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Developing Peer-to-Peer (P2P) Energy Trading Model for Malaysia: A Review and Proposed Implementation

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ABSTRACT A decade ago, Malaysia introduced the Renewable Energy Act 2011. This led to the RE proliferation, especially with the adoption of solar photovoltaics as an alternative energy source for prosumers to generate green energy and reduce their energy costs. Since then, the RE policies have evolved with the introduction of feed-in tariff (FiT) and various version of Net Energy Metering (NEM) schemes. Such initiatives may not be holistic enough to benefit all stakeholders; thus, Malaysia introduced its first pilot P2P energy trading in 2019. However, there was no significant progress to the P2P pilot thereafter, with a Go-to-Market plan. As such, this review proposes a model for P2P energy trading for Malaysia based on several key success factors including the market design, trading mechanism, physical and virtual infrastructure, policy and governance and social. Malaysia's electricity market structure is also compared to South Korea, Germany, Thailand, United Kingdom, and Singapore (ranked in the top 20 Ease of Getting Electricity by World Bank in 2019) to understand the implication of P2P energy trading adoption. Apart from that, this paper also highlights the key technical and non-technical reviews of the P2P energy trading implementation.

INDEX TERMS Electricity market structure, energy trading, peer-to-peer, trading mechanism.

I. INTRODUCTION

According to the Third Biennial Update Report from Malaysia to the United Nations Framework Convention on Climate Change (UNFCCC) in December 2020, Malaysia focuses on energy, industrial processes and product use (IPPU), agriculture, land use, land use change, and forestry (LULUCF), and waste sectors to mitigate greenhouse gas emissions [1]. The largest source of carbon dioxide emissions in Malaysia in 2016 was the electricity and heat production sector at 103.047 million tonnes of CO_2 (39%) out of a total of 263.577 million tonnes of CO_2. This was followed by emission from the road transportation at 55.188 million tonnes of CO_2 (21%). Manufacturing industries and construction were the third largest contributors to CO_2 emissions at 23.856 million tonnes of CO_2 (9%). As the electricity sector

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plays a major role in contributing to carbon footprint reduction, it is key that the energy generation becomes increasingly sustainable. The energy trilemma highlights the need for an energy supply that is sustainable, secure, and affordable [2]. This led to countries moving towards energy transition plans by focusing on renewable energy (RE) generation and net zero carbon emissions. The impact of increasing RE generation from the FiT program, hydropower, and other public RE licenses coupled with energy efficiency adoption contributed to CO_2 emission avoidance of 7.72 million tonnes CO_2 eq. in 2016 [1].

As global warming issues are alarming, countries are adopting sustainability measures in their energy policies. Malaysia developed its energy policy after the oil crisis that occurred in 1973 and 1979 [3]. Subsequently, the focus was on oil and natural gas as the primary sources to secure the nation's energy requirements. Over the years, the energy policy was revised and diversified to include other energy

sources such as hydro, coal, and RE. In the last decade, there has been an increasing emphasis on renewable energy adoption and advancement. Electricity is no longer produced by conventional large fossil fuel generators, but also from distributed generators. Consumers are evolving to become prosumers (producers and consumers) and potentially becoming prosumagers (producers, consumers, and energy storage) in the near future [4]. The increasing affordability and availability of RE generators such as solar photovoltaics (PV) has led to energy decentralization and further decarbonization.

This is clearly seen in the introduction of the Renewable Energy Act 2011, which was formulated and approved by the Malaysian Government [5], [6]. The implementation of the RE Act 2011 has given a huge boost to the adoption of RE sources such as solar, biomass, and biogas. It also entails the establishment and implementation of a feed-in tariff (FIT) to catalyze the generation of renewable energy. The initial rates for FIT holders were very attractive, especially for solar PV owners with a starting rate of RM 1.23/kWh. Through the RE Act of 2011, the RE fund was established to support the FIT implementation, whereby 1.6% surcharge from the existing electricity bills are collected from all electricity users in Malaysia to support the fund. Parallel to this, the Government had also introduced the Green Technology Financing Scheme (GTFS) in 2010 to financially support the manufacturer as well as adopters of green technology.

