia towards the possibility of a more sustainable future [5].

2. Problem Statement
Supply chain is essential for an organization as it helps to maximize the operations which are profitable through the production, capacity, subcontracting, inventory and stock outs optimum levels. It is
challenging for conventional supply chain management as it requires high cost of documentation, but very often result in inaccuracy and useless data [1]. The traditional supply chain lacks in adaptability. Most of the large enterprise cannot configure the key custom requirements accurately, causing difficult work-around or solutions. Another problem is the advanced analytics. As mentioned by Chopra and Mendl (2001), conventional supply chain is highly complicated and needed highly specialized data analyst. Good data scientists are in short supply and high demand, and the tools that are used by them are not designed to be accessed and deployed to business users throughout the company [9]. These problems lead to low efficiency in SCM which in return affecting the decision making and strategy planning. As renewable energy research has gained much focus on making an economically practical production. Pinch analysis is a useful tool that incorporates less complicated mathematics compared to other optimization tools [10]. Therefore, utilizes pinch analysis into the supply chain of renewable energy enable one to perform more efficient SCM.

The reason why POME is chosen to be converted to biogas to produce electricity is due to the abundance of POME available in Malaysia. Malaysia accounts for one of the major exporters and manufacturers of palm oil in the world. POME is produced during the production of palm oil, which can then be used as a feed for biogas production [5]. By capturing the methane gas produced from POME, biogas, which is a type of renewable resources is the produced. Biogas can be used as a fuel to generate electricity and heat from its energy [11]. According to New Strait Times News (2018), the government has pledged to increase the generation of renewable energy increased to 20% by 2025 from the current figure at 2%. The government has also aimed to make the renewable energy in Malaysia to be reasonably priced and accessible. On top of that, another pledge was made to plan to reduce 40% of carbon emissions by 2020. However, all these targets are expected to take longer than expected [12]. The current 2% of renewable energy generation is still far away from the target of 20% generation [12]. Being another largest exporter and producer of palm oil in the world, Indonesia has already established projects that capture and convert biogas to energy from POME [13]. Therefore, in Malaysia, biogas from POME can be one of the solutions to renewable energy contributions to Malaysia.

In conclusion, the objectives of this study are to predict, plan and project the optimum supply chain of biogas production from POME by using cascade analysis. However, there are a lot of factors that can affect the projection such as economic issues, natural disaster, government policies, global market trends and many others. Hence, a more accurate result can be further justified by including all possible factors with Monte Carlo Simulation, aiming to reach the most optimal and accurate planning of supply chain for biogas production.

3. Methodology
This study involved the supply chain concept using process integration techniques to obtain the optimum planning of biogas production from POME. The biogas production was optimized by obtaining the demand for biogas from literature reviews, then getting the POME supply data with supply chain concept. This study focused on implementing pinch analysis or also known as process integration techniques in the supply chain for the optimal planning of biogas production. Upon getting the supply and demand data, Monte Carlo Simulation tool was used to analyse the production rate up-scaling to 10% increment of demand for each five years projected to 35 years. The four main steps of simulation included data collection, optimization, estimation and analysis of data and result. The preliminary step was collecting data. This step was done by obtaining the data of biogas demand in the next five years and the POME supply in Malaysia from Chin et al. (2013). After this, followed with the data collected, pinch analysis concept was used to carry out several case studies in order to determine the multi-objective optimization problems. The simulation data generated from the case studies was being used in Microsoft Excel software to conduct pinch analysis. The rest of the simulation steps including estimating the production rate with 10% increment each year for 35 years were being conducted with Monte Carlo Simulation tool. Data collection was the first step in the multi-objective optimization. It was involved
in all steps before the simulation generated from the case studies were exported to the Monte Carlo Simulation.

The primary data collected was the supply and demand for electricity in Peninsular Malaysia, with the year 2016 as the base case of this study. The data collected for the year 2016 were all based on actual statistic form Energy Commission of Malaysia. The initial entries of supply and demand would then proceed to more detailed entries, from actual data obtained to projected data to the year 2050. The projection data from 2020 to 2035 was obtained from the prediction by Energy Commission of Malaysia in 2017, as shown in Figure 2 and Figure 3. Figure 2 shows the sales of electricity from the year 2005 onwards, forecasted to the year 2035. Figure 3 shows the electricity generation electricity from the year 2005 onwards, forecasted to the year 2035.

