Inter-entities symbiotic relationships with the use of multi-period methodology in energy planning

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Abstract. The deficiency of natural resources and serious climate change have driven the global community to optimize energy planning using various process integration approaches. The inter-entities energy planning that allows internal sharing of resources poses a great potential to enhance energy planning. It is believed that the effective management of such relationships is crucial to gaining collaborative synergies, which provide economic benefits and minimize environmental impact. The developed inter-collaborated energy sharing model gives a handy lens to evaluate the effectiveness of the suggested inter-entities collaboration and how it provides economic benefits for the involved “players”. To demonstrate the economic viability of the inter-entities’ energy planning, an energy sharing model is developed and applied to an illustrative case study that involved two entities. The results show that, when energy sharing is enabled, the involved entities can reduce their monthly electricity bill by 16.72 % (MYR 14940.73) for entity 1 and 14.29 % (MYR 14218.50) for entity 2, with a 20 % carbon emission constraint limit.

1. Introduction and Literature Review

Energy has always been the main fuel for the nation’s economy as well as mankind’s development worldwide. However, the exploitation of energy comes assuredly with climate change due to the increasing consumption of fossil-based energies for industrialization and urbanization [1,2]. The impacts of climate change have been experienced drastically in every nook and cranny, urging the need in limiting climate change and adapting the inevitable [3-4]. Numerous actions have been implemented to focus on climate change issues, but yet, they have been insufficient [5]. International Panel on Climate Change (IPCC) [4] stated that greenhouse gases (GHG) emissions need to be reduced by 50-85 % by 2050 compared with those at 2000 to limit global warming to 1.5 ℃.

Nonetheless, the global GHG emissions are not decreasing at a desired rate [5]. Given the global energy-related emissions in 2020 is about 31.5 Gt, it is still far to achieve a “net-zero” emission goal, which is planned to be achieved by 2050 [5,6]. To that extent, efforts are tremendously required especially in developing carbon-constrained energy planning to reduce GHG emissions and mitigate climate change. Many developing countries have already taken their actions by focusing on renewable energy as an alternative for fossil-based energies in adapting to climate change [7]. Nearly 70 % of
worldwide power capacities are generated from renewable energy sources in 2017 [8], showing that the evolution of renewables has gained massive attention from various nations.

Numerous process integration (PI) techniques and mathematical optimization models have been developed in handling carbon-constrained energy planning problems (e.g., pinch analysis [9], mixed-integer linear programming (MILP) [10], Automated Targeting Model (ATM) [11], and etc.) with the use of renewables. For example, Tan and Foo [9] solved the carbon-constrained energy planning using Carbon Emission Pinch Analysis (CEPA) and Ooi et al. [11] developed an Automated Targeting Model (ATM) for the carbon-constrained energy planning with the consideration of carbon capture and storage (CCS) systems. Thereafter, the provision research areas of PI techniques for energy planning-related problems have been critically reviewed by Klemes et al. [12] and lately, by Kong et al. [13]. Both works outlined the need for accurate time-sliced based model for more reliable energy planning.

Recently, Kong et al. [14] developed a two-step multi-period optimization model that incorporated billing system in a proposed carbon-constrained energy planning. The minimum amount of self-generated renewables required to attain the carbon emissions target is determined in the first step (Targeting step). They will be optimally distributed in the second step (Scheduling step) with the aim of minimizing the total electricity bill of a given entity. The self-generated and consumed renewables made the owners active prosumers in the case study. Given this context, Tushar et al. [15] presented a comprehensive peer-to-peer (P2P) energy sharing concept in which the prosumers can independently decide their energy sharing parameters (e.g., who and when to share the energy, unit price of the shared energy, and etc.) to ensure the “players” involved gain economic benefits. This concept has been subsequently extended by Zhou et al. [16], where various P2P energy sharing models are developed to effectively reduce the energy bill of the prosumers.

It has been shown that idea of P2P energy sharing is one of the effective mechanisms for future smart grid, which enables direct energy trading between energy prosumers and consumers [15]. The P2P energy sharing concept can help in empowering the prosumers and give them flexibility in managing their own generated energy. To the best of the authors’ knowledge, there are no specific P2P energy-sharing models developed that incorporate the actual billing system with micro time-basis (minutes) for carbon-constrained energy planning to-date.

To address this research gap, a modified version of multi-period P2P energy sharing model that incorporates an actual billing system is developed in this paper. A two-entity case based in Malaysia is used to demonstrate the effectiveness of the proposed model. Thus, the billing scheme from Tenaga Nasional Berhad (TNB), one of the largest electricity retailers in Malaysia, is adopted in this case study. Note that the offered P2P energy sharing is supposed to be flexible between peers, in which the excess energy can be traded or sold locally to one another as long as the scheme poses an overall positive impact to the “players” involved. The developed model is then benchmarked with the normal scenario where energy sharing is not considered, so that the feasibility of having collaborative involvement among entities (or “players”) can be demonstrated.

2. Problem Statement
The multi-period pinch-based framework, which was proposed by Kong et al. [14], is adopted in this work and has been further modified to enable inter-entities collaborations among entities. Two different scenarios are carried out for both entities. The first scenario is assumed wherein both entities do not consider energy sharing whereas the sharing of energy between entities is performed in the latter scenario. The first two steps of the framework (targeting and scheduling) proposed by Kong et al. [14] is performed individually for both entities that allow the entities to meet the overall emission limit and minimize the total electricity bill in the first scenario. Finally, the extended step, energy sharing between entities is used to determine how the different energy resources should be allocated in order to further reduce the electricity bill for both entities. Therefore, in this work, the multi-period energy plannings for two entities, with and without consideration of inter-entity energy sharing are performed. The objective of this work is to evaluate the feasibility and the effectiveness of P2P energy sharing between
entities with the utilization of multi-period carbon-constrained energy planning framework. The daily energy usage of these two entities is presented in figure 1.

Figure 1. Daily energy usage of two entities.