As the RE fund was depleting over time, the FIT was phased out, and this led to the introduction of net energy metering (NEM) in 2016 [7]. NEM adopts the concept of using the local RE first, before excess energy is sold to the power off-taker at a displaced cost. This scheme is deemed less attractive because the displaced cost is far lower than the prevailing tariff: RM 0.31/kWh for low-voltage (LV) grid-connected customers and RM 0.238/kWh for medium-voltage (MV) customers. In 2018, the second version of the NEM scheme (NEM 2.0) was launched to provide better returns to prosumers [7]. Through this improvised scheme, all excess energy is now being offset on a 1-on-1 basis with the energy consumed from the grid. Its commercial value is higher than the displaced cost set in the original NEM, especially for prosumers with high electricity bills. Quotas of NEM 2.0, were offered since January 2019, and these quotas were all filled by the end of 2020. Due to the overwhelming response and take-up rate of NEM 2.0, the Malaysian government launched NEM 3.0 in December 2020, to enable customers to opt for renewable energy from solar PV and other RE generators that will provide them with savings on their electricity bills [8]. This was an additional 500 MW of quota offered to soon-to-be prosumers.

The NEM quota was limited to a certain extent, and thus, there was a need for a wholesome mechanism that will further drive the growth of renewable energy in Malaysia. This led to the introduction of P2P energy trading piloted under the regulatory sandbox by Sustainable Energy Development Authority (SEDA) in Malaysia in 2019 [9]. However, after the end of the P2P energy trading pilot, there was no specific continuation for P2P energy trading to be developed further in Malaysia. Hence, an in-depth research is required to provide a better understanding of the electricity market structure and several focus areas of P2P energy trading [10] in Malaysia before a suitable model can be developed effectively.

This study benchmarks the P2P energy trading initiatives in countries such as South Korea, Germany, Thailand, the United Kingdom, and Singapore (which are ranked top in terms of ease of getting electricity by World Bank in 2019 [11]) with Malaysia. A thorough review was conducted on the pilot P2P in these countries and the challenges faced.

Several key contributions are made in this paper. This paper:

a) Highlighted the various electricity market structure in comparison to Malaysia in adopting P2P energy trading. The electricity market structures were correlated to the P2P energy trading adoption, where fully liberalized markets experienced faster adoption and with more pilots taking place.

b) Reviewed the challenges and issues in implementing P2P energy trading for selected countries (South Korea, Germany, Thailand, the United Kingdom, and Singapore). The comparison made between these countries includes the technical and non-technical aspects.

c) Proposed a novel P2P energy trading model for Malaysia based on the key attributes and success factors of P2P energy trading. The proposal will serve as a good fundamental for further research including areas such as market design, trading mechanism, physical and virtual infrastructure, policy and governance and social.

This paper is organized as follows: Section II describes the various energy market structures and reviews the P2P pilot projects conducted in selected countries. Section III presents a comparison and analysis of the pilot P2P rollout and the key challenges for successful rollout. Section IV presents the key areas of P2P energy trading and the proposed model for Malaysia. Section V concludes the paper and highlight the future research.

II. BENCHMARKING OF P2P ENERGY TRADING
A. EASE OF GETTING ELECTRICITY

The ease of obtaining electricity is defined by the procedures, time, and cost of connection to the electrical grid and the reliability and transparency of tariffs in a country [11]. The ranking is comprehensively done by the World Bank and reflects the maturity and performance of the country's electric industry from the technical, commercial, and governance perspectives. This includes the maturity of the electricity infrastructure, how long it takes to get electricity to a premise, how affordable the electricity supply rates are, how stable the supply service is, and how well the prevailing laws and regulations govern the electricity supply. Thus, the countries chosen from the top 20 rankings, namely South Korea, Germany, Thailand, the United Kingdom, and Singapore will

TABLE 1. Selected top 20 ease of getting electricity supply countries ranking by world bank [11].