FIGURE 2       Electricity sales starting from the year 2005 forecasted to 2035. [14]

FIGURE 3       Electricity generation starting from the year 2005 forecasted to 2035. [14]

3.1. Base Case Development
The supply and demand data beyond 2035 until 2050 were calculated based on the average growth rate per annum, as shown in Equation (A.1). Starting from 2036 onwards until 2050, both supply and demand data were calculated by multiplying the previous year data with the average growth rate per annum,
followed by the division of the number of hours that the gas engine operates per annum. The number of hours the gas engine operates per annum was assumed to be 8000 [15]. The average growth rate was obtained from the Outlook 2017 reported by Energy Commission of Malaysia. In this study, the growth rate from 2016 to 2035 was the same throughout until 2050.

Before proceeding to cascade analysis, the electricity production from biogas was obtained by taking the crude palm oil production (CPO) in Peninsular Malaysia. The CPO production statistic in the year 2016 was obtained from Malaysia Palm Oil Board, whereas the CPO production statistic from 2020 to 2035 was obtained from Gan & Li (2012), as shown in Figure 4. Figure 4 shows the production of crude palm oil in million tonnes from the year 1961 to 2035.

![Figure 4: Total production of CPO in million tonnes versus the year of projection. [16]](image)

In order to obtain the production of CPO projected to the year 2050, the average growth rate from the year 2016 to 2035 needed to be obtained. Firstly, the growth rate for each five years was obtained by using Equation (A.2). Upon finding the growth rate every five years, the average growth rate could be obtained which then used to project the total CPO production from the year 2040 to 2050. The growth rate of the total CPO production starting from the year 2040 to 2050 in this study were the same throughout. Next, the projected reading after the year 2035 to 2050 was found by using Equation (A.3). It was calculated by taking the CPO production from five years before multiply by the average growth rate every five years. CPO production, \( P_t \) calculated was in million tonnes. The value \( P_t \) included all CPO production in Peninsular Malaysia. About 60% of the area of oil palm plantations belonged to large plantation companies [17]. Upon calculating the production of CPO, the POME yield could be found. Equation (A.4) was the POME generation by taking CPO multiplying the POME conversion yield from CPO, which was 3m. Equation (A.5) showed the conversion of biogas from POME, with the assumption that about 28m of biogas was produced from per tonne of POME produced [15]. From the POME yield value calculated, electricity was calculated by using Equation (A.6). The electricity to grid percentage was about 13.13% [18]. Therefore, electricity to grid was calculated by taking POME yield in million tonnes multiplied by electricity conversion from POME and the percentage of electricity to grid. The estimated electricity generation was 13,600 MWh per tonne of POME generated [15]. Equation (A.7) showed the conversion of electricity from MWh to GW.

3.2 Cascade Analysis
The steps in cascade analysis were cascade designing, data gathering and interventions linking. It involved formulating process integration problem, assessing application feasibility of cascade analysis, constructing initial design process flow diagram, construct actual time-material diagram and actual cascade diagram by applying pinch rules and other predefined constraints. Cascade analysis tool should
be as flexible as it could be. It was the visual representation of entities distribution throughout a compartmental model in reference to time. The first step of cascade analysis begun with cascade design [19].

Upon obtaining the supply and demand of the data, a cascade diagram could be constructed. In this step, initial production had to be determined as well. At the time where the inventory was zero, it indicated the optimum production of POME to biogas, which was the pinch point. There were a few cases developed for cascade analysis, which were base case and another three different cases of different scenarios. The inventory \( I_t \) was calculated by taking the differences between production or supply, \( P_t \) and demand or consumption, \( D_t \) then added with the previous inventory, \( I_{t-1} \). The inventory equation was shown in Equation (A.8) [17]. By using cascade analysis, the amount of inventory throughout the years could be identified. There could be deficit or surplus of inventory depending on the amount of inventory carry forward previously, electricity demand and production.

3.2.1 Cascade Analysis – Pinch Method

Upon obtaining the supply and demand of the data, a cascade diagram could be constructed. In this step, initial production, demand and inventory had to be determined as well. At the time where the inventory which was the electricity inventory was equivalent to zero, it indicated the optimum production of biogas from POME, which was the pinch point. The pinch point could be obtained at the biggest negative value or smallest positive number from cascade analysis [20]. Upon obtaining pinch point, for case with inventory of smallest positive number difference, all the inventory with smallest positive number was deducted, whereas for case with inventory of biggest negative number difference, all the inventory with the biggest negative number difference was added. The initial inventory, \( I_0 \) should not be considered as it indicated the minimum electricity supply, which should be zero at the start.