3. Model Formulation

The multi-period energy planning model is an extension of the two-step optimization model developed by Kong et al. [14], which incorporates energy sharing possibilities between entities. The time intervals of 30 min in a month is assigned as $T = \{1, 2, \ldots, N\}$, while the total energy demand in each interval is represented as $\text{DEMAND} = \{D_{T1}, D_{T2}, \ldots, D_{TN}\}$. The energy sources, i.e., renewables energies, fossil-based energies (derived from TNB), energy from the energy storage system, and shared renewables from the partner entity are assigned as $\text{SOURCES} = \{S_R, S_{ER}, S_{SR}\}$, which are used to fulfill the total energy demand. Each energy supply has its emission factor (denoted as $C_{IF}$ and $C_{IR}$ for fossil and renewable energy sources). Energy storage system with a capacity of $S_{ER}$ is allocated to allow energy to be stored during a given time. The stored energy can either be self-consumed or sold to the partner entity. Note that the shared renewables and the energy from the storage system utilized the same emission factor with renewables as they are homogeneous. The renewable source considered in this work is assumed to be solar energy. Furthermore, the operation of the case study is also assumed to operate at steady-state condition. The following subsection presents the formulation of the proposed model.

3.1. Carbon Emission Pinch Analysis (CEPA) -- Targeting

In this targeting step, Carbon Emission Pinch Analysis (CEPA), which was developed by Tan and Foo [9], is used to determine the minimum amount of renewables required (so that the pre-defined carbon emission limit can be achieved) for both entities. The minimum amount of renewables is identified in this step as the deployment of renewable energy is still more cost-intensive as compared to the use of conventional energy sources (oil, natural gas, and coal). As shown in equation (1), the objective of this work is to determine the minimum amount of renewables needed for each entity, so that the additional investment for renewable energy deployment can be kept minimal while ensuring the targeted carbon emission limit is achieved. Note that $S_{Total\, Renewables}$ (kWh) indicates the total renewables required across the one-month period while $S_{R,T}$ (kWh) denotes the amount of renewable energy that is applied to the system at time interval T.

$$
\text{Min } S_{Total\, Renewables} = \sum_T S_{R,T} + \sum_T S_{ER,T}
$$

The carbon emission of each time interval, $E_T$ (kg) is the product of energy demand and their respective carbon intensity, $C_{IF}$ and $C_{IR}$ (kg/kWh), by using the equation (2). Note that the renewables and
energy storage utilizes the same carbon intensity, $CI_R$ in this case, as they are derived from the same energy supply.

$$E_T = S_{F,T} CI_F + S_{R,T} CI_R + S_{ER,T} CI_R \quad \forall T$$

Equation (3) represents the energy demand at each time interval $T$, ($D_T$ (kWh)), which can be fulfilled by either fossil-based ($S_{F,T}$), renewables energies ($S_{R,T}$) or energy storage for renewables ($S_{ER,T}$) during day time (7 a.m. to 7 p.m.)

$$D_T = S_{F,T} + S_{R,T} + S_{ER,T} \quad \forall T$$

Whereas on the other hand, equation (4) ensures that the renewable energy supply is only derived from energy storage from 12 a.m. to 7 a.m. and 7 p.m. to 12 a.m.

$$D_T = S_{F,T} + S_{ER,T} \quad \forall T$$

The initial carbon emission limit, $E_{in}$ (kg) is presumed to be caused by fossil-based energy sources, which are derived from TNB, so it can be expressed as equation (5):

$$E_{in} = \sum_T (S_{F,T} \times CI_F)$$

As for the carbon emission limit $E_L$ (kg), it can be represented as equation (6) where $\beta$ indicates the emission reduction ratio. Note that in this work, the emission reduction ratio is set as 0.2 (20 % lower than the initial emission), but the emission reduction ratio can vary based on the preferences of the decision-makers and policymakers.

$$E_L = E_{in} \times (1 - \beta)$$

The above equations are incorporated into the first linear programming model, which is solved using LINGO 18.0 [17].

3.2. Automated Targeting Model (ATM) – Scheduling

As for the scheduling step, optimal energy allocations of renewable energy for both entities are performed. The optimized energy allocation can be determined via the developed mixed-integer linear programming (MILP) model using LINGO 18.0 [17]. Note that the total amount of renewables distributed in this step is equivalent to the targeted amount of renewables in the first step. The objective of the scheduling step is to minimize the total electricity bill, $Cost_{Total,Without Sharing}$ across all time intervals, which is expressed as equation (7). The indicated $C_T$ denotes the electricity cost at time interval $T$ while $C_{MD}$ is the MD charges:

$$\text{Min } Cost_{Total,Without Sharing} = \sum_T C_T + C_{MD}$$

The electricity cost at time interval $T$, $C_T$ (MYR), can be mathematically expressed as equation (8), whereas $CF_F$ (MYR/kWh) and $CF_R$ (MYR/kWh) are the cost factor of fossil-based energy and renewable energy at different time intervals (indicated in table 1).

$$C_T = (S_{F,T} \times CF_F) + (S_{R,T} \times CF_R) \quad \forall T$$
For the MD charges, the highest MD value is selected between mid-peak, $MD_{Mid\text{-}peak}$ (kW) or peak period $MD_{Peak}$ (kW), and multiply it with their respective MD cost factor, $MD_{Mid\text{-}peak}$ and $MD_{Peak}$ (MYR/kW). The $MD_{Mid\text{-}peak}$ can be obtained by dividing the summation of fossil-based energies in every mid-peak period ($\sum_{T=Mid\text{-}peak} S_{F,T}$) to the number of mid-peak time intervals ($\sum_{T} T = Mid\text{-}peak$). Whereas $MD_{Peak}$ can be obtained by dividing the summation of fossil-based energies in every peak period ($\sum_{T=Peak} S_{F,T}$) to the number of peak-time intervals ($\sum_{T} T = peak$). The selection of the MD value of mid-peak and peak period can be expressed as equation (9) and (10).

$$MD_{Mid\text{-}peak} = \frac{\sum_{T=Mid\text{-}peak} S_{F,T}}{\sum_{T} T = Mid\text{-}peak}$$  \hspace{1cm} (9)

$$MD_{Peak} = \frac{\sum_{T=Peak} S_{F,T}}{\sum_{T} T = Peak}$$ \hspace{1cm} (10)

Whereas the MD charges can be expressed as equation (11):

$$C_{MD} = \max(MD_{Mid\text{-}peak}, MD_{Peak}) \times \left\{ \begin{array}{ll}
MD_{Mid\text{-}peak} & \text{if } MD_{Mid\text{-}peak} = \max \\
0.5 & \text{if } MD_{Peak} = \max
\end{array} \right\}$$ \hspace{1cm} (11)

Note that the original electricity bill ($Cost_{Total\text{, Original}}$) can be calculated using equation (8) to equation (11), the calculation can be formally represented as equation (12).

$$Cost_{Total\text{, Original}} = \sum_{T} C_{T} + C_{MD}$$ \hspace{1cm} (12)

