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A two-stage multi microgrids p2p energy trading with motivational game-theory: A case study in malaysia

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Abstract

Peer-to-peer (P2P) energy trading is expected to be emerged as a new energy management paradigm that allows the transaction of energy from one prosumer to another prosumer without any dependency on a central controller. In Malaysia, first pilot test of P2P trading has been conducted recently, which exclusively participated by industrial prosumers and commercial consumers only. In order to investigate the impact of P2P energy trading to Malaysia market, this paper proposes an auction-based two-stage P2P trading market-clearing strategy, for multi-cities and intra-city in Malaysia. A motivational game theory-based price scheme is presented to ensure an unbiased market operation, to maximize the saving and payoff for each prosumer, at the same time benefits the power utility company. The proposed two-stage market clearing model is solved by Linear Programming optimization approach. A realistic representation of P2P trading in Malaysia is constructed and tested out under multi-cities and intra-city energy trading test cases. Comparison between the proposed P2P energy trading with existing solar generation net metering scheme is also presented. The numerical results indicate the viability and potential of motivational game theory based P2P trading in future Malaysia transactive energy market.

1 | INTRODUCTION

Global warming and the resultant climate change are mainly due to the greenhouse gas emissions from conventional fossil fuel generations. Nowadays, people are encouraged to use environmentally friendly technologies and generate their own renewable power, in order to reduce carbon emissions. As such, renewable distributed energy resources (DER) installation at the edge of the grid, is introduced and the adoption rate by the community is increasing rapidly [1]. DER can include combined solar photovoltaic generation, electric water heaters, and electric vehicles [2]. Based on the prediction from World Energy Council, solar generation is the main driver of global renewable generation growth, as it is predicted to set new records for deployment each year after 2022 [3]. Therefore, renewable energy generation, especially solar DER is expected to be grown rapidly over the next few years. Peer-to-Peer (P2P) energy trading, which is predicted to be the solution for future smart grid problems, will be suitable platform for next generation renewable DER implementation.

1.1 | Existing P2P energy trading platforms

Several projects on P2P trading have been initiated and carried out recently. Most of them focus on business models and energy market platforms which act similarly to the supplier's role in the electricity sector. The first project is Piclo which was established in the UK, a collaboration between "Good Energy" and "Open Utility" [4]. Open Utility has developed a software that matches prosumers and consumers every 30 minutes based on their locality and preferences. Moreover, there is also a P2P platform from Bangladesh called SOLshare [5] which installs small-scale microgrids that connect local consumers and allow them to share energy within the locality. Prosumers who have solar panels on their homes can supply excess energy to other consumers who do not have access to electricity. Other than those mentioned above, there are many more projects that are currently being developed across the world, such as Valley Housing Project in Fremantle, Western Australia [6], Brooklyn Microgrid in New York [7], and the blockchain-based Enerchain Project in Europe [8].

1.2 | Existing studies of P2P market clearing models

In general, to constructively increase the usage of DER while improving the trading benefits, market-clearing models based on game-theoretic approaches manage to attract a lot of attention from recent researchers [9]. In literature [10], a market-clearing game is proposed to determine the market-clearing price, which is based on a fairness index, defined as "customers with higher participation level can reduce their individual cost more than those with lower participation level within the same community," which is attainable by customizing trading prices. Although this method can obviously simplify the bidding process, this pricing scheme seems unappealing to independent prosumers who intend to trade energy with various peers at different rates [9]. In order to overcome this drawback, a multi-leader multi-follower game by considering the flexibility of both buyers and sellers is proposed in [11]. However, the trading prices in the proposed model are primarily decided by sellers, while the buyers are always placed in a passive position. Since every participant is intuitively expecting to gain more benefits in a fair manner [12], this method could undermine the buyers' incentives to participate in the P2P trading. Based on the literature, it clearly shows that there is a need for a fair price scheme to encourage participation while providing freedom for prosumers to interact with each other.

On the other hand, various research has been conducted, to access the potential benefits of P2P trading to the power systems. Guerrero *et al.* have analyzed the impact of P2P transactions on the network grid and proved that the exchange of energy does not violate the constraints for the network [13]. Paudel et al. implemented two types of game theory in the P2P trading system which are evolutionary game and non-cooperative game among buyer and seller respectively [14]. During the energy trading, the seller will update the amount of energy and the price to sell, whereas the buyer has the option to purchase energy from the seller based on the pricing. Thusar et al. proposed an algorithm that would decide the threshold for load demand to encourage people to take part in the P2P system by increasing the electricity cost bought from utility companies [15]. The result proved that by increasing the electricity cost at peak demand not only helped the prosumer to save cost but also helped to release the network congestion. However, non-peak hours are simply neglected, and no game theory involved to boost the participation rate. Malaysia is a country located in the equatorial zone, thus there is no four seasons' effects, and we have longer sunshine hour. Therefore, having a pricing scheme that motivate prosumer to participate in P2P trading for whole sunshine hour will be the more suitable solution for Malaysia.

During the development of effective P2P trading, one of the essential stages is the design of market clearing mechanisms. In P2P trading, energy allocation and electricity price should be decided in a way that incentivizes both prosumers to participate in the market. For market clearing mechanism, the auction-based approach is selected as it is applicable in any market without considering the number of sellers and buyers. Besides that, in the auction, the price of goods is decided by the buyer and seller, thus it helps to avoid conflict about money. Khorasany et al. proposed the knapsack approximation algorithm for the single seller to multiple buyer auction for P2P market-clearing [16]. During the auction, sellers have the right to sell a portion of the energy requested by the buyer. Furthermore, the Vickrey–Clarke–Groves (VCG) mechanism is implemented to maximize the social welfare in demand-side management [17]. Khorasany et al. [18] applied the greedy algorithm as market-clearing mechanism where buying order is sorted from highest to lowest based on the buyer's bidding price which will boost the profit for the seller. However, by implementing the greedy algorithm, sellers and buyers are unable to sell or buy a portion of energy, as the energy need to sell in lump sum. Therefore, a modified greedy algorithm is proposed in [16] to enable buyers and sellers to buy or sell a portion of energy by introducing a weightage factor. Kalysh et al. have proposed dynamic programming optimization (DPO) which aims to maximize profit for the seller [19]. The DPO distributes the energy to a smaller amount and sells to multiple buyers that bid the highest price to maximize the profit. Similar auction concept is implemented in this paper, by introducing priority indices, formulated as a linear programming model, which enable portion of energy transaction between prosumers.

1.3 | Research gaps and contributions

Numerous researchers have contributed to devising energy trading algorithms [20], modelling of the trading price [21], incentivizing prosumers [22], and maintaining network constraints [13]. However, an essential research gap is rarely tackled by researchers: what are the characteristics and considerations to design a prosumer-centric energy trading with P2P, within multiple communities or a community, that will ensure sustainable commitment among the prosumers? Generally, a P2P trading platform is a trustless system, mainly due to the lack of a central controller for coordinating the trading [2]. Thus, encouraging prosumers to trust each other and ultimately collaborate to trade their energy resources with peers would be a huge challenge. On the other hand, due to the possible negative effect on their earning, power utility companies might not dare to take the risk in investing and kickstart P2P trading without a robust trading scheme and market-clearing mechanism.

In 2019, SEDA has initiated a pilot run of the P2P energy trading within a regulatory sandbox which was approved by the Energy Commission of Malaysia [23]. The regulatory sandbox allows prosumers to sell excess solar PV electricity to the power utility company, Tenaga Nasional Berhad's (TNB) consumers. Currently, TNBX Sdn. Bhd. a subsidiary company of TNB, has taken over the responsibility to further explore the P2P trading potential in Malaysia. Through a collaboration with TNBX, this paper proposes a motivational game theory-based two-stage P2P trading market-clearing strategy for multi-cities and intra-city in Malaysia. Furthermore, the proposed P2P market-clearing strategy is based on an auction, utilizing priority indices for prosumers matching, which is ideally tailored to maximize the Malaysian prosumers and the power system utility social welfare. Most of the research is done by prioritized the benefit on the prosumer side, which will directly reduce the income for power utility provider. Therefore, a price difference algorithm is implemented into the P2P trading system to minimize the loss of the power utility provider. Besides that, the bidding range is limited to a certain range and is further developed to avoid any bias towards buyers or sellers which will then create a win-win situation. To evaluate the performance of game theory in the P2P trading system, the result is compared to the current solar generation net metering business scheme (NEM) in Malaysia, and the potential and feasibility of the proposed solution for real-world implementation in Malaysia are investigated.