3.3 Monte Carlo Simulation

Monte Carlo Simulation was performed for the year 2016, 2020, 2025, 2030 and 2035. In order to perform the simulation, the data for average production growth and yearly standard deviation were required. For all the Monte Carlo Simulation done for the year 2016 to 2035, the objective was to determine the probability of occurrence when the production of electricity from biogas increased more than 10% and decreased more than 10% at the end of each five years for the year 2016 to 2035.

Next, the normal distribution of the yearly growth rate for electricity production was simulated. In this study, probability was replaced with formula \( = \text{RAND()} \). This generated any number in between zero and one. The RAND function always automatically recalculated the numbers it generated when a worksheet was opened or when new information was entered into the worksheet. The random numbers were also recalculated every time when the F9 key was pressed [21]. Upon finding the normal distribution of the yearly growth rate for electricity production, the cumulative production growth at the end of five years was calculated by using Equation (A.16). The cumulative production growth would be obtained at the end of the fifth year. Do note that the calculation for the first year of that five years, the cumulative production growth was equivalent to the first year of the normal distribution of the yearly growth rate for electricity production. For example, the Monte Carlo simulation was done every year from 2012 to 2016. The cumulative production growth at the end of the five years, \( N_{GR} \) was obtained. Next, the cumulative production growth at the end of five years, the number of simulations and the probability of the production performance were computed. This step helped to determine the average and standard deviation of the production trend in percentage, the probability of the production to increase or decrease more than 10%. Subsequently, the analysis was performed by using “What-If Analysis” function in Microsoft Excel. The calculation of the average, standard deviation, probability of increasing more than 10% or decreasing more than 10% for electricity production from POME were done. The formulas used for Microsoft Excel were shown in Table 1 [22].

| TABLE 1 | Formulas used in Microsoft Excel. |
| Calculations | Formulas in Microsoft Excel |
|---|---|

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From Table 2, it can be observed that the supply of electricity was enough to accommodate its demand from the year 2016 to 2045 [14]. The electricity supply from 2016 to 2045 exceeded the electricity demand. However, starting from 2045 onwards, it was observed that the supply was only 0.08 GW more than the demand, which could be critical if there was any unwanted incident that might disrupt the electricity supply. By the end of the year 2050, the demand exceeded the supply by about 1.75 GW. This indicated that the electricity supply was insufficient to meet its demand.

**TABLE 2** Table of electricity supply, demand and its differences from the year 2016 to 2050 with every five years interval.

| Year | Supply (GW) | Demand (GW) | Differences (GW) |
|------|------------|-------------|-----------------|
| 2016 | 15.00      | 13.75       | 1.25            |
| 2020 | 17.25      | 15.25       | 2.00            |
| 2025 | 19.25      | 17.50       | 1.75            |
| 2030 | 20.63      | 19.38       | 1.25            |
| 2035 | 22.38      | 20.63       | 1.75            |
| 2040 | 24.22      | 22.49       | 1.73            |
| 2045 | 24.61      | 24.53       | 0.08            |
| 2050 | 25.00      | 26.76       | -1.75           |

Figure 5 shows the graph of electricity to grid in GW from 2011 to 2035. Based on Figure 5, it could be observed that there were fluctuations in electricity to grid from 2011 to 2019. This was due to the fluctuations in production of CPO in Peninsular Malaysia, which in turn affecting the POME and electricity production. In 2016, there was a sharp decrease in CPO production for about 19% because of prolonged dry weather conditions and below average rainfall brought about by the El-Nino weather phenomena during the second half of 2015 and into the first half of 2016 had impacted the Malaysian oil palm industry performance in 2016 [23]. Starting from 2019 onwards, the total CPO production was expected to increase up until 2050, estimated to be the highest in 2050 with 29.52 million tonnes of CPO production based on Figure 5.
Figure 6 shows the cascade analysis of base case. The initial inventory was zero, which was the minimum electricity supply initially. This indicated that no electricity before the year 2020 was brought forward initially. In Figure 6, all electricity inventory showed positive values, which indicated that there was no shortage of inventory, or stored electricity. All the electricity inventories started accumulating starting from the year 2020 until 2050. Despite a linear increasing trend of electricity demand and supply from 2020 until the end of 2050, the trend of the inventories of electricity did not show a similar trend. From 2020 onwards until 2045, the greatest increase in electricity inventory was 1.75 GW, which occurred in between 2020 to 2025 and 2030 to 2035. The least increase in electricity inventory was about 0.08 GW, which was in between 2040 to 2045. The inventory dropped by 1.75 GW between 2045 to 2050.