In this step, a modified version of ATM is presented. Three different cascades (energy cascade, emission cascade, and cost cascade) are performed simultaneously to determine the optimal scheduling of renewables at different time intervals. Figure 2 shows the generic Automated Targeting Model (ATM); while the cost factors of different time classifications are tabulated in Table 1. Note that, the models formulated in Section 3.1 and Section 3.2 are modified from Kong et al. [14], where they are used to determine the optimal renewable energy allocation without the consideration of energy sharing.
Table 1. Cost factor and MD charge for each time interval.

| Time Interval (30 min/interval/day) | Classification | Cost Factor<sup>a</sup>, $CF_{F,T}$ (MYR/kWh) | Maximum Demand Charge<sup>b</sup>, $MD_T$ (MYR/kW) | Cost Factor<sup>b</sup>, $CF_{R,T}$ (MYR/kWh) |
|-------------------------------------|----------------|---------------------------------|---------------------------|---------------------------------|
| 00:00-08:30                         | Off-Peak       | 0.202                           | 0.00                      |                                 |
| 08:30-11:30                         | Mid-Peak       | 0.327                           | 35.00                     |                                 |
| 11:30-12:30                         | Peak           | 0.576                           | 38.30                     |                                 |
| 12:30-14:30                         | Mid-Peak       | 0.327                           | 35.00                     | 0.276                           |
| 14:30-17:30                         | Peak           | 0.576                           | 38.30                     |                                 |
| 17:30-21:00                         | Mid-Peak       | 0.327                           | 35.00                     |                                 |
| 22:00-24:00                         | Off-Peak       | 0.202                           | 0.00                      |                                 |

<sup>a</sup>Data obtained from Tenaga Nasional Berhad [18]

<sup>b</sup>Data obtained from Renewable Power Generation Costs in 2019, IRENA [19].

3.3. Energy Sharing

This subsection presents the mathematical model, which incorporates energy sharing. In this illustration, the developed model only enables energy sharing during the off period of the participating entities. As shown in figure 1, less energy is consumed on the off-period (i.e., day 3, 10, 17, 24, and 31) for entity 2. The allocated renewables for entity 2 during the off period can, therefore, be sold to entity 1. The optimal allocation of the shared renewables that allows both entities to achieve their minimum electricity bill can be determined via the model developed below.

The objective of the energy sharing model is expressed as equation (13), which is to maximize the weighted-sum satisfaction of both entities ($S_E$), where $\omega$ refers to the assigned weighting coefficients (both entities are assumed equally important, thus 0.5 is taken for each entity). The index $E$ represents the type of entity indicated (i.e., entity 1 and entity 2). The objective function ensures both entities can further minimize their electricity bills compared to the one without energy sharing.

$$\text{Max} \sum_E S_E \times \omega$$

(13)
The calculation of total electricity bill normalization of each entity can be expressed as equation (14), whereas the $C_{Total,Sharing,E}$ represents the total electricity bill after energy sharing where sharing cost, $C_{SR,E}$ (MYR) (positive sign is taken when energy is sold; negative sign is used when energy is imported from the partner entity), is incorporated.

$$S_E = \frac{C_{Total,Without,Sharing,E} - C_{Total,Sharing,E}}{C_{Total,Original,E} - C_{Total,Sharing,E}}$$  \hspace{1cm} (14)

$$Cost_{Total,Sharing,E} = \sum T C_{T,E} + C_{MD} \pm C_{SR,E}$$  \hspace{1cm} (15)

The sharing cost can be expressed as equation (16), in which $CF_{SR}$ represents the unit cost of each kWh of renewables sold and $S_{SR,T,E}$ denotes the amount of shared renewable energy that is applied to the system at time interval T. It is set as MYR 0.45/kWh in this work (assumed to be 21.88 % lower than the cost factor in the peak period).

$$C_{SR,E} = \sum T S_{SR,T,E} \times CF_{SR}$$  \hspace{1cm} (16)

It should be noted that the carbon emission and energy demand at each time interval of entity 1 during entity 2’s off days are then revised as equations (17) to (18).

$$E_T = S_{F,T} CI_F + S_{R,T} CI_R + S_{ER,T} CI_R + S_{SR,T} CI_R \hspace{1cm} \forall T$$  \hspace{1cm} (17)

$$D_T = \left\{ \begin{array}{ll} S_{F,T} + S_{R,T} + S_{ER,T} + S_{SR,T} & 7\text{ a.m. to } 7\text{ p.m.} \\ S_{F,T} + S_{ER,T} + S_{SR,T} & 7\text{ p.m. to } 7\text{ a.m.} \end{array} \right\} \forall T$$  \hspace{1cm} (18)

The carbon emission and energy demand of entity 2 during its’ off days are then revised as equations (19) and (20):

$$E_T = S_{F,T} CI_F \hspace{1cm} \forall T$$  \hspace{1cm} (19)

$$D_T = S_{F,T} \hspace{1cm} \forall T$$  \hspace{1cm} (20)

4. Results and Discussion

The original electricity bill for entity 1 and entity 2 is tabulated as in Table 2. Both entities do not utilize any renewables and the original electricity bill serves as the benchmark of the study.

| Table 2. Original Electricity bill for entity 1 and 2 (without energy planning) |
|----------------|----------------|----------------|
|                | Entity 1      | Entity 2      |
| Mid peak value (kWh) | 209.9268      | 213.9410      |
| Peak value (kWh)       | 237.7551      | 212.0308      |
| Maximum Demand Cost (MYR) | 9106.0222 | 7487.9367 |
| Normal Electricity Cost (MYR) | 95059.336 | 105683.002 |
| Total Electricity Bill (MYR) | 104165.40 | 113170.90 |
| Carbon Emission (kg)    | 210998.9      | 262465.20     |
The minimum renewable energy required can be determined using the equations formulated in Section 3.1. The results are illustrated in figure 3.

Figure 3 provides the visualization results of carbon emission pinch analysis for entity 1 and entity 2. The graph encompasses two composite curves, i.e., (i) source composite curve (SCC) and (ii) demand composite curve (DCC). SCC is the total energy supply (input) while the DCC is the emission limit of the problem. The intersection point is known as the pinch point. The horizontal distance (right side) between the two composite curves denotes the minimum amount of renewable energy required to meet the emission limit. In this work, 20% of carbon emission reduction is set as the constraint for both entities and the minimum renewables needed for entity 1 and entity 2 are $6.93 \times 10^4$ kWh and $5.57 \times 10^4$ kWh, respectively.