The rest of the paper is organized as follows. Section 2 introduces various P2P market schemes and the motivational psychology behind P2P trading. The motivational game-theory price scheme and problem formulation of the auction-based two-stage P2P market-clearing model are described in Section 3. Section 4 presents the test cases' numerical results and discussion. Finally, Section 5 concludes the paper.

2 | P2P MARKET SCHEME

Throughout the literature, there are a few configurations of P2P trading models, such as microgrid-to-microgrid P2P trading, intra-microgrid P2P trading, and peer-to-microgrid trading, which are summarized in Figure 1(a–c) and Table 1.

According to SEDA's first pilot project in 2019 [23], the P2P energy sharing concept used an interesting concept to share energy between peers and the main grid as shown in Figure 2(a). Generally, the concept involves four prosumers and eight commercial consumers in Klang Valley, Malaysia, where they are connected to the grid without a battery with a grid-connected solar system. If there is an energy surplus or deficiency after

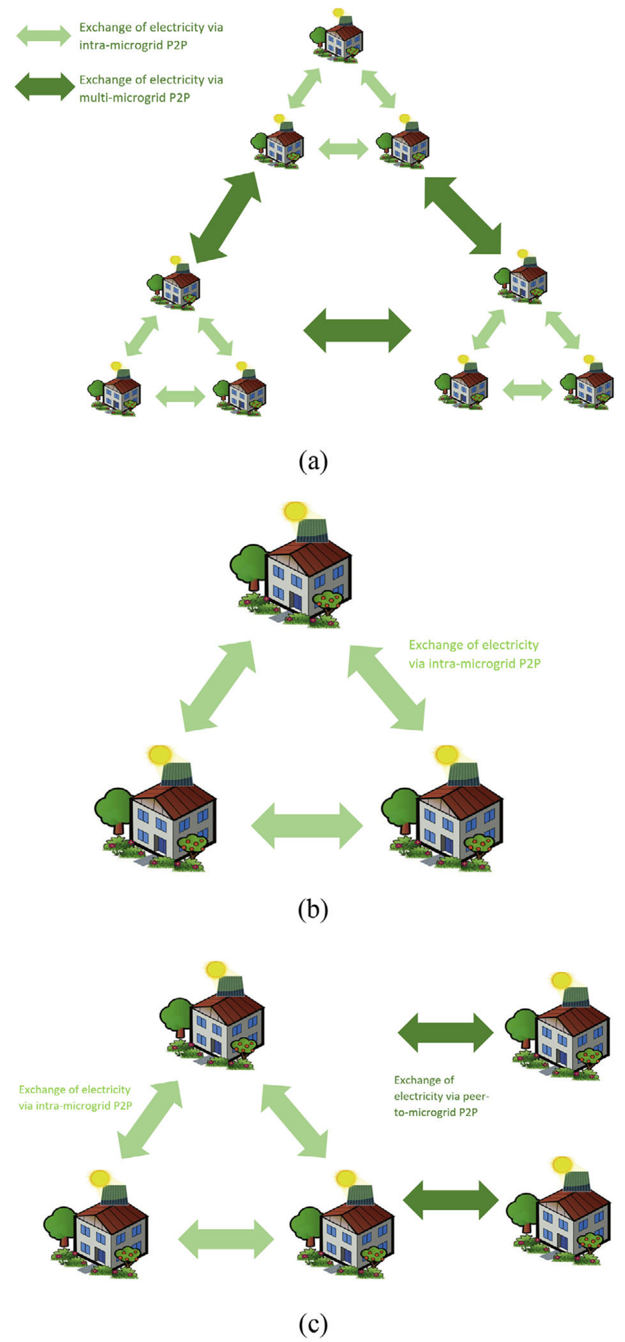

FIGURE 1 Different types of P2P trading scheme available in the literature [2]. (a) Microgrid-to-microgrid P2P, (b) intra-microgrid P2P, (c) peer-to-microgrid P2P

the market-clearing of P2P trading, the prosumer may further interact with the grid with the tariff price. In this paper, the P2P trading model is expanded into a two-stage model, where the first stage is the multi-cities P2P trading, as shown in Figure 2(b). In multi-cities P2P trading, it is assumed that there will be aggregators in each city to manage the energy trading, along with participation from large-scale solar farm generation companies. In the second stage, the intra-city P2P trading model will be implemented to trade energy between prosumers and power utility companies, as depicted in Figure 2(b). The key goal

TABLE 1 Summary of different types of P2P trading scheme available in the literature [2]

Type of P2P trading	Microgrid-to-microgrid P2P	Intra-microgrid P2P	Peer-to-microgrid P2P
Graphical illustration	As shown in Figure 1(a).	As shown in Figure 1(b).	As shown in Figure 1(c).
The general focus of the study	The difference between the supply and demand of energy in each microgrid is balanced via the energy trading between microgrids. This also improves the utilization of the collective renewable energy generation.	Modelling the market-clearing or decision-making process of exchanging energy between prosumers and consumers within a microgrid. This is done by coordinating the DERs to mitigate the fluctuation and unpredictability of renewable generation within the microgrid.	Long-term planning of connected industrial microgrids by coupling the decision of long-term investments and short-term operations.

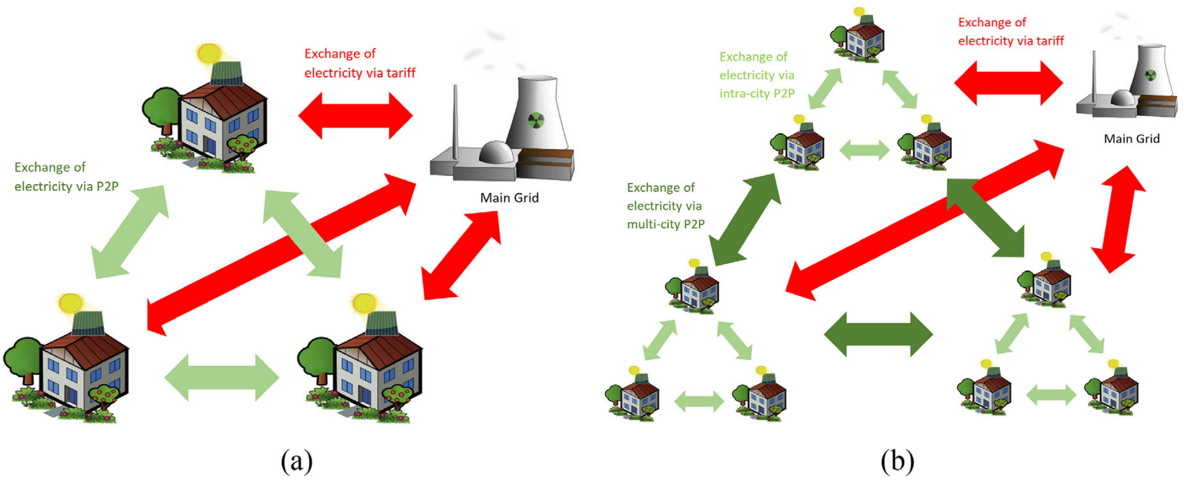

FIGURE 2 Various configurations of possible P2P trading in Malaysia. Intra-city peer-to-grid energy trading, (b) multi-cities to grid energy trading

is to encourage all peers to make a long-term commitment while retaining a reasonable profit for utility companies to fund the cost of service and maintenance.