According to Figure 7, the electricity inventory showed an increasing trend only from the year 2020 to 2045. It started to decrease starting from 2045 to 2050. Both electricity supply and demand increased throughout 2020 to 2050. In spite of the increasing trend, the electricity supply was not enough to fulfil the demand. The electricity demand exceeded the supply in 2050. In 2045, the difference between the

| Year | Electricity Supply (GW) | Electricity Inventory (GW) | Electricity Demand (GW) |
|------|------------------------|---------------------------|------------------------|
| 2020 | 17.25                  | T=1                        | 15.25                  |
| 2025 | 19.25                  | T=2                        | 17.50                  |
| 2030 | 20.63                  | T=3                        | 19.38                  |
| 2035 | 22.38                  | T=4                        | 20.63                  |
| 2040 | 24.22                  | T=5                        | 22.49                  |
| 2045 | 24.61                  | T=6                        | 24.53                  |
| 2050 | 25.00                  | T=7                        | 26.76                  |

FIGURE 5  Electricity to Grid in GW from 2011 to 2050.

FIGURE 6  Cascade diagram for base case.
supply and demand was very small, in which indicated that there was very little surplus of electricity. It is however still sufficient enough to fulfill the electricity demand.

4.1 Case 1: 4% of Electricity Supply from Renewable Energy until 2020, 20% of Electricity Demand from Renewable Energy by 2025, 20% of Electricity Demand from Renewable Energy from 2020 to 2050

Appendix J shows the percentage of electricity supply and demand from renewable energy, from the year 2020 to 2050. For electricity supply, the electricity supplied from renewable energy was 4% currently from the base case data [24]. The renewable energy in national power mix of 4% was applicable only for current data until 2020. Starting from 2025, the renewable energy in power mix was 20%. This was set in accordance to Malaysia renewable energy target of 20% by 2025 [24]. In this case study, the percentage of renewable energy supply of 20% was applied up until 2050 starting from 2025. For electricity demand, all the data was set in accordance to the Malaysia renewable energy demand of 20% from 2020 to 2050. Table 3 shows the cascade analysis for Case 1 before applying pinch method.

| Year | Electricity Supply (GW) | Electricity Demand (GW) | Inventory (GW) | Before Pinch | After Pinch |
|------|-------------------------|--------------------------|----------------|-------------|-------------|
| 2020 | 0.69                    | 3.05                     | Iₐ             | 0.00        | 2.36        |
| 2025 | 3.85                    | 3.50                     | I₁             | -2.36       | 0.00        |
| 2030 | 4.13                    | 3.88                     | I₂             | -2.01       | 0.35        |
| 2035 | 4.48                    | 4.13                     | I₃             | -1.76       | 0.60        |
| 2040 | 4.84                    | 4.50                     | I₄             | -1.41       | 0.95        |
| 2045 | 4.92                    | 4.91                     | I₅             | -1.06       | 1.30        |
| 2050 | 5.00                    | 5.35                     | I₆             | -1.05       | 1.31        |

Based on Figure 8, both the renewable electricity supply and demand shows a linear increment respectively. However, it is predicted that the renewable electricity supply is not enough to meet the demand during 2020 and 2050. The renewable electricity demand was at 3.05 GW and 5 GW in 2020 and 2050 respectively. Starting from the year 2025 up until 2045, the demand of electricity generated from renewable energy was able to be met, and with surplus as well. The greatest difference between the supply and demand from the year 2025 to 2045 was 0.35 GW and the smallest difference was 0.01 GW in 2045. Unlike the inventory trend showed in Figure 7, all the inventories in Case 1 had negative
values, which were below the zero-value axis as shown in Figure 8. This indicated that there was insufficient electricity generated from renewable energy from 2020. The deficit in electricity was brought forward and was not enough to be countered off by the surplus inventories, even when there was a surplus of inventories from the year 2025 to 2045.