The scheduling part, on the other hand, is designed to obtain the optimal allocation of the renewables targeted from the targeting step for both entities. Similar to the targeting step, the minimum electricity bill and optimal allocation of renewables can be determined through MILP model developed in Section 3.2. As for the energy sharing part, it can be solved through the model developed in Section 3.3 by using LINGO V18 [17]. The sharing of renewables allows both entities to benefit from trading the excess renewables to another, which leads to lower net cost. Table 3 shows the total electricity bill for both entities after energy sharing. Note that the total renewables used in both entities are still the same, therefore, the sharing of energy does not affect the total carbon emission. In other words, the net carbon emissions still fulfill the total emissions reduction target. The respective optimal energy allocation for both entities (before and after energy sharing) are illustrated in figure 4 to figure 7. The complete ATMs (1st to 31st day) for both entities are compiled in Appendix A-Appendix D.
Figure 4. Energy allocation of entity 1 before energy sharing.
Figure 5. Energy allocation of entity 1 after energy sharing.
Figure 6. Energy allocation of entity 2 before energy sharing.
Figure 7. Energy allocation of entity 2 after energy sharing.
Table 3. Electricity bill for entity 1 and 2 (before and after energy sharing)

|                        | Before energy sharing | After energy sharing |
|------------------------|-----------------------|----------------------|
|                        | Entity 1  | Entity 2  | Entity 1  | Entity 2  |
| Mid peak value (kWh)   | 180.9352 | 177.8171 | 160.3396 | 217.8014 |
| Peak value (kWh)       | 92.7970  | 69.6838  | 45.9429  | 109.38   |
| Maximum Demand Cost (MYR) | 6332.7316 | 6223.5980 | 5611.884 | 7623.049 |
| Normal Electricity Cost (MYR) | 67588.449 | 74086.268 | 52633.75 | 87863.20 |
| Renewables Cost (MYR)  | 15421.60 | 19183.20 | 15421.59 | 19183.2  |
| Sharing Renewables Cost (MYR) | -       | +15557.40 | -       | +15557.40 |
| Total Electricity Bill (MYR) | 89342.80 | 99493.04 | 89224.63 | 99112.05 |
| Carbon Emission (kg)   | 168799.20| 209972.1 | 236166.87| 142604.43|

The results show that with the aid of the targeting and scheduling steps, entity 1 and 2 can reduce their electricity bill by 14.23% and 12.08%, respectively. In the first scenario (before energy sharing), the utilization of renewables and the optimal scheduling strategy enables both entities to drastically reduce their MD charges by 30.4% (MYR 2773.29) and 16.95% (MYR1269.21), respectively. The targeted renewables are distributed in mid-peak and peak periods accordingly. As for the second scenario (energy sharing scenario), 34572.01 kWh of renewables generated from entity 2 are proposed to be sold to entity 1 with a unit cost of MYR 0.45 per kWh. It can be seen from the ATMs (Appendix B) and energy allocation models (figure 5) that the sold renewables are mainly distributed to the mid-peak and peak-period for entity 1, which effectively further reduces the MD charges (MYR 720.85) and the normal electricity cost (MYR 14594.69). As for the peak periods for entity 1, more renewables are utilized (from the solar panel, energy storage, and renewables from entity 2) as the MD charges are higher than that of the mid-peak periods. Thus, with the aid of energy sharing, entity 1 can further reduce its electricity bill by MYR 118.17 (0.13%) even though 34742.66 kWh of renewables are purchased from entity 2. On the other hand, entity 2 can mitigate its total electricity bill by MYR 380.98 (0.38%) by exporting its generated renewables to the partner entity (figure 7 and Appendix D). Note that even though the MD cost and normal electricity cost of entity 2 have been increased by MYR 1399.45 and MYR 13776.93, respectively due to lower utilization of renewables, the income generated from the energy sharing (MYR 15557.40) is high enough to compensate for the losses. By looking at the comparative results illustrated in Table 3, the proposed multi-period energy sharing framework that incorporates the actual billing system of TNB has shown the positive economic benefits of energy sharing for both entities in energy planning.

5. Conclusions
This work evaluates the potential of P2P energy sharing between two entities using the proposed multi-period optimisation model. This work benchmarks the two energy planning scenarios, i.e., with and without the consideration of energy sharing between entities, while ensuring the overall electricity bills are kept at minimal. The results generated from the developed model proved that the sharing of the renewables can reduce the electricity bill by 14.34% (MYR 14940.77) and 12.42% (MYR 14058.90) as compared to the original scenario where the energy planning is not optimised. It is worth emphasizing that the P2P energy sharing concept is capable of offering positive impacts on carbon-constrained energy planning, particularly in enhancing the economic viability without the need of compromising the environmental benefit. However, the P2P energy sharing concept is often limited by a series of barriers, which include environmental regulation constraints, lack of information sharing, and trust issues between the players in the industries [20]. Therefore, more effort is needed in exploring game-theoretic
solutions to rationalize the energy sharing scheme [13]. In addition, the model can be extended to
determine the optimal carbon reduction ratio, without the compromising the profitability of each entity.