Therefore, in order to achieve the above goal, cooperation and interaction among peers within energy networks are crucial. However, to achieve this level of participation, there are some qualities of the P2P trading mechanisms that need to be considered to motivate the prosumers to participate and engage in the trading. A motivational psychology framework can be used to increase the number of participants and motivate prosumers to participate in P2P trading, which is discussed in the next subsection.

2.1 | Motivational psychology

Motivation is a process that initiates, guides, and maintains goal-oriented behaviours. In daily life, motivation is frequently used to describe why a person does something. It is the driving force behind all human actions. Psychology is the science of behaviour and mind for understanding and solving problems, emotional factors of a situation, and mental characteristics of the attitude of a person or group. In short, motivational psychology is the science of behaviour and mind that drives us to behave in a particular way and achieve goals. It is identified as a new tool for designing P2P trading. Furthermore, how a motivational psychology framework can be used to motivate prosumers to participate in P2P trading is discussed in this subsection.

2.1.1 | Behaviour change

In general, participating in P2P trading does not drastically change human behaviour towards taking an action. In [2], the authors state that intentional behaviour change is a process occurring in a series of stages, as illustrated in Figure 3.

Based on the five stages of behaviour change, it shows that the development of a good motivational psychology model is crucial to motivate more prosumers to participate in P2P trading. However, the main challenge is to enable prosumer to pass through these motivational stages in order to have sustainable participation in P2P trading. Therefore, throughout the literature, several motivational models are proposed, which are described in the next subsection.

2.1.2 | Motivational psychology models

In order to have a thriving P2P trading platform, a large number of stage 5 prosumers are required in this process.

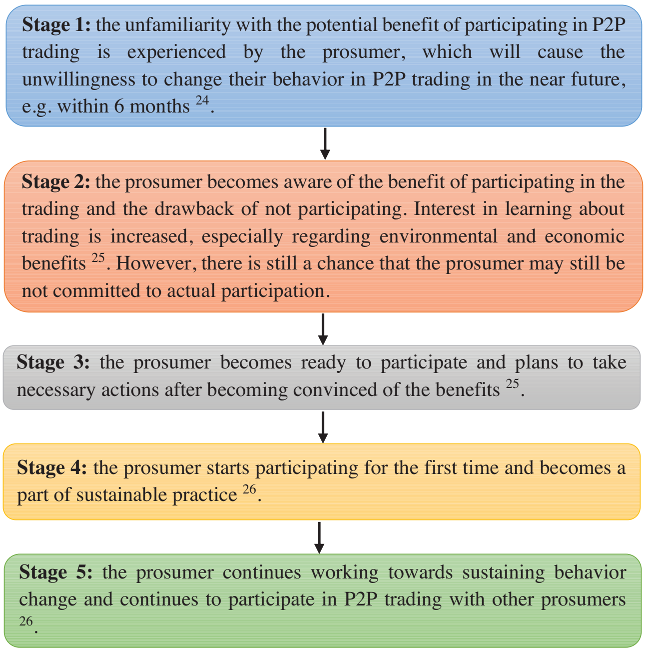

FIGURE 3 Summary of different stages that a prosumer need to pass through before agreeing to continue participating in P2P trading

TABLE 2 List of behavior models [2]

Informational model	• People will take appropriate measures to find a solution. • By providing useful information like economic profit and environmental benefit, people are motivated to participate in P2P trading.
Elaboration likelihood model	• People will search for expert information or act based on expert advice. • General information provided by utility companies (experts) about the P2P trading system will encourage people to think positively towards the project and hence take part in it.
Attitude model	• People act based on belief. • As long as environmentally-conscious people are convinced that the P2P trading system will reduce environmental pollution, they will participate in it.
Positive reinforcement model	• People act based on previous experience. • Through reward of lower electricity cost or additional income, there is a high chance that prosumers and consumers will participate in the P2P trading system again.
Rational-economic model	• People act based on benefit. • Monetary cost is the key motivator for prosumers to take part in P2P trading.

In motivational psychology, multiple models can be studied to motivate the user to adopt certain behaviours and continue to participate in P2P trading. Examples of such behaviour models are listed in Table 2 below.

TABLE 3 Different type of coalition game

Coalition graph game	• Investigates the properties such as efficiency and stability for the network form by players.
Coalition formation game	• Investigates the adaptability and properties of the structure from the formation of coalition structure through players' interaction.
Canonical coalition game	• Investigate the gains result from the coalition and method to distribute the gains in a fair manner.

3 | PROBLEM FORMULATION

3.1 | Game theory

A game theory is then introduced and applied to construct the P2P trading scheme, due to the energy trading process that required the users to be interactive. The purpose of game theory is to get the outcome of a player's action, depending on other players' actions. Game theory is the mathematical tool that analyses the competitive situation strategies [2]. Two types of game theory will be briefly explained below, which are non-cooperative game and cooperative game.

3.1.1 | Non-cooperative game

In general, a non-cooperative game deals with the situation when there is an absence of coalitions. Players are assumed to act independently without any collaboration or communication with other players. The most popular solution concept of the non-cooperative game is the Nash equilibrium. Basically, the Nash equilibrium can be described as a vector of action that leads a non-cooperative game to a stable state, in which no player can be better rewarded by arbitrarily deviating from its Nash equilibrium action while the actions of other players are according to the Nash equilibrium [2].

3.1.2 | Cooperative game

The cooperative game motivates players to cooperate and act as one to improve their benefit in the game. The purpose of the method is to observe the number of people that are willing to form a coalition (Nash bargaining) and the formation of coalitions (coalition game) [9]. Coalition game can be categorized into three categories as shown in Table 3:

In short, the effectiveness of energy management in the smart grid can be secured, by implementing the canonical coalition game in the proposed P2P trading system. The choice of the cooperative game is due to the benefit of P2P trading system, which requires the prosumers to work together to further reduce electricity cost and carbon dioxide (CO_2) emission. Furthermore, by using canonical coalition game, it is possible to understand if the participating prosumers can form a stable coalition with each other, which subsequently answers the question of whether the prosumers find it beneficial for them to remain in the coalition in order to participate in P2P trading [2].

As the proposed P2P trading scheme relies on a cooperative motivating game, prosumer have to work together as one to optimize the P2P trading price. Under the proposed P2P trading scheme, three separate scenarios are considered to determine the optimum hourly price for the procurement and selling of electricity. In each scenario, to encourage participation in P2P trading, higher priority will be given to trade electricity among prosumers, as opposed to trading with the power utility company, TNB.

3.2 | P2P trading price setting

Scenario 1: ($TE_t^s = TE_t^d$). In this scenario, the energy surplus is equal to the demand of prosumer, which indicates that it is sufficient for prosumers to consume it in the P2P trading system. Thus, prosumers only need to participate in P2P trading and do not need to trade energy with TNB. Based on the mid-market rate, the procurement and selling price in P2P trading system can be calculated through Equation (1).

$$P_{Buy,t}^{P2P} = P_{Sell,t}^{P2P} = \left(P_{Buy,t}^{TNB} + P_{Sell,t}^{TNB}\right)/2 \tag{1}$$

In this paper, a new tariff pricing is introduced for P2P trading system in Malaysia, for both multi-cities and intra-city energy trading. In summary, $P_{Buy,t}^{TNB}$ is set to RM0.40 per kWh, which is set based on the average tariff price for residential, commercial and industrial customers [24]. $P_{Sell,t}^{TNB}$ is set to RM0.20 per kWh, which indicates that the prosumers will sell the solar energy with the lowest price to the utility provider. Nevertheless, based on the mid-market pricing in Equation (1), $P_{Buy,t}^{P2P} = P_{Sell,t}^{P2P}$, both procurement and selling prices are set to RM0.30 per kWh.