In order to resolve the issue of insufficiency, there had to be an optimal planning of the supply chain of electricity generated from renewable energy. Pinch method application should be on the smallest number in the inventory [2]. In this case, pinch method occurred at I1, which the smallest number was -2.36 GW among all the other inventory values. The value was added as minimum electricity production to the initial electricity supply. As observed in Table 3, all the inventory values were positive after applying pinch method. 2.36 GW of electricity was added as initial inventory, Io. The added electricity was supposed to be generated by biogas from POME. The pinch point was observed to be at I1, which was where the smallest number value of inventory before applying pinch method. Based on Table 3, the pinch point was at I1, which the inventory value was zero. This indicated that there was no surplus or deficit of inventory. This resulted in an optimal planning of supply chain in this case, which no excess of electricity was stored. All the electricity demand from renewable energy was met after pinch method application. The initial minimum supply of electricity from renewable energy should be 2.36 GW. The inventory was the stored electricity that will be used for supply if there was insufficient supply to meet the demand. The available electricity generated from renewable energy could be used by reducing the usage of electricity from non-renewable energy. This could reduce the dependency on non-renewable fuels like fossil fuels, which would bring impacts to the environment.

4.2 Case 2: 4% of Electricity Supply from Renewable Energy until 2020, 20% of Electricity Demand from Renewable Energy by 2025, 45% of Electricity Demand from Renewable Energy by 2030, 20% of Electricity Demand from Renewable Energy from 2020 to 2025, 45% of Electricity Demand from Renewable Energy from 2030 to 2050

In comparison to Case 1, Case 2 was similar but with slight modifications. Malaysia aimed to reduce the emissions of carbon by 45% by 2030 [25]. Similar as Case 1, the renewable energy in power mix supply was 4% for current data until 2020 and 20% by 2025 [24]. By 2030 until 2050, the electricity supply and demand from renewable energy was set in accordance to the national aim in reducing carbon emission by 45%. Unlike in Case 1 with all negative inventory values, there were two positive inventory values in the between 2040 to 2050. The pinch point location was first determined at the smallest inventory value, which was I1.

The electricity supply and demand both showed an increasing trend. There was a drastic increase for the electricity supply from 0.69 GW to 3.85 GW, and 9.28 GW in 2020, 2025 and 2030 respectively.
This was due to the increase in electricity supply as shown in Appendix D, with 2020 at only 4% of electricity supply relative to 20% and 45% of electricity supply in renewable energy in 2025 and 2030 respectively. The negative inventory value indicated that there was insufficient electricity generated from renewable energy carried forward from 2020. Even though there were positive inventory values, which indicated production surplus, it was however not enough to balance off the deficit values. This indicated the supply chain in this case was not optimum.

| Year | Electricity Demand (GW) | Electricity Supply (GW) | Inventory (GW) |
|------|--------------------------|-------------------------|----------------|
|      | Before Pinch | After Pinch | Before Pinch | After Pinch |
| Io   | 0.00 | 2.36 |                     |               |
| 2020 | 0.69 | 3.05 | I1 | -2.36 | 0.00 |
| 2025 | 3.85 | 3.50 | I2 | -2.01 | 0.35 |
| 2030 | 9.28 | 8.72 | I3 | -1.45 | 0.91 |
| 2035 | 10.07 | 9.28 | I4 | -0.66 | 1.70 |
| 2040 | 10.90 | 10.12 | I5 | 0.12 | 2.48 |
| 2045 | 11.07 | 11.04 | I6 | 0.15 | 2.51 |
| 2050 | 11.25 | 12.04 | I7 | -0.63 | 1.73 |

In order to achieve the optimum planning of supply chain, pinch method was once again applied. Based on Figure 4.8, the minimum electricity supplied was 2.36 GW. The pinch point was observed to be at I1, which was where the smallest number value of inventory before applying pinch method. The inventory value of zero was the pinch point and the location of pinch point was at I1, which it occurred at the time frame in between 2020 to 2025. Upon adding the initial inventory of 2.36 GW, all the inventory values had turned positive. The addition of initial minimum inventory was supposed to be supplied by biogas that was produced from POME. This indicated that the electricity supply and the previous inventory were sufficient to meet electricity demand generated from renewable energy. Since there was a surplus in electricity generated from renewable energy, the usage of electricity from non-renewable sources could be reduced. The largest inventory value was 2.51 at I6 in between 2045 to 2050, as shown in Table 4.