References
[1] Cao X 2003 Climate change and energy development: Implications for developing countries Resour. Pol. 29 61–67
[2] IRENA 2018 Global energy transformation: A roadmap to 2050 International Renewable Energy, Abu Dhabi International Renewable Energy Agency
[3] IPCC 2014 Climate Change 2014: Synthesis Report Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)] Intergovernmental panel on climate change
[4] IPCC 2018 Summary for Policymakers In: Global warming of 1.5°C, 2018: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)] Intergovernmental panel on climate change
[5] Hurlimann A C, Moosavi S and Browne G R 2021 Climate change transformation: A definition and typology to guide decision making in urban environments Sustain. Cities. Soc. 70 102890.
[6] IEA 2021 Global Energy Review 2021 IEA Paris International Energy Agency
[7] Tan X, Zhu, K, Meng X, Gu B, Wang Y, Meng F, Liu G, Tu T and Li H 2021 Research on the status and priority needs of developing countries to address climate change J. Clean. Prod. 289 125669
[8] REN21 2018 Renewables 2018 Global Status Report (Paris: REN21 Secretariat) Renewables now
[9] Tan R R and Foo D C Y 2007 Pinch analysis approach to carbon-constrained energy sector planning Energy 32(8) 1422–1429
[10] Hashim H, Douglas P, Elkamel A and Croiset E 2005 Optimization model for energy planning with CO₂ emission considerations Ind. Eng. Chem. Res. 44(4) 879–890
[11] Ooi R E H, Foo D C Y and Tan R R 2014 Targeting for carbon sequestration retrofit planning in the power generation sector for multi-period problems Appl. Energ. 113 477–487
[12] Klemes J J, Varbanov P, Walmsley T S and Jia X 2018 New directions in the implementation of Pinch Methodology (PM) Renew. Sust. Energ. Rev. 98 439–468
[13] Kong K G H, How B S, Teng S Y, Leong W D, Foo D C Y, Tan R R and Sunarso J 2021 Towards data-driven process integration for renewable energy planning Curr. Opin. Chem. Eng. 31 100665
[14] Kong K G H, Lo S L Y, How B S, Leong W D, Teng S Y, Ng W P and Sunarso J 2020 Enhanced Automated Targeting Model for Multi-Period Energy Planning Chem. Eng. Trans. 81 607–612
[15] Tushar W, Yuen C, Saha TK, Morstyn T, Chapman A C, Alam M J E, Hanif S and Vincent P H 2021 Peer-to-peer energy systems for connected communities: A review of recent advances and emerging challenges Appl. Energ. 282, Part A 116131
[16] Zhou Y, Wu J, Long C, Cheng M and Zhang C 2017 Performance evaluation of peer-to-peer energy sharing models Energy Procedia 143 817–822
[17] Lindo system INC 2020 LINGO 19.0 - Optimization Modeling Software for Linear, Nonlinear, and Integer Programming Lindo system INC
[18] Tenaga Nasional Berhad 2014 Tenaga Nasional Berhad Enhanced Time of Use (ETOU) Tenaga Nasional Berhad
[19] IRENA 2019 Renewable Power Generation Costs in 2019 International Renewable Energy
Agency

[20] Golev A, Corder G A and Giuro D P 2014 Barriers to industrial symbiosis: Insights from the use of a maturity grid *J. Ind. Ecol.* **19**(1) 141–153

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### Article I. Appendix

**Appendix A: Automated Targeting Model for entity 1 (Before Energy sharing) 1st - 30th day**

| 1st Classification | Time Interval (0-10) | Energy (Energy (EPA)) | Embodied Carbon (kg) | Cost Carbon (US$) | 4th | Classification | Time Interval (11-20) | Energy (Energy (EPA)) | Embodied Carbon (kg) | Cost Carbon (US$) | 7th | Classification | Time Interval (21-30) | Energy (Energy (EPA)) | Embodied Carbon (kg) | Cost Carbon (US$) |
|--------------------|---------------------|-----------------------|---------------------|------------------|-----|----------------|---------------------|---------------------|---------------------|------------------|-----|----------------|---------------------|---------------------|---------------------|------------------|
| Off-Peak           | 1.96                | 600.98                | 1439.30             | 278.60           | Off-Peak | 1.14            | 851.48              | 1531.44             | 1754.75             | 162.25           | Off-Peak | 1.14            | 5691.13             | 5614.65             | 754.98              | 117.07           |
| Grid-Peak          | 27.12               | 74.90                 | 750.37              | 2309.13          | Grid-Peak | 17.11           | 69.90               | 2480.79             | 2064.53             | 74.90            | Grid-Peak | 27.12           | 4654.88             | 4654.88             | 74.90               | 27.12            |
| Peak               | 33.54               | 296.55                | 845.53              | 2402.77          | Peak     | 25.21           | 396.83              | 2402.77             | 2402.77             | 396.83           | Peak     | 33.54           | 2309.13             | 2309.13             | 2309.13             | 2309.13         |
| Mid-Peak           | 29.80               | 46.11                 | 2449.31             | 2064.53          | Mid-Peak | 29.29           | 46.11               | 2449.31             | 2449.31             | 46.11            | Mid-Peak | 29.80           | 1008.78             | 1008.78             | 1008.78             | 1008.78         |
| Peak               | 30.96               | 228.40                | 2402.77             | 2402.77          | Peak     | 30.96           | 228.40              | 2402.77             | 2402.77             | 228.40           | Peak     | 30.96           | 2449.31             | 2449.31             | 2449.31             | 2449.31         |
| Mid-Peak           | 35.61               | 457.76                | 2449.31             | 2449.31          | Mid-Peak | 35.61           | 457.76              | 2449.31             | 2449.31             | 457.76           | Mid-Peak | 35.61           | 2449.31             | 2449.31             | 2449.31             | 2449.31         |
| Off-Peak           | 41.40               | 977.70                | 2449.31             | 2449.31          | Off-Peak | 41.40           | 977.70              | 2449.31             | 2449.31             | 977.70           | Off-Peak | 41.40           | 2449.31             | 2449.31             | 2449.31             | 2449.31         |

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**Figure 1:** Graphical representation of the automated targeting model showing energy consumption, embodied carbon, and cost carbon for entity 1 during the 1st - 30th days. The model illustrates the impact of energy sharing on carbon emissions and economic costs. The data is summarized in the accompanying table.
| 28th Classification | Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (kg) | Cost Cascade (MYR) | 30th Classification | Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (kg) | Cost Cascade (MYR) |
|---------------------|------------------------|----------------------|----------------------|-------------------|---------------------|------------------------|----------------------|----------------------|---------------------|
| Off-Peak            | 1-16                   | 1627.14              | 1271.33              | 361.409           | Off-Peak            | 1-16                   | 1711.82              | 1337.18             | 308.50              |
| Mid-Peak            | 17-22                  | 74.093               | 1018.91              | 2712.94           | Mid-Peak            | 17-22                  | 74.093               | 906.588              | 2792.82             | 748.064             |
| Peak                | 22-24                  | 299.54               | 216.342              | 3228.06           | Peak                | 22-24                  | 299.54               | 196.616              | 2277.42             | 795.95              |
| Mid-Peak            | 25-28                  | 740.115              | 4548.54              | 9440.90           | Mid-Peak            | 25-28                  | 740.115              | 710.118              | 4295.11             | 1265.48             |
| Peak                | 29-34                  | 900.74               | 667.356              | 5814.95           | Peak                | 29-34                  | 900.74               | 635.138             | 5829.01             | 1876.32             |
| Mid-Peak            | 35-44                  | 224.601              | 2380.09              | 8457.31           | Mid-Peak            | 35-44                  | 224.601              | 2361.96              | 8415.66             | 5214.119            |
| Off-Peak            | 45-48                  | 558.788              | 9014.05              | 5603.22           | Off-Peak            | 45-48                  | 558.788              | 9971.04             | 5648.058            | 2766.59             |