Location	Getting Electricity Rank	Time (days)*	Electricity Market Structure	Generation Sources	% of RE Penetration
South Korea	2	13	Partial Vertically Integrated Utility	2020: Coal (60.8%), Natural Gas (24.7%), Nuclear (8.7%), Oil (3.2%) and Other RE Resources (2.7%) [16]	2.7%
Malaysia	4	24	Manage Market Model	2020: Coal (65.84%), Natural Gas (29.67%), Hydro (3.78%), Solar (0.7%) and Others (0.01%) [15]	4.48%
Germany	5	28	Fully liberalized market	2020: RE (45.4%), Lignite (15.7%), Natural Gas (16.6%), Nuclear (11.3%), Hard Coal (7.2%) and Others (3.8%) [21]	45.4%
Thailand	6	30	Partial Vertically Integrated Utility	2020: Natural Gas (58.68%), Coal (18.27%), RE (6.9%), Oil (0.5%), Storage from Hydro (0.24%) and Import from Other Countries (15.41%) [23]	6.9%
United Kingdom	8	46	Fully liberalized market	2019: Gas (40.6%), RE (37.1%), Nuclear (17.3%), Coal (2.1%) and Others (2.9%) [26]	37.1%
Singapore	19	26	Fully liberalized market	2020: Natural Gas (95.76%), Petroleum Products (0.36%) and Others (3.88%) [30]	< 3.88%

* Average number of days to obtain supply for a new premise.

be a good benchmark for Malaysia to compare its P2P energy trading efforts.

Malaysia was ranked 4th in the world in 2019, as shown in Table 1. From the top 20 ranked countries, Thailand and Singapore are chosen as they are the neighboring countries to Malaysia in Southeast Asia and have exemplify successful P2P energy trading pilot, which will be discussed in the next section. In addition, Germany, United Kingdom, and Singapore have adopted a fully liberalized electricity market, while South Korea and Thailand have partially vertically integrated electric utilities that are similar to Malaysia. Germany and the United Kingdom have been the early adopters of P2P energy trading pilots with various research and development on the platform [12]. Meanwhile, South Korea has several P2P pilots [11].
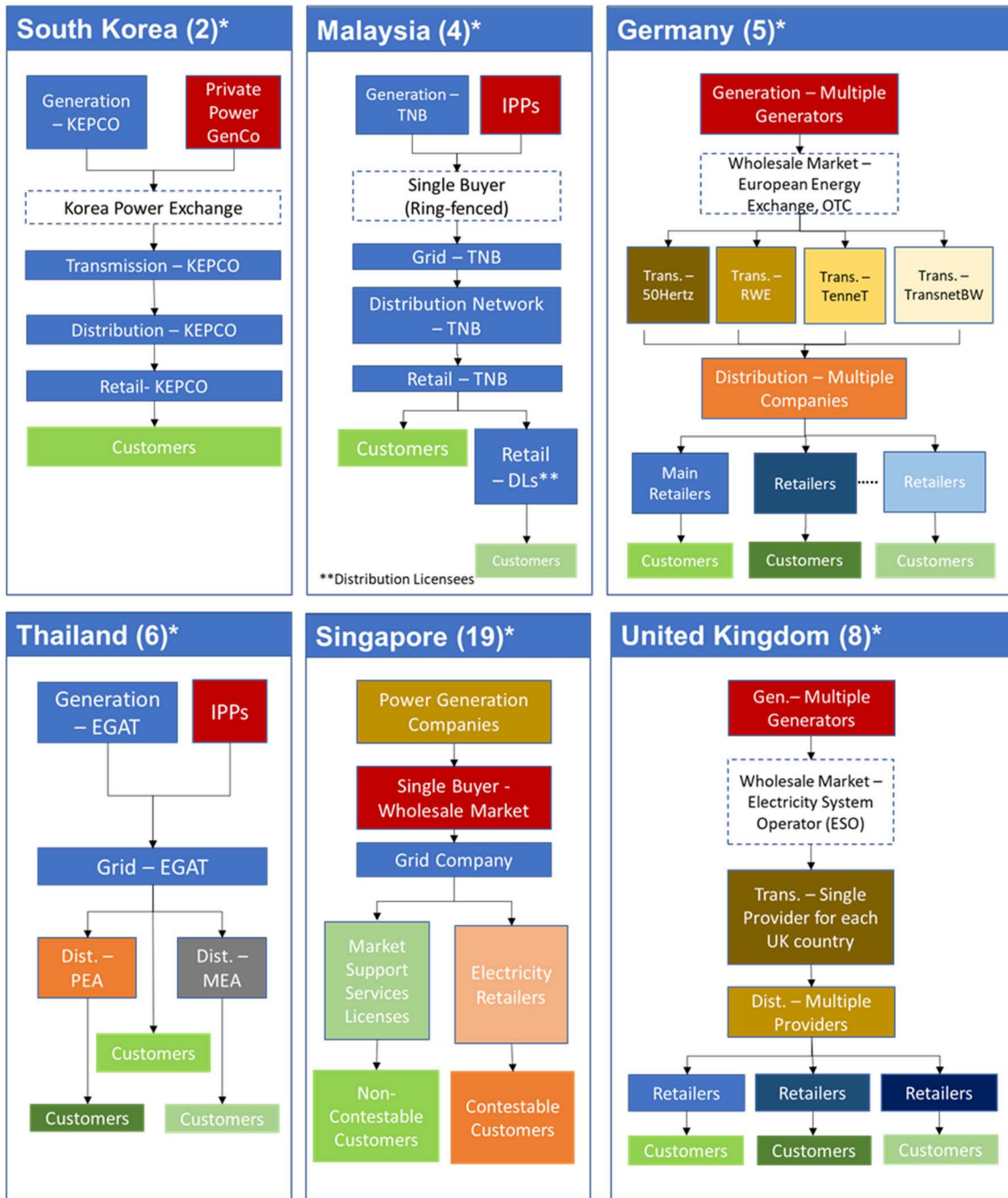
B. ELECTRICITY MARKET STRUCTURE
The electricity market structures of the six countries selected are compared in Figure 1 to understand the level of liberalization and differences.