Scenario 2: ($TE_t^s > TE_t^d$). For this scenario, energy generated by the prosumers who participated in P2P trading system is sufficient for all participants, while also having excess energy to sell off to TNB. The selling price will be tuned and charged according to the motivational cooperative game theory, as expressed in Equation (2), whereas $P_{Buy,t}^{P2P}$ remains the same as Scenario 1.

$$P_{Sell,t}^{P2P} = \left(P_{Buy,t}^{P2P} \times \sum_{i}^{I_b} E_{i,t}^d + P_{Sell,t}^{TNB} \times TE_t^s\right) / \sum_{i}^{I_s} E_{i,t}^s \tag{2}$$

Equation (2) will calculate the optimal selling price based on the amount of electricity surplus and deficiency to achieve a win-win situation for both parties in the P2P trading system. Besides that, the equation also follows the law of supply and demand. The selling price increase when the supply (electricity surplus) decreases and demand (electricity deficiency) increase.

Scenario 3: ($TE_t^s < TE_t^d$) In general, Scenario 3 is the opposite of Scenario 2, where the surplus energy from prosumers in the P2P trading system is only sufficient to fulfil the load demand for certain prosumers. As a result, some of the prosumers are expected to purchase energy directly from TNB. P_{Sell}^{P2P} will be similar as expressed in Scenario 1, whereas the P2P trading procurement price can be derived as:

$$P_{Buy,t}^{P2P} = \left(P_{Sell,t}^{P2P} \times \sum_{i}^{I_s} E_{i,t}^s + P_{Buy,t}^{TNB} \times TE_t^d\right) / \sum_{i}^{I_b} E_{i,t}^d \tag{3}$$

Equation (3) will calculate the optimal buying price based on the amount of electricity surplus and deficiency at any time t. Identical to Equation (2), when supply decrease and demand increase, the buying price will be reduced.

3.3 | Auction approach for P2P market clearing

After the P2P trading price scheme is set, an auction approach is hereby implemented to handle the transaction priority for prosumers during Scenario 2 and 3. Auction is defined as ‘a well-specified negotiation mechanism mediated by an intermediary that can be considered as an automated set of rules’ [25]. Besides that, with the consideration of computation tractability, the proposed auction-based P2P market-clearing problem is formulated into a linear programming (LP) model.

The proposed day-ahead auction-based P2P market-clearing problem is then expanded into a two-stage optimization problem, where the first stage is for clearing the P2P trading for multi-cities based on the forecasted load demand of each city, and the second stage is implemented for intra-city P2P trading. The schematic diagram in Figure 4, shows the flow of the proposed two-stage P2P trading framework. During the Data Preparation Stage, load demand and solar energy generated in the previous 24 h is collected. At 8:00 PM, based on the previous 24 h of the cities' hourly solar generation and load demand data, electricity surplus and deficiency are forecasted. Before 10:00 PM, prosumers are required to bid their buying price and selling price based on optimal pricing calculated from game theory. Next, the system will clear the day-ahead market in first stage and the results such as energy purchase from other cities ($TSE_{c,t}$), final buying price ($P_{Buy,t}^{Final,1st}$), and final selling price ($P_{Sell,t}^{Final,1st}$) are carried forward to the second-stage model. For second stage, the algorithm will solve for the market clearing for prosumer within the city. The P2P trading will start at 7:00 AM, then the online rolling real-time P2P market will be started, and final settlement of the transactions will be finalized at 7:00 PM. It is noted that the online rolling real-time P2P trading is out of the scope of this paper.

3.3.1 | Problem formulation for first stage market clearing

The day ahead auction-based P2P market-clearing for first stage, mainly deals with the multi-cities P2P trading, which can be

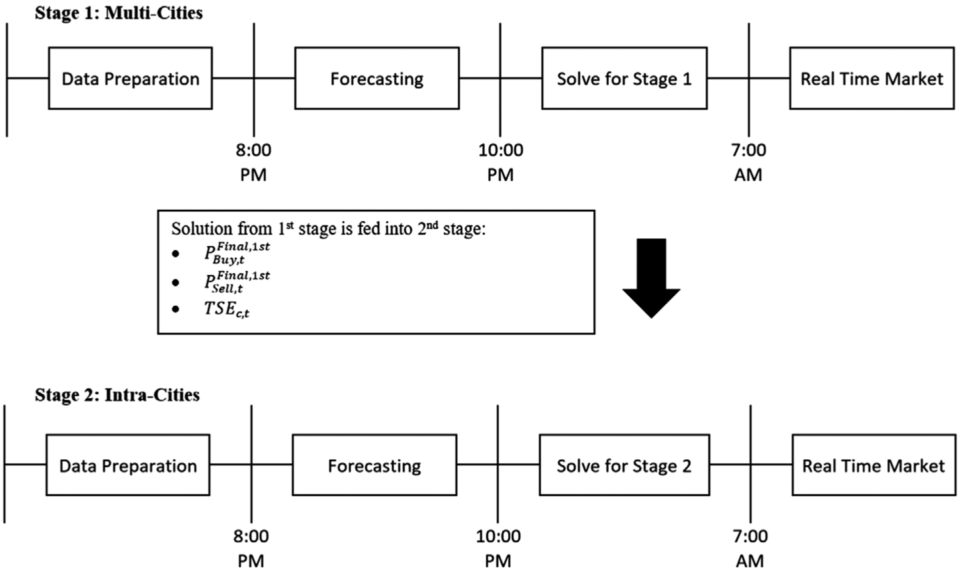

FIGURE 4 Proposed two-stage P2P trading framework

expressed as:

$$Min \sum_{n}^{C}\sum_{t}^{T}\left[\left(EP_{c,t}^{P2P}\times Q_{c,t}^{Buy}\right)+\left(ES_{c,t}^{P2P}\times Q_{c,t}^{Sell}\right)\right.$$
$$\left.+M\left(EP_{c,t}^{TNB}-ES_{c,t}^{TNB}\right)\right] \tag{4}$$

s.t.

$$Q_{c,t}^{Buy}=1-\left[P_{Buy,c,t}^{P2P}/\max\left(P_{Buy,c,t}^{P2P}\right)\right] \tag{5}$$

$$Q_{c,t}^{Sell}=P_{Sell,c,t}^{P2P}/\max\left(P_{Sell,c,t}^{P2P}\right) \tag{6}$$

$$\sum_{n}^{C}\sum_{t}^{T}\left[EP_{c,t}^{P2P}\right]=\sum_{n}^{C}\sum_{t}^{T}\left[ES_{c,t}^{P2P}\right] \tag{7}$$

$$EP_{c,t}^{P2P}+EP_{c,t}^{TNB}=TNL_{c,t} \tag{8}$$

$$ES_{c,t}^{P2P}+ES_{c,t}^{TNB}=TSE_{c,t} \tag{9}$$

An objective formulation for the first stage P2P market clearing is expressed in Equation (4), with the aim to maximize total social welfare for cities, is subjected to several constrains, which covers Equations (7)–(9). Due to the nature of an auction, the bidding prices are further normalized into priority indices, with a range from 0.0 to 1.0, through Equations (5) and (6). In general, since the objective function is formulated as a minimization problem, a transaction that is of higher priority will be indicated by a lower value in the priority index. Therefore, as shown in Equation (5), after the normalization process, the procurement priority is further inverted by subtracting $Q_{c,t}^{Buy}$ from 1.0. Alternatively, priority for trading with TNB, is set to a big positive number M, for example, a value of 10, indicating the lowest priority. Thus, the city can purchase excess energy from other cities before they purchase from TNB. In short, the purpose of the objective function is to match prosumers with consumers and minimize their electricity cost based on the pricing they bid.

Moreover, energy trading balance constraint in Equation (7), ensures that the amount of energy procurements and sales in P2P trading are equal for every time t. Through this constraint, the amount of electricity sold to P2P is guaranteed to be purchased by other prosumers. Net load balance constraint in Equation (8), and energy surplus balance constraint in Equation (9), are applied to ensure energy surplus and net load from the cities are cleared in the P2P energy market. In particular, Equation (8) is applied on every prosumer who is purchasing electricity, to ensure the total amount of electricity procured from P2P and TNB, is equal to the prosumer's load demand required at time t. Moreover, Equation (9) is applied on every prosumer who is selling electricity, to ensure that total electricity sold to P2P and TNB, is equal to the prosumer's excess electricity at time t. For simplicity, the transmission power losses are assumed to be negligible, as the excess energy will be utilized by nearby customers in the distribution system.