| 29th Classification | Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (kg) | Cost Cascade (MYR) | 31st Classification | Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (kg) | Cost Cascade (MYR) |
|---------------------|------------------------|----------------------|----------------------|-------------------|---------------------|------------------------|----------------------|----------------------|---------------------|
| Off-Peak            | 1-16                   | 1646.18              | 1296.17              | 366.286           | Off-Peak            | 1-16                   | 1655.71              | 1293.654            | 372.63              |
| Mid-Peak            | 17-22                  | 74.005               | 973.61               | 2602.04           | Mid-Peak            | 17-22                  | 74.895               | 900.66              | 2721.26             | 734.440             |
| Peak                | 22-24                  | 299.54               | 198.699              | 2846.65           | Peak                | 22-24                  | 299.54               | 189.001             | 3209.84             | 910.379             |
| Mid-Peak            | 25-28                  | 710.966              | 4192.78              | 7218.771          | Mid-Peak            | 25-28                  | 710.966              | 682.562             | 4171.99             | 1229.16             |
| Peak                | 29-34                  | 909.71               | 555.54               | 5646.96           | Peak                | 29-34                  | 909.71               | 558.404             | 5629.13             | 1794.20             |
| Mid-Peak            | 35-44                  | 774.405              | 2206.59              | 5105.257          | Mid-Peak            | 35-44                  | 774.405              | 2321.62             | 5026.591            | 2562.27             |
| Off-Peak            | 45-48                  | 558.849              | 8712.14              | 5445.689          | Off-Peak            | 45-48                  | 558.849              | 8732.24             | 5442.273            | 2876.91             |
### Appendix B: Automated Targeting Model for entity 1 (After Energy sharing) 1st - 30th day

| Classification | Time Interval (1st-30th) | Energy (kWh) | Cost (USD) | 5th Classification | Time Interval (5th-30th) | Energy (kWh) | Cost (USD) |
|----------------|--------------------------|--------------|------------|------------------|--------------------------|--------------|------------|
| Off-Peak       | 1.16                     | 1274.57      | 561.87     | Off-Peak         | 1.36                     | 2714.91      | 641.17     |
| Mid-Peak       | 17.22                    | 3315.35      | 796.64     | Mid-Peak         | 17.36                    | 3892.81      | 841.43     |
| Peak           | 23.18                    | 4595.92      | 972.16     | Peak             | 23.32                    | 4908.31      | 1029.23    |
| Off-Peak       | 29.58                    | 6773.75      | 1330.71    | Off-Peak         | 30.53                    | 7040.12      | 1358.12    |
| Mid-Peak       | 36.21                    | 8931.32      | 1647.09    | Mid-Peak         | 36.35                    | 9150.72      | 1675.31    |
| Peak           | 42.61                    | 11093.47     | 2104.24    | Peak             | 42.92                    | 11336.47     | 2131.63    |
| Off-Peak       | 49.48                    | 13251.23     | 2412.78    | Off-Peak         | 50.51                    | 13547.83     | 2440.21    |

### 2nd Classification

| Classification | Time Interval (1st-30th) | Energy (kWh) | Cost (USD) | 5th Classification | Time Interval (5th-30th) | Energy (kWh) | Cost (USD) |
|----------------|--------------------------|--------------|------------|------------------|--------------------------|--------------|------------|
| Off-Peak       | 1.16                     | 1274.57      | 561.87     | Off-Peak         | 1.36                     | 2714.91      | 641.17     |
| Mid-Peak       | 17.22                    | 3315.35      | 796.64     | Mid-Peak         | 17.36                    | 3892.81      | 841.43     |
| Peak           | 23.18                    | 4595.92      | 972.16     | Peak             | 23.32                    | 4908.31      | 1029.23    |
| Off-Peak       | 29.58                    | 6773.75      | 1330.71    | Off-Peak         | 30.53                    | 7040.12      | 1358.12    |
| Mid-Peak       | 36.21                    | 8931.32      | 1647.09    | Mid-Peak         | 36.35                    | 9150.72      | 1675.31    |
| Peak           | 42.61                    | 11093.47     | 2104.24    | Peak             | 42.92                    | 11336.47     | 2131.63    |
| Off-Peak       | 49.48                    | 13251.23     | 2412.78    | Off-Peak         | 50.51                    | 13547.83     | 2440.21    |

### 3rd Classification

| Classification | Time Interval (1st-30th) | Energy (kWh) | Cost (USD) | 5th Classification | Time Interval (5th-30th) | Energy (kWh) | Cost (USD) |
|----------------|--------------------------|--------------|------------|------------------|--------------------------|--------------|------------|
| Off-Peak       | 1.16                     | 1274.57      | 561.87     | Off-Peak         | 1.36                     | 2714.91      | 641.17     |
| Mid-Peak       | 17.22                    | 3315.35      | 796.64     | Mid-Peak         | 17.36                    | 3892.81      | 841.43     |
| Peak           | 23.18                    | 4595.92      | 972.16     | Peak             | 23.32                    | 4908.31      | 1029.23    |
| Off-Peak       | 29.58                    | 6773.75      | 1330.71    | Off-Peak         | 30.53                    | 7040.12      | 1358.12    |
| Mid-Peak       | 36.21                    | 8931.32      | 1647.09    | Mid-Peak         | 36.35                    | 9150.72      | 1675.31    |
| Peak           | 42.61                    | 11093.47     | 2104.24    | Peak             | 42.92                    | 11336.47     | 2131.63    |
| Off-Peak       | 49.48                    | 13251.23     | 2412.78    | Off-Peak         | 50.51                    | 13547.83     | 2440.21    |

### 4th Classification

| Classification | Time Interval (1st-30th) | Energy (kWh) | Cost (USD) | 5th Classification | Time Interval (5th-30th) | Energy (kWh) | Cost (USD) |
|----------------|--------------------------|--------------|------------|------------------|--------------------------|--------------|------------|
| Off-Peak       | 1.16                     | 1274.57      | 561.87     | Off-Peak         | 1.36                     | 2714.91      | 641.17     |
| Mid-Peak       | 17.22                    | 3315.35      | 796.64     | Mid-Peak         | 17.36                    | 3892.81      | 841.43     |
| Peak           | 23.18                    | 4595.92      | 972.16     | Peak             | 23.32                    | 4908.31      | 1029.23    |
| Off-Peak       | 29.58                    | 6773.75      | 1330.71    | Off-Peak         | 30.53                    | 7040.12      | 1358.12    |
| Mid-Peak       | 36.21                    | 8931.32      | 1647.09    | Mid-Peak         | 36.35                    | 9150.72      | 1675.31    |
| Peak           | 42.61                    | 11093.47     | 2104.24    | Peak             | 42.92                    | 11336.47     | 2131.63    |
| Off-Peak       | 49.48                    | 13251.23     | 2412.78    | Off-Peak         | 50.51                    | 13547.83     | 2440.21    |