4.3 Case 3: Taking 1% of electricity supply generated fully from biogas with POME as raw feed material, to fully supply and meet the projected demand.

Case 3 only considered the electricity that was generated from biogas that was produced from POME. Only 13.13% of electricity generated from renewable energy was sold to grid [18]. Therefore, in this case, only 13.13% of electricity generated from biogas produced from POME was considered. From the total amount of electricity sold to grid, only 1% of it was used for the electricity supply in Peninsular Malaysia. 100% of electricity from renewable energy was needed for the electricity demand in Case 3. Based on Table 4, the electricity supply, demand and inventory showed all positive values. On top of that, all the electricity supply values were greater than the demand. This resulted in all positive inventory values. The smallest inventory value was at I1 as well, which was 13.02 GW. The positive inventories indicated that there was more than enough supply of renewable energy to meet the demand in energy. It was possible to be fully reliant on renewable energy, solely from the biogas captured and processed from POME. It indicated that it was possible to rule out the use of non-renewable energy that could impact the environment and many environment issues could also be solved. Pinch method was applied in order to achieve optimum planning. Unlike Case 1 and 2, the Io value was negative, as shown in Table 3 and 10. This indicated that minimum amount of electricity supplied initially had to be decreased. The Io value was at -11.02 GW, which also meant that the supply had to reduce by 11.02 GW. The reduced
electricity supply could also be used in other fields or other forms of energy, like fuel. After applying pinch method, the pinch point was found to be at \( I_1 \), where the inventory value was zero.

### TABLE 5 Cascade analysis for Case 3 before applying pinch method.

| Year | Electricity Supply (GW) | Electricity Demand (GW) | Inventory (GW) | Before Pinch | After Pinch |
|------|--------------------------|--------------------------|----------------|--------------|-------------|
| 2020 | 28.86                    | 17.25                    | I_o            | 0.00         | -11.61      |
| 2025 | 30.27                    | 19.25                    | I_1            | 11.61        | 0.00        |
| 2030 | 32.38                    | 20.63                    | I_2            | 22.63        | 11.02       |
| 2035 | 34.63                    | 22.38                    | I_3            | 34.38        | 22.77       |
| 2040 | 36.80                    | 24.22                    | I_4            | 46.64        | 35.03       |
| 2045 | 39.11                    | 24.61                    | I_5            | 59.22        | 47.61       |
| 2050 | 41.56                    | 25.00                    | I_6            | 73.72        | 62.11       |

### 4.4 Monte Carlo Simulation

In this study, Monte Carlo Simulation was done to further justify and prove the findings. This was also to testify the accuracy and the sustainability of cascade analysis and pinch method in supply chain industry. It was also to identify the practicability of the study. This was done by including unexpected incidents and other uncertainties with the use of Monte Carlo Simulation. The simulation of Monte Carlo was done every five years interval, from 2020 to 2035, with 2016 being the base case. The Monte Carlo Simulation was projected until 2035 to extend the observation for five years. To begin Monte Carlo Simulation, the average production growth for each five years and yearly standard deviation of the total electricity generated from biogas were required. To simulate the probability of CPO production at the end of each five years interval, the yearly probability had to be identified first. Then, the cumulative value of the production, which was the probability at the end of the five years interval was calculated. The cumulative value was found to be -11.93%. This indicated that by the end of 2016, the probability that the production performance would be reduced by 52%. As observed from Appendix E, most of the data were mainly scattered in between the range of negative value of 20% to 80%. This also indicated that in most of the simulations, the probability of the production performance fell between the range of -80% to -20%. Table 6 shows the results obtained from Microsoft Excel after running Monte Carlo Simulation for 10000 times from 2016 to 2035. Since the data for 2016 were of actual data, this had justified and proven the accuracy and practicability of Monte Carlo Simulation in this study. The graphical representation for the year 2025 to 2035 were shown in Appendix G, H and I respectively.