1) MALAYSIA ELECTRICITY MARKET STRUCTURE
Malaysia's electricity market structure started from a monopoly model until 1990. Thereafter, to further achieve energy security of the grid, the Malaysian Government opened the generation entity to other generators to provide diversity of providers, known as the independent power producer (IPP). This signaled the evolution of the electricity market structure comprising of three conventional entities: the generation, transmission, and distribution of electricity. The Energy Commission (EC) of Malaysia was formed in 2001 to regulate Malaysia's energy supply industry (MESI) [13].

Fast forward to 2014, in order to further improve the reliability and security of supply, MESI has been developed to manage the market model design whereby this involves the unbundling accounts of the national electric utility into five separate entities: generation, single buyer, transmission, distribution network, and retail [14]. Parallel to this, the EC started implementing incentive-based regulation (IBR) to the national electric utility. The IBR framework is such that the IBR mechanism is set every three years as the regulatory period. The IBR mechanism will be reviewed after every regulatory period. The factors considered in the review include the base tariff, weighted average cost of capital (WACC) return for licensee and operational efficiency. In 2020, Malaysia's generation mix comprised of 65.84% coal, 29.67% natural gas, 3.78% hydro, 0.7% from solar, and 0.01% other sources [15]. The RE in Malaysia has a huge potential and is expected to achieve its 31% RE target by 2025 [2].

South Korea (2)*

Generation – KEPCO | Private Power GenCo
Korea Power Exchange
Transmission – KEPCO
Distribution – KEPCO
Retail- KEPCO
Customers

Malaysia (4)*

Generation – TNB | IPPs
Single Buyer (Ring-fenced)
Grid – TNB
Distribution Network – TNB
Retail – TNB
Customers | Retail – DLs**
Customers
**Distribution Licensees

Germany (5)*

Generation – Multiple Generators
Wholesale Market – European Energy Exchange, OTC
Trans. – 50Hertz | Trans. – RWE | Trans. – TenneT | Trans. – TransnetBW
Distribution – Multiple Companies
Main Retailers | Retailers ···· Retailers
Customers | Customers | Customers