### 5th Classification

| Classification | Time Interval (1st-30th) | Energy (kWh) | Cost (USD) | 5th Classification | Time Interval (5th-30th) | Energy (kWh) | Cost (USD) |
|----------------|--------------------------|--------------|------------|------------------|--------------------------|--------------|------------|
| Off-Peak       | 1.16                     | 1274.57      | 561.87     | Off-Peak         | 1.36                     | 2714.91      | 641.17     |
| Mid-Peak       | 17.22                    | 3315.35      | 796.64     | Mid-Peak         | 17.36                    | 3892.81      | 841.43     |
| Peak           | 23.18                    | 4595.92      | 972.16     | Peak             | 23.32                    | 4908.31      | 1029.23    |
| Off-Peak       | 29.58                    | 6773.75      | 1330.71    | Off-Peak         | 30.53                    | 7040.12      | 1358.12    |
| Mid-Peak       | 36.21                    | 8931.32      | 1647.09    | Mid-Peak         | 36.35                    | 9150.72      | 1675.31    |
| Peak           | 42.61                    | 11093.47     | 2104.24    | Peak             | 42.92                    | 11336.47     | 2131.63    |
| Off-Peak       | 49.48                    | 13251.23     | 2412.78    | Off-Peak         | 50.51                    | 13547.83     | 2440.21    |
| Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (kg) | Cost Cascade (MYR) |
|------------------------|-----------------------|-----------------------|-------------------|
| Off-Peak 1-15          | 1446.35               | 1172.735              | 3437.93           |
| Mid-Peak 17-22         | 308.48                | 145.56                | 2542.25           |
| Peak 23-24              | 556.706               | 243.75                | 647.957           |
| Mid-Peak 25-28         | 1146.04               | 1767.358              | 841.62            |
| Peak 29-34              | 950.81                | 243.75                | 647.957           |
| Mid-Peak 35-44         | 856.25                | 243.75                | 647.957           |
| Off-Peak 45-48         | 856.25                | 243.75                | 647.957           |

| Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (kg) | Cost Cascade (MYR) |
|------------------------|-----------------------|-----------------------|-------------------|
| Off-Peak 1-15          | 1446.35               | 1172.735              | 3437.93           |
| Mid-Peak 17-22         | 308.48                | 145.56                | 2542.25           |
| Peak 23-24              | 556.706               | 243.75                | 647.957           |
| Mid-Peak 25-28         | 1146.04               | 1767.358              | 841.62            |
| Peak 29-34              | 950.81                | 243.75                | 647.957           |
| Mid-Peak 35-44         | 856.25                | 243.75                | 647.957           |
| Off-Peak 45-48         | 856.25                | 243.75                | 647.957           |
Appendix C: Automated Targeting Model for entity 2 (Before Energy sharing) 1st - 30th day
| Classification | Time Interval (h) | Energy Causality (KJ) | Entropy Causality (KJ) | Cost Causality (KJ) |
|----------------|------------------|----------------------|-----------------------|--------------------|
| Off-Pk         | 1.16             | 2.01                 | 0.90                  | 0.33               |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 1.16             | 2.01                 | 0.90                  | 0.33               |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 42.48            | 737.79               | 737.79                | 737.79             |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 1.16             | 2.01                 | 0.90                  | 0.33               |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 42.48            | 737.79               | 737.79                | 737.79             |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 1.16             | 2.01                 | 0.90                  | 0.33               |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 42.48            | 737.79               | 737.79                | 737.79             |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 1.16             | 2.01                 | 0.90                  | 0.33               |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 42.48            | 737.79               | 737.79                | 737.79             |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 1.16             | 2.01                 | 0.90                  | 0.33               |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 42.48            | 737.79               | 737.79                | 737.79             |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 1.16             | 2.01                 | 0.90                  | 0.33               |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 42.48            | 737.79               | 737.79                | 737.79             |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 1.16             | 2.01                 | 0.90                  | 0.33               |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 42.48            | 737.79               | 737.79                | 737.79             |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 1.16             | 2.01                 | 0.90                  | 0.33               |
| Mid-Pk         | 17.22            | 251.33               | 250.35                | 124.60             |
| Off-Pk         | 42.48            | 737.79               | 737.79                | 737.79             |
| Classification | Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (t) | Cost Cascade (MYR) |
|----------------|------------------------|----------------------|---------------------|-------------------|
| Off-Peak       | 1-16                   | 4008.38              | 3194.30             | 870.19            |
| Mid-Peak       | 17-22                  | 1108.98              | 4076.47             | 1435.66           |
| Peak           | 23-24                  | 689.46               | 4293.60             | 1642.47           |
| Mid-Peak       | 25-28                  | 732.64               | 4356.67             | 1900.43           |
| Peak           | 29-32                  | 1083.82              | 839.25              | 3453.49           |
| Mid-Peak       | 35-44                  | 1852.50              | 2763.10             | 3453.29           |
| Off-Peak       | 45-48                  | 1087.06              | 8112.65             | 3672.88           |

| Classification | Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (t) | Cost Cascade (MYR) |
|----------------|------------------------|----------------------|---------------------|-------------------|
| Off-Peak       | 1-16                   | 4387.08              | 3396.59             | 917.04            |
| Mid-Peak       | 17-22                  | 585.91               | 4159.04             | 1737.18           |
| Peak           | 23-24                  | 0                    | 4103.01             | 1657.67           |
| Mid-Peak       | 25-28                  | 499.86               | 450.13              | 1857.09           |
| Peak           | 29-32                  | 836.69               | 4822.92             | 2253.51           |
| Mid-Peak       | 35-44                  | 1123.00              | 6979.65             | 3057.50           |
| Off-Peak       | 45-48                  | 907.10               | 7759.90             | 3256.97           |
### Appendix D: Automated Targeting Model for entity 2 (After Energy sharing) 1st - 30th day

| 1st Classification | Time Interval (Days) | Energy Costs (KWh) | Cost-Carriers (KWh) |
|--------------------|----------------------|--------------------|---------------------|
| Off-Peak           | 1-30                 | 329.12             | 721.06              |
| Mid-Peak           | 31-40                | 329.12             | 721.06              |
| Peak               | 41-50                | 329.12             | 721.06              |