### TABLE 6 Results obtained after running Monte Carlo Simulation for 10000 times with Microsoft Excel for the year 2016 to 2035.

| Descriptions                                      | Probability (%) |
|---------------------------------------------------|-----------------|
|                                                   | 2016  | 2020  | 2025  | 2030  | 2035  |
| Average                                          | -13.61 | 171.90 | 3.97  | 7.81  | 8.10  |
| Standard Deviation                                | 70.05  | 171.07 | 80.81 | 92.24 | 85.44 |
| Probability that the production increased more than 10% | 27.30  | 86.84  | 35.89 | 36.56 | 37.55 |
| Probability that the production decreased more than 10% | 62.95  | 8.40   | 53.82 | 54.42 | 52.11 |

Table 7 showed the summary of all probability of production to increase and decreased more than 10% for every five years interval from 2016 to 2035. Each probability value in each column varied by 1% to
2%. This was because the number value automatically recalculated when a worksheet was opened, when new information was entered into the worksheet or every time when the F9 key was pressed.

**TABLE 7** Table of the probability of production to increase and decrease more than 10% for every five years interval from 2016 to 2035.

| Year | Probability that the production increased more than 10% | Probability that the production decreased more than 10% |
|------|--------------------------------------------------------|--------------------------------------------------------|
| 2016 | 27.30                                                  | 62.95                                                  |
| 2020 | 86.84                                                  | 8.40                                                   |
| 2025 | 35.89                                                  | 53.82                                                  |
| 2030 | 36.56                                                  | 54.42                                                  |
| 2035 | 37.55                                                  | 52.11                                                  |

Based on Figure 9, it could be observed that there was a significant different from the probability calculated compared to at the end of 2016 and 2020. This could be due to a lot of factors such as FFB yield, weather change, plantation area, market demand, economic growth and etc. In 2016, the probability of production to decrease more than 10% was 62.95%, which it had happened from the historical data. For 2020, the probability that the production would increase more than 10% was 86.84%, which indicated that the production was highly likely to be increased. Starting from the year 2025 onwards, the probability of the production to increase showed an increasing trend, from 35.89% to 37.55%. However, it was still lower than the simulated probability of more than 10% decreased in production, by about 30% to 35%. For the decreased production of more than 10%, the probability fluctuated a little from 2025 to 2035, but remained within the range of 50% to 55%.

**FIGURE 9** Probability of production decreased or increased more than 10%, from 2016 to 2035 of every five years interval.

**5. Conclusion and Recommendation**

This study aimed to optimize the production of biofuel by using pinch analysis in supply chain industry. The case study used was the electricity production generated from biogas, which originated from palm oil mill effluent. In the development of base case, the supply and demand data for electricity was obtained. The base case data consisted historical data of 2016 and projected data to 2050. Cascade analysis was performed for all three cases with different scenarios. Each case considered the electricity supply and demand generated from renewable energy. First case was Case 1. It was developed with 4% of renewable energy in 2016 then with 20% of renewable energy demand starting from 2020. It supplied
with 20% of renewable energy throughout the years. Pinch point was achieved in the year 2020 with initial inventory of minimum electricity supply of 2.36 GW. Similar with Case 1, Case 2 was developed with slight modification of 45% of renewable energy supply and demand starting from 2030. Pinch point was achieved in the year 2020 with initial inventory of minimum electricity supply of 2.36 GW. Case 3 was developed only 1% of the electricity supply from biogas production was used. However, it was enough to meet the demand with 100% electricity generated from biogas which was produced from palm oil mill effluent. There was even surplus of electricity, which was about 11.61 GW while meeting the demand Pinch point was achieved in the year 2020 with reduced inventory of minimum electricity supply of 11.61 GW. This could result in lower usage of non-renewable energy, which could solve many environmental issues. The optimum biogas production was determined from the composites pinch point(s). Monte Carlo Simulation was used to analyse the up-scale production rate with 10 % increment for each year for five years as the sensitivity analysis in this study. It considered all the uncertainties and unexpected events that could affect the prediction. The simulated values showed that in 2020, the probability that the production to increase for more than 10% was 86.84%. For the year end of 2025, 2030 and 2035, the probability of production to decrease more than 10% were 53.82%, 54.42% and 52.11% respectively. The result showed that the production was more likely to downscale by more than 10% at the end of 205, 2030 and 2035.

In conclusion, pinch analysis and cascade analysis were useful in identifying the optimum planning in supply chain. Monte Carlo Simulation provided a good insight and helped greatly with decision making. As recommendations, the Monte Carlo Simulation could be performed in per year basis in order to obtain a more accurate representation of the projected data. Besides that, there could be more variation in the biogas production to further investigate the optimum percentage of usage at different time. The study could also be broadened to using biogas as a fuel for vehicles and other machineries.

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