3.3.2 | Problem formulation for second stage market clearing

Furthermore, Equation (10) is the second-stage objective function, which is aimed to maximize the total social welfare for intra-city prosumers, where prosumers will be allowed to procure energy from other cities (from the first-stage model), as well as trade energy within the intra-city community, before trading with TNB. Identical to stage 1, the objective function's lower value in the priority index (calculated in Equations (11) and (12)) will have higher priority to trade.

$$Min \sum_{i}^{I}\sum_{t}^{T}\Big[\left(EP_{i,t}^{P2P}\times Q_{i,t}^{Buy}\right)+\left(ES_{i,t}^{P2P}\times Q_{i,t}^{Sell}\right) + M\left(EP_{i,t}^{TNB}-ES_{i,t}^{TNB}\right)+\left(EP_{i,t}^{eSurplus}\times\left(Q_{i,t}^{Buy}+1\right) - ES_{i,t}^{eSurplus}\times\left(Q_{i,t}^{Buy}+1\right)\right)\Big] \tag{10}$$

s.t.

$$Q_{i,t}^{Buy}=1-\left[P_{Buy,i,t}^{P2P}/\max\left(P_{Buy,i,t}^{P2P}\right)\right] \tag{11}$$

$$Q_{i,t}^{Sell}=P_{Sell,i,t}^{P2P}/\max\left(P_{Sell,i,t}^{P2P}\right) \tag{12}$$

$$\sum_{i}^{I}\sum_{t}^{T}EP_{i,t}^{P2P}=\sum_{i}^{I}\sum_{t}^{T}ES_{i,t}^{P2P} \tag{13}$$

$$EP_{i,t}^{P2P}+EP_{i,t}^{TNB}=TNL_{i,t} \tag{14}$$

$$ES_{i,t}^{P2P}+ES_{i,t}^{TNB}=TSE_{i,t} \tag{15}$$

$$\sum_{i}^{I}\sum_{t}^{T}EP_{i,t}^{eSurplus}\leq TSE_{c,t} \tag{16}$$

Similar to the first-stage model, the objective function in the second stage is also subjected to several constraints, such as energy trading balance constraint in Equation (13), net load balance constraint in Equation (14), and the energy surplus balance constraint in Equation (15). A new inequality constraint is added as Equation (16), which entails that the total energy surplus available in intra-city P2P trading, is capped at a maximum amount that procured from other cities, traded in the first stage model.

3.4 | Auction properties and rules

In general, buyers and sellers who participate in P2P trading system must follow specific rules set by the system operator. First, as discussed in Section 3.2, optimal pricing is obtained from the motivational cooperative game theory for day-ahead, and the range for bidding price will be set to ±20 % of the optimal price. In practice, the day ahead P2P trading will be fine-tuned with a real-time P2P trading model which is assumed to run for every 30 min interval, to schedule the procurement and sales with updated solar generation and load demand. However, the real-time model is out of the scope of this paper. Once the market starts, the final transaction price (P_{Buy}^{Final} and P_{Sell}^{Final}) for first and second stages will be calculated, by taking an average value of the bidding prices, as shown in Equations (17)–(20). The bidding prices by prosumers will be further converted into priority indices, as discussed in the P2P market-clearing problem formulation.

Furthermore, total daily energy settlement cost, SC_i for each prosumer, i is calculated with Equation (21). Profit of solar farm, $profit^{Solar}$ can be calculated by using Equation (22). In contrast, TNB is assumed to earn 15% from P_{Buy}^{TNB} for each kWh sold to customers, RM 0.20 per kWh (P_{Buy}^{TNB} - P_{Sell}^{TNB}) for energy obtained from intra-city and solar farms (assuming TNB sells all the energy with RM 0.40 to other customers), as well as the price difference between P_{Buy}^{Final} and P_{Sell}^{Final} from the first and second stages of the P2P market-clearing model. In brief, total daily profit earned by TNB, $profit^{TNB}$, is expressed in Equation (23).

$$P_{Buy,t}^{Final,1st}=\left(\sum_{c}^{C}P_{Buy,c,t}^{P2P}\right)/C \tag{17}$$

$$P_{Sell,t}^{Final,1st}=\left(\sum_{c}^{C}P_{Sell,c,t}^{P2P}\right)/C \tag{18}$$

$$P_{Buy,t}^{Final,2nd}=\left(\sum_{i}^{I}P_{Buy,i,t}^{P2P}\right)/I \tag{19}$$

$$P_{Sell,t}^{Final,2nd}=\left(\sum_{i}^{I}P_{Sell,i,t}^{P2P}\right)/I \tag{20}$$

$$SC_i=\sum_{t}^{T}\Big[\left(EP_{i,t}^{P2P}\times P_{Buy,t}^{Final,2nd}\right)-\left(ES_{i,t}^{P2P}\times P_{Sell,t}^{Final,2nd}\right) + \left(EP_{i,t}^{TNB}\times P_{Buy,t}^{TNB}\right)-\left(ES_{i,t}^{TNB}\times P_{Sell,t}^{TNB}\right) + \left(EP_{i,t}^{eSurplus}\times P_{Buy,t}^{Final,1st}\right)-\left(ES_{i,t}^{eSurplus}\times P_{Sell,t}^{Final,1st}\right)\Big] \tag{21}$$

$$profit^{Solar}=\sum_{c}^{C}\sum_{t}^{T}\Big[\left(TP_{c,t}^{eSurplus}\times P_{Buy,t}^{Final,2nd}\right)+\left(TS_{t}^{TNB}\times P_{Sell,t}^{TNB}\right)\Big] \tag{22}$$

$$profit^{TNB}=\sum_{i}^{I}\sum_{c}^{C}\sum_{t}^{T}\Big[\left(TT_{C,t}^{P2P}\times\left|P_{Buy,t}^{Final,1st}-P_{Sell,t}^{Final,1st}\right|\right) + \left(TT_{I,t}^{P2P}\times\left|P_{Buy,t}^{Final,2nd}-P_{Sell,t}^{Final,2nd}\right|\right) + \left(EP_{i,c,t}^{TNB}\times P_{Buy,t}^{TNB}\times 0.15\right)+\left(ES_{i,c,t}^{TNB}\times 0.2\right) + \left(ES_{c,t}^{TNB}\times(0.2)\right)\Big] \tag{23}$$

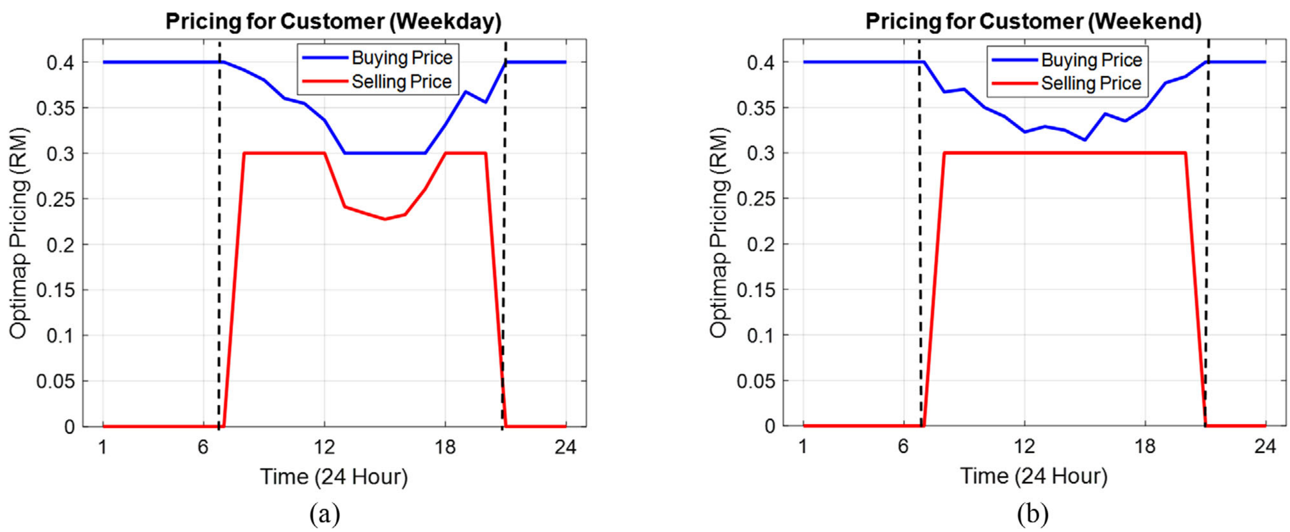

FIGURE 5 Optimal P2P temporal price curve. (a) For weekdays. (b) For weekends

4 | NUMERICAL RESULT

In this section, numerical results are simulated under two test cases, Case 1: P2P trading within a community or city, Case 2: P2P trading throughout multiple cities (two-stage P2P trading). The proposed auction-based two-stage P2P market-clearing problem is executed on a 2.80 GHz Intel Core i7 workstation with 8GB RAM, coded in C++, and solved with IBM CPLEX Optimizer.