| 2nd Classification | Time Interval (Days) | Energy Costs (KWh) | Cost-Carriers (KWh) |
|--------------------|----------------------|--------------------|---------------------|
| Off-Peak           | 1-30                 | 329.12             | 721.06              |
| Mid-Peak           | 31-40                | 329.12             | 721.06              |
| Peak               | 41-50                | 329.12             | 721.06              |

| 3rd Classification | Time Interval (Days) | Energy Costs (KWh) | Cost-Carriers (KWh) |
|--------------------|----------------------|--------------------|---------------------|
| Off-Peak           | 1-30                 | 329.12             | 721.06              |
| Mid-Peak           | 31-40                | 329.12             | 721.06              |
| Peak               | 41-50                | 329.12             | 721.06              |

| 4th Classification | Time Interval (Days) | Energy Costs (KWh) | Cost-Carriers (KWh) |
|--------------------|----------------------|--------------------|---------------------|
| Off-Peak           | 1-30                 | 329.12             | 721.06              |
| Mid-Peak           | 31-40                | 329.12             | 721.06              |
| Peak               | 41-50                | 329.12             | 721.06              |

| 5th Classification | Time Interval (Days) | Energy Costs (KWh) | Cost-Carriers (KWh) |
|--------------------|----------------------|--------------------|---------------------|
| Off-Peak           | 1-30                 | 329.12             | 721.06              |
| Mid-Peak           | 31-40                | 329.12             | 721.06              |
| Peak               | 41-50                | 329.12             | 721.06              |

| 6th Classification | Time Interval (Days) | Energy Costs (KWh) | Cost-Carriers (KWh) |
|--------------------|----------------------|--------------------|---------------------|
| Off-Peak           | 1-30                 | 329.12             | 721.06              |
| Mid-Peak           | 31-40                | 329.12             | 721.06              |
| Peak               | 41-50                | 329.12             | 721.06              |

| 7th Classification | Time Interval (Days) | Energy Costs (KWh) | Cost-Carriers (KWh) |
|--------------------|----------------------|--------------------|---------------------|
| Off-Peak           | 1-30                 | 329.12             | 721.06              |
| Mid-Peak           | 31-40                | 329.12             | 721.06              |
| Peak               | 41-50                | 329.12             | 721.06              |

| 8th Classification | Time Interval (Days) | Energy Costs (KWh) | Cost-Carriers (KWh) |
|--------------------|----------------------|--------------------|---------------------|
| Off-Peak           | 1-30                 | 329.12             | 721.06              |
| Mid-Peak           | 31-40                | 329.12             | 721.06              |
| Peak               | 41-50                | 329.12             | 721.06              |

| 9th Classification | Time Interval (Days) | Energy Costs (KWh) | Cost-Carriers (KWh) |
|--------------------|----------------------|--------------------|---------------------|
| Off-Peak           | 1-30                 | 329.12             | 721.06              |
| Mid-Peak           | 31-40                | 329.12             | 721.06              |
| Peak               | 41-50                | 329.12             | 721.06              |
| 28th Classification | Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (kg) | Cost Cascade (MYR) |
|---------------------|------------------------|----------------------|----------------------|-------------------|
| Off-Peak            | 1-16                   | 4.00 (38)            | 3.98 (38)            | 026.29            |
| Mid-Peak            | 17-22                  | 125.09 (38)          | 163.39 (38)          | 5.094.46          |
| Peak                | 23-24                  | 351.79 (38)          | 387.31 (38)          | 447.10 (38)       |
| Mid-Peak            | 25-28                  | 92.46 (38)           | 746.65 (38)          | 1488.69           |
| Peak                | 29-34                  | 973.91 (38)          | 9016.74 (38)         | 1675.32 (38)      |
| Mid-Peak            | 35-44                  | 197.27 (38)          | 2706.96 (38)         | 2464.90 (38)      |
| Off-Peak            | 45-48                  | 2087.06 (38)         | 3291.53 (38)         | 3741.85 (38)      |

| 29th Classification | Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (kg) | Cost Cascade (MYR) |
|---------------------|------------------------|----------------------|----------------------|-------------------|
| Off-Peak            | 1-16                   | 4271.77              | 3337.56              | 906.76            |
| Mid-Peak            | 17-22                  | 445.76               | 1105.28              | 5892.42           |
| Peak                | 23-24                  | 278.17               | 369.88               | 4421.43           |
| Mid-Peak            | 25-28                  | 344.47               | 663.68               | 5034.07           |
| Peak                | 29-34                  | 769.82               | 526.49               | 5478.06           |
| Mid-Peak            | 35-44                  | 203.93               | 2143.44              | 2151.77           |
| Off-Peak            | 45-48                  | 1078.36              | 2232.03              | 3480.48           |

| 30th Classification | Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (kg) | Cost Cascade (MYR) |
|---------------------|------------------------|----------------------|----------------------|-------------------|
| Off-Peak            | 1-16                   | 4271.77              | 3337.56              | 906.76            |
| Mid-Peak            | 17-22                  | 445.76               | 1105.28              | 5892.42           |
| Peak                | 23-24                  | 278.17               | 369.88               | 4421.43           |
| Mid-Peak            | 25-28                  | 344.47               | 663.68               | 5034.07           |
| Peak                | 29-34                  | 769.82               | 526.49               | 5478.06           |
| Mid-Peak            | 35-44                  | 203.93               | 2143.44              | 2151.77           |
| Off-Peak            | 45-48                  | 1078.36              | 2232.03              | 3480.48           |

| 31st Classification | Time Interval (30 min) | Energy Cascade (kWh) | Emission Cascade (kg) | Cost Cascade (MYR) |
|---------------------|------------------------|----------------------|----------------------|-------------------|
| Off-Peak            | 1-16                   | 2976.86              | 2976.86              | 3187.24           |
| Mid-Peak            | 17-22                  | 348.28               | 4325.152             | 3379.37           |
| Peak                | 23-24                  | 258.80               | 5654.21              | 3461.54           |
| Mid-Peak            | 25-28                  | 258.80               | 5654.21              | 3461.54           |
| Peak                | 29-34                  | 258.80               | 5654.21              | 3461.54           |
| Mid-Peak            | 35-44                  | 258.80               | 5654.21              | 3461.54           |
| Off-Peak            | 45-48                  | 258.80               | 5654.21              | 3461.54           |

[^1]: 32nd Symposium of Malaysian Chemical Engineers (SOMChE2021)
[^2]: IOP Conf. Series: Materials Science and Engineering
[^3]: doi:10.1088/1757-899X/1195/1/012011