4.1 | Optimal P2P price based on motivational cooperative game theory

As shown in the previous section, three possible scenarios will result in three possible sets of pricing for each hour. In this paper, two temporal price curves are considered for numerical results simulation, which are weekdays and weekends hourly price curves, as depicted in Figure 5. Through observation of the two price curves, during non-sunshine hours, as there is no energy generated by the prosumer, the P2P trading system will be shut down during these periods. Thus, prosumer only can obtain energy from TNB, and the optimal pricing will be P_{Buy}^{TNB}.

4.2 | Case 1: Intra-microgrid P2P trading

To simulate a small community for intra-microgrid trading, the community is set to have consisted of 20 prosumers. Only stage 2 of the P2P trading is considered in this test case. All prosumers are assumed to have eight solar PV panels with 72 cells, which are capable of generating 3.24 kWp of renewable energy. Solar generation and various load demand curves for different types of prosumers (high middle-, middle- and low middle-income residents, shop lots, and restaurants), can be obtained from [26]. In Case 1, high middle-income residents are labelled as prosumers 1–5, middle-income residents are labelled as prosumers 6–9, lower middle-income residents are labelled as prosumers 10–14, shop lots are labelled as prosumers 15–17, and restaurants are labelled as prosumers 18–20. For the ease of analysis, prosumers 1–3 and prosumers 10–12 are set to have the highest priority to buy and sell energy.

Based on the result in Table 4, it shows that in Scenario 2, prosumers 10–12 have the highest priority to sell excess energy to the P2P trading system, and they can avoid selling electricity to TNB at a lower tariff price. While in Scenario 3, as shown in Table 5, prosumers 1–3 have higher priority than other prosumers, thus they can avoid procurement of energy from TNB at a higher tariff price. This proves the efficiency of the proposed P2P price scheme and model in handling the energy transactions within the intra-city environment.

In general, NEM is a solar PV initiative that was introduced by SEDA in 2019, which adopts the true net energy metering concept and this will allow excess solar energy generated from prosumers' PV panels to be exported back to the grid on a "one-on-one" offset basis [27]. As a smart prosumer they would not install capacity that more than their demand as they got not additional reward by exporting excess electricity back to utility company. Therefore, it is assumed that prosumers who participate in NEM will only install sufficient PV generation, up to the amount that capable of fully compensate their electricity bill. Whereas, "normal" is the system that calculates the cost based on conventional tariff [24]. To further investigate the practicability of the proposed P2P price scheme, a one-month simulation is done to compare the proposed motivational game theory price scheme with NEM and normal tariff. The monthly electricity cost and saving for each prosumer in Case 1, are depicted in Figures 6 and 7, respectively, which shows that by utilizing the proposed P2P trading system, electricity costs of prosumers are reduced with higher percentage, as compared to NEM. This is mainly due to the proposed P2P trading system allows prosumers to sell off their hourly excess energy, with an

TABLE 4 Transaction result for prosumers in Case 1 for weekday at Hour 14

	Weekday hour 14					
	P2P				TNB	
Prosumer	Buy from (kWh)	Priority	Sell To (kWh)	Priority	Buy from (kWh)	Sell to (kWh)
1	0.00	0	0.00	7	0.00	1.10
2	0.00	0	0.00	12	0.00	1.10
3	0.00	0	0.00	13	0.00	1.10
4	0.00	0	0.00	9	0.00	1.10
5	0.00	0	0.00	11	0.00	1.10
6	0.00	0	0.00	4	0.00	2.00
7	0.00	0	0.00	6	0.00	2.00
8	0.00	0	0.00	10	0.00	2.00
9	0.00	0	0.00	8	0.00	2.00
10	0.00	0	2.77	1	0.00	0.00
11	0.00	0	2.77	2	0.00	0.00
12	0.00	0	1.96	3	0.00	0.81
13	0.00	0	0.00	5	0.00	2.77
14	0.00	0	0.00	14	0.00	2.77
15	1.00	6	0.00	0	0.00	0.00
16	1.00	3	0.00	0	0.00	0.00
17	1.00	1	0.00	0	0.00	0.00
18	1.50	2	0.00	0	0.00	0.00
19	1.50	4	0.00	0	0.00	0.00
20	1.50	5	0.00	0	0.00	0.00

TABLE 5 Transaction result for prosumers in Case 1 for weekend at Hour 18

	Weekend hour 18					
	P2P				TNB	
Prosumer	Buy from (kWh)	Priority	Sell to (kWh	Priority	Buy from (kWh)	Sell to (kWh)
1	1	1	1	1	1	1
2	5.33	2	0.00	0	0.00	0.00
3	1.05	3	0.00	0	4.28	0.00
4	0.00	12	0.00	0	5.33	0.00
5	0.00	9	0.00	0	5.33	0.00
6	0.00	8	0.00	0	2.33	0.00
7	0.00	11	0.00	0	2.33	0.00
8	0.00	6	0.00	0	2.33	0.00
9	0.00	7	0.00	0	2.33	0.00
10	0.00	0	1.46	1	0.00	0.00
11	0.00	0	1.46	2	0.00	0.00
12	0.00	0	1.46	3	0.00	0.00
13	0.00	0	1.46	5	0.00	0.00
14	0.00	0	1.46	8	0.00	0.00
15	0.00	0	1.47	7	0.00	0.00
16	0.00	0	1.47	4	0.00	0.00
17	0.00	0	1.47	6	0.00	0.00
18	0.00	5	0.00	0	5.33	0.00
19	0.00	4	0.00	0	5.33	0.00
20	0.00	10	0.00	0	5.33	0.00

average higher price. Furthermore, it also enables certain prosumers with lower electricity consumption to make a profit. As shown in Figure 6, prosumers 10–14 earn an additional income of RM 81 (average).

It is clearly observed that applying either NEM or P2P trading system would still yield the same result where the profit gained by TNB is decreased as shown in Table 6. This is because prosumers procure less energy from TNB after participating in NEM or P2P trading system, as they have solar panels to generate energy for their own use. However, the difference between profit by TNB obtained through NEM and P2P trading system is negligible, which demonstrates the practicability of the proposed P2P price scheme. The reason that prosumer using NEM will lead to higher electricity costs is because NEM will take excess electricity generated by prosumers for free. On other hand, the amount of CO_2 emission shows a significant reduction in NEM and P2P trading system, since less energy had to be generated through fossil fuels. Interestingly, implementing the P2P trading system can further reduce CO_2 emission compared to NEM, as shown in Table 7. The relationship between electricity and CO_2 emission can be calculated by multiplying the electricity generated with a coefficient of 0.00069 [28].

TABLE 6 Expected profit gained by TNB in Case 1

	Expected profit (RM)			Decrement (%)	
	Normal	NEM	P2P	NEM	P2P
TNB	2,138.39	1,377.39	1,408.17	35.59%	34.15%

4.3 | Case 2: Trading within multiple city

In this test case, the proposed two-stage P2P trading optimization problem will be tested under a multi-cities' environment with a new set of data, where the first stage is used to optimize the energy trading between the cities, while the second stage is similar to Case 1, which is for intra-city simulation, as discussed in Section 3. Generally, the multi-cities environment is modelled based on five cities in Malaysia near the capital of Malaysia, Kuala Lumpur, as listed in Table 8. Two solar farms are available in Ipoh and Klang, which are capable of generating up to 25,000 and 30,000 kWh per day, respectively. The energy generated from the solar farms are prioritized for prosumers in Ipoh and Klang respectively before selling to other cities. Furthermore, each city is assumed to have 50% prosumers (with solar generation) and 50% consumers (without solar generation).

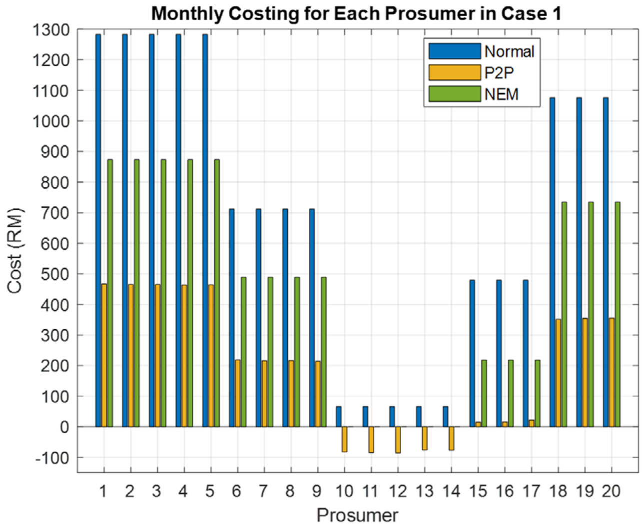

FIGURE 6 Monthly costing for each prosumer Case 1

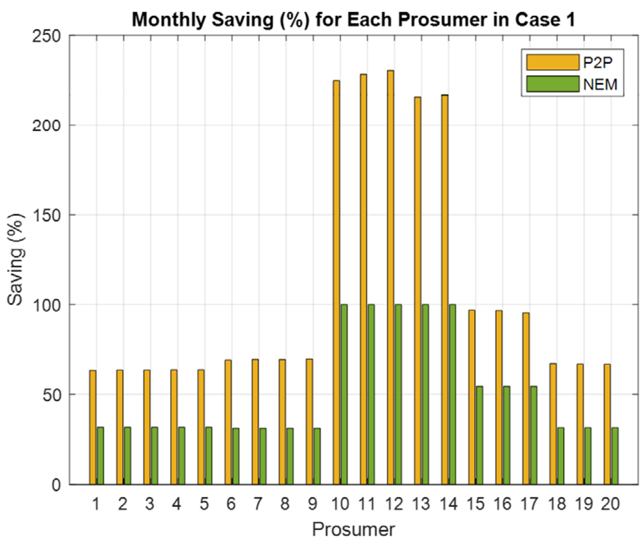

FIGURE 7 Monthly saving for each prosumer in Case 1

For ease of labelling, prosumers 1, 3, 5, 7, 9, 11 are upper-income family, middle-income family, low-income family, shopping mall, restaurant, and industrial company with solar generation, while consumers 2, 4, 6, 8, 10, 12 are upper-income family, middle-income family, low-income family, shopping mall, restaurant, and industrial company, which did not participate in the P2P Trading System and therefore cannot trade with peers.

TABLE 7 Carbon dioxide reduction in Case 1 [26]

	Electricity generated (kWh)	Carbon dioxide (Tonne) Emission	Reduction	Saving (%)
Normal	28,229.00	19.59	–	–
P2P	15,647.80	10.86	8.73	44.56%
NEM	17,425.00	12.09	7.50	38.28%

Table 8 shows the costing and saving for each city that participated in the P2P trading system. From the result, it is clearly shown that all cities have an average of 24.36% saving per month. Since Subang Jaya, Kuala Lumpur and Petaling Jaya do not have nearby solar farms for their own use, these cities can bid the price to buy energy from other cities' solar farms. Identical to Case 1, all these cities also have the priority to purchase energy from the solar farm. After solving the first-stage multi-cities model, the energy purchase from other cities will be labelled as $TES_{c,t}$. In the second stage, all prosumers can buy the energy ($TES_{c,t}$) at the hourly final procurement price, which was set in the first stage. In contrast, the solar farm will receive its revenue from the hourly final selling price set in the first stage.

Moreover, Tables 9 and 10 show the savings or revenue received by prosumers and solar farms after participating in the proposed two-stage P2P trading framework. Table 9 clearly shows that participating in the P2P trading system will contribute to at least 34% saving per month for prosumers. The main reason for this is the purchase of much cheaper energy compared to the TNB tariff. Table 10 shows that solar farms participating in the P2P trading system will have an increment in an average profit of 59.83%. This is due to the flexibility of P2P trading, as solar farms can sell to prosumers with P2P temporal price, instead of the fixed price of RM 0.18 kWh to TNB [29]. Although in the proposed P2P trading system, the selling price to TNB is set at a higher rate of RM 0.20 kWh, most of the time, the energy demand from cities is usually greater than the solar farms' excess energy. Thus, solar farms can sell most of their energy to P2P trading instead of to TNB. Nonetheless, as explained in Equation (24), TNB will profit from the price difference trading between multi-city and prosumers in intra-city, 15% of the cost from energy bought by prosumer from TNB, and RM 0.20 kWh from energy sold by prosumers and solar farms to TNB. Table 11 lists out the profit earned by TNB, which shows a similar pattern as in Case 1. There is a slight decrease in profit, but this might be compensated by the relief of congestion of power flow in certain distribution areas, which may delay the need for distribution line expansion in the near future. This is out of the scope of this paper, and will be covered in future work in collaboration with TNBX. Finally, Table 12 shows the CO_2 emission for normal tariff and P2P trading, as expected, the P2P trading manage to reduce the CO_2 emission, by generating more energy from renewable solar generation.

4.4 | Discussion from motivational psychology perspective

Nevertheless, based on the results in Case 1 and 2, the proposed two-stage P2P trading model is evaluated based on the ability in fulfilling the motivational psychology models described in Section 2.1. Results proved that it satisfies all the described motivational models as follows:

TABLE 8 Total trade amount and cost for each city in Case 2

City	Total electricity trade (kWh) P2P Buy	P2P Sell	TNB Buy	TNB Sell	Total cost (RM) With P2P	Without P2P	Saving
Subang Jaya	154,349.00	0.00	1,200,240.00	0.00	574,517.14	704,823.63	18.49%
Kuala Lumpur	219,555.00	0.00	1,135,200.00	0.00	522,704.99	704,909.63	25.85%
Ipoh	0.00	230,901.00	852,675.00	17,346.90	531,384.56	704,739.63	24.60%
Petaling Jaya	209,611.00	0.00	1,144,620.00	0.00	522,136.46	704,637.63	25.90%
Klang	0.00	352,613.00	813,692.00	6,525.60	514,935.81	704,805.63	26.94%

TABLE 9 Saving for each prosumer or consumer in cities in Case 2

Prosumer or consumer	Subang Jaya Cost (RM)	Subang Jaya Saving	Kuala Lumpur Cost (RM)	Kuala Lumpur Saving	Ipoh Cost (RM)	Ipoh Saving	Petaling Jaya Cost (RM)	Petaling Jaya Saving	Klang Cost (RM)	Klang Saving
1	275.75	34.97%	212.01	50.00%	211.74	50.07%	219.71	48.19%	202.97	52.13%
2	424.04	–	424.04	–	424.04	–	424.04	–	424.04	–
3	114.74	65.51%	87.11	73.82%	86.75	73.92%	87.65	73.65%	86.09	74.12%
4	332.70	–	332.70	–	332.70	–	332.70	–	332.70	–
5	31.43	75.32%	24.55	80.72%	25.15	80.25%	25.71	79.82%	25.20	80.21%
6	127.36	–	127.36	–	127.36	–	127.36	–	127.36	–
7	1,637.31	47.00%	1,390.99	54.97%	1,390.12	55.00%	1,497.45	51.52%	1,193.08	61.38%
8	3,088.98	–	3,088.98	–	3,088.98	–	3,088.98	–	3,088.98	–
9	1,687.09	45.40%	1,372.52	55.58%	1,374.88	55.50%	1,472.22	52.35%	1,202.66	61.08%
10	3,089.74	–	3,089.74	–	3,089.74	–	3,089.74	–	3,089.74	–
11	218,359.00	36.77%	167,163.00	51.60%	166,729.00	51.71%	175,712.00	49.11%	159,823.00	53.72%
12	345,349.00	–	345,392.00	–	345,256.00	–	345,307.00	–	345,340.00	–

1. Informational model: By accommodating prosumers with proper information on environmental benefit and economical profit, which is proven from the numerical results of P2P trading, prosumers can be encouraged to take part in the process, which adheres to the information model.
2. Elaboration likelihood model: Since the technical details on how the P2P trading can be performed is hard to be interpreted by prosumers generally, the advantages such as electricity bill reduction and environmental sustainability can be easily exploited to encourage prosumers to participate in the trading process. Based on the advantages mentioned above which prosumers really care about, peripheral route processing can help users to be an essential part of P2P trading.
3. Attitude model: The result of P2P trading also reinforces the attitude model, as the designed system shows a steady performance of CO_2 emission reduction, which might potentially be able to convince environment-conscious prosumers to participate in P2P trading.
4. Positive reinforcement model: Numerical results point out a steady performance of monthly profit and CO_2 emission

TABLE 10 Profit for solar farm in Case 2

Solar farm	With P2P trading system: Total sell to P2P (kWh)	Total sell to TNB (kWh)	Profit (RM)	Without P2P trading system: Sell to TNB (kWh)	Profit (RM)	Increment
Solar Farm 1	230,901.00	17,346.90	70,647.80	248,247.90	44,684.62	58.10%
Solar Farm 2	352,613.00	6,525.60	104,440.00	359,138.60	64,644.95	61.56%

TABLE 11 Profit for TNB in Case 2

	Profit (RM)		Decrement (%)
	Normal	P2P	P2P
TNB	528,587.42	413,545.53	21.76%

TABLE 12 Carbon dioxide reduction in Case 2

		Carbon dioxide (Tonne)		
	Electricity generated (kWh)	Emission	Reduction	Saving (%)
Normal	5,729,942	3953.66	–	–
P2P	5,146,427	3551.03	402.63	10.18%

reduction when prosumers participate in P2P trading. The proposed P2P trading scheme satisfies the definition of the model (described in Section 2.1.2) and accommodates prosumers to grow as far as Stage 5 participants.

5. Rational-economic model: The benefit of P2P trading in terms of cost-saving per prosumer in Figures 6 and 7, will definitely become the key motivator for more prosumers to participate in the P2P trading, as it satisfies the rational-economic model.

5 | CONCLUSION

The deep transformation trend towards decarbonisation is characterized by integrating increased proportions of renewable generation into the grid system, which leads to the growth of interests in P2P energy trading in both industrial and academia. This paper proposes a market platform for P2P trading, formulated in an auction-based market-clearing model, with a price scheme that is derived from motivational cooperative game theory. A multi-cities and intra-city model have been proposed, formulated in a two-stage P2P market clearing problem, which aims to maximize the total social welfare of all parties. The bidding from both prosumers and consumers will be further converted to priority indices, for matching between buyers and sellers in the P2P trading. Nonetheless, numerical results confirm that the proposed P2P trading can benefits prosumers, consumers, and power utility company, at the same time encouraging prosumers to utilize more renewable energy, thus further lowering the pollution index through the reduction of CO_2 emission. For future work, experimental and hardware-in-the-loop (HIL) setup and simulation, can be further explored on the impact of P2P trading on the network congestion in Malaysia, by inserting the network constraints into the optimization model. Facilities such as a home-based battery, centralized energy storage, as well as electric vehicle charging stations, can also be included in the P2P transactive energy market, as technologies are expected to be available in Malaysia in the foreseeable future.

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MUM ASEAN Research Grant.

Nomenclature

$EP_{i,t}^{P2P}$	Energy procurement from P2P trading [kWh]
$EP_{i,t}^{TNB}$	Energy procurement from TNB [kWh]
$EP_{i,t}^{eSurplus}$	Energy procurement from other city [kWh]
$EP_{i,c,t}^{TNB}$	Energy procurement from TNB city c [kWh]
$ES_{i,c,t}^{TNB}$	Energy sell to TNB in city c [kWh]
$ES_{i,t}^{P2P}$	Energy sell to P2P trading [kWh]
$ES_{i,t}^{TNB}$	Energy sell to TNB [kWh]
$ES_{i,t}^{eSurplus}$	Energy sell to other city [kWh]
$EP_{c,t}^{P2P}$	Energy procurement from P2P trading [kWh]
$EP_{c,t}^{TNB}$	Energy procurement from TNB [kWh]
$ES_{c,t}^{P2P}$	Energy sell to P2P trading [kWh]
$ES_{c,t}^{TNB}$	Energy sell to TNB for city [kWh]
$TP_{c,t}^{eSurplus}$	Total energy procurement from other city [kWh]
$profit^{Solar}$	Total profit by solar farm [RM]
$profit^{TNB}$	Total profit by TNB [RM]
SC_i	Energy settlement cost for each prosumer
TS_t^{TNB}	Total energy sells to TNB at time t [kWh]
$TT_{I,t}^{P2P}$	Total energy trade in intra-city P2P trading system at time t [kWh]
$TT_{C,t}^{P2P}$	Total energy trade in multi-cities P2P trading system at time t [kWh]
$E_{i,t}^{s}$	Energy surplus for each prosumer i [kWh]
$E_{i,t}^{d}$	Energy deficiency for each prosumer i [kWh]
$P_{Buy,t}^{P2P}$	Procurement price from P2P trading [RM]
$P_{Sell,t}^{P2P}$	Selling price to P2P trading [RM]
$P_{Buy,i,t}^{P2P}$	Procurement price from P2P for prosumer i [RM]
$P_{Sell,i,t}^{P2P}$	Selling price to P2P for prosumer i [RM]
$P_{Buy,c,t}^{P2P}$	Procurement price from P2P for city c [RM]
$P_{Sell,c,t}^{P2P}$	Selling price to P2P for city c [RM]
$P_{Buy,t}^{TNB}$	Procurement price from TNB [RM]
$P_{Sell,t}^{TNB}$	Selling price to TNB [RM]
$P_{Buy,t}^{Final,1st}$	Final procurement price set in first stage [RM]
$P_{Sell,t}^{Final,1st}$	Final selling price set in first stage [RM]
$P_{Buy,t}^{Final,2nd}$	Final procurement price set in second stage [RM]
$P_{Sell,t}^{Final,2nd}$	Final selling price set in second stage [RM]
$Q_{i,t}^{Buy}$	Procurement priority index for prosumer i
$Q_{i,t}^{Sell}$	Selling priority index for prosumer i
$Q_{c,t}^{Buy}$	Procurement priority index for city c

$Q^{Sell}_{c,t}$ Selling priority index for city c
TE^{s}_{t} Total energy surplus [kWh]
TE^{d}_{t} Total energy deficiency [kWh]
$TNL_{i,t}$ Total net load for prosumer i [kW]
$TNL_{c,t}$ Total net load for city c [kW]
$TSE_{i,t}$ Total energy surplus for prosumer i [kWh]
$TSE_{c,t}$ Total energy surplus for city c [kWh]
I_b Sets of buyers within P2P trading system
I_s Sets of sellers withing P2P trading system
Continuous decision variables for city c at time t
Continuous decision variables for prosumer i at time t
M A big positive number
Others continuous decision variable
Parameters
Parameters at time t

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