Thailand (6)*

Generation – EGAT | IPPs
Grid – EGAT
Dist. – PEA | Dist. – MEA
Customers
Customers | Customers

Singapore (19)*

Power Generation Companies
Single Buyer - Wholesale Market
Grid Company
Market Support Services Licenses | Electricity Retailers
Non-Contestable Customers | Contestable Customers

United Kingdom (8)*

Gen.– Multiple Generators
Wholesale Market – Electricity System Operator (ESO)
Trans. – Single Provider for each UK country
Dist. – Multiple Providers
Retailers | Retailers | Retailers
Customers | Customers | Customers

*(x) – Ease of Getting Electricity Countries Ranking

FIGURE 1. Comparison of electric market structure (South Korea, Malaysia, Germany, Thailand, UK, Singapore).

2) SOUTH KOREA ELECTRICITY MARKET STRUCTURE

South Korea's electricity structure has been monopolistic in nature through KEPCO. KEPCO is supported by the government, with 51% stake [16]. However, the generation sector has been opened to other private power-generation companies. South Korea's generation mix in 2020 comprised of 60.8% coal, 24.7% natural gas, 8.7% nuclear, 3.2% oil, and 2.7% other RE resources [16]. The Korea Power Exchange acts as a wholesale market to facilitate grid generation [17]. The transmission, distribution grid, and retail section are operated by KEPCO, making it almost fully vertically integrated.

3) GERMANY ELECTRICITY MARKET STRUCTURE

Before 1998, electric utilities in Germany operated in a fully monopoly model by area, based on the Energy Industry Act

of 1935. Thereafter, Germany became among the first European countries to fully liberalize its electricity market whereby the value chain for electricity generation was unbundled i.e. network involving transmission and network third party access. The National Regulatory Authority for Germany, the Federal Network Agency for electricity, gas, telecommunications, post, and railway markets was established [18].

Geographically, Germany shares borders with nine European countries and is electrically connected to its neighboring countries. To achieve European energy goals, several organizations and public authorities are bundled at the European level. These lead to the formation of entities such as ENTSO-E and ENTSO-G (group of electricity and gas), ACER (agency for the cooperation of national regulatory authorities), and EU Commission. There are four major transmission system operators (TSOs) in Germany, with a distribution system operator (DSO) of nearly 1,000 [19]. The transmission and distribution revenues are under incentive regulation through the adjustment of revenue caps every five years [20]. End customers can choose the preferred energy retailers or choose to remain with their default local main retailers. Germany's generation mix in 2020 comprised 45.4% of RE, 15.7% of lignite, 16.6% of natural gas, 11.3% of nuclear, 7.2% of hard coal, and 3.8% of other sources [21].

4) THAILAND ELECTRICITY MARKET STRUCTURE

The energy sector in Thailand is highly regulated and governed by the Ministry of Energy and managed by the National Energy Policy Council (NEPC). It is regulated by the independent Energy Regulatory Commission (ERC), which monitors energy market conditions, reviews tariffs, issues licenses, approves power purchases, and reviews development planning and investment in the electricity industry. Thailand has adopted a single-buyer model in the power sector, under which state-owned utility allows limited private sector participation in electricity generation while maintaining control over system planning, operation, and pricing [22].

Thailand's Electricity Generating Authority of Thailand (EGAT) is state-owned. EGAT owns and operates most of the country's power generation capacity and transmission networks. It operates the system and is the principal power off-taker. Essentially, it sells the power it generates or purchases from private power producers and neighboring countries to two state-owned enterprises: the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA). The MEA and PEA distribute power to retail, commercial, and industrial consumers throughout Thailand and owns the electricity distribution networks in their regions of operation. The MEA has exclusive rights to distribute and sell power to end users in the Bangkok metropolitan area, and PEA has these rights in all other areas. EGAT sells electricity to the MEA and PEA at a regulated rate approved. In 2020, Thailand's generation mix consisted of 58.68% natural gas, 18.27% coal, 6.9% RE, 0.5% oil,

0.24% storage pumped hydro, and 15.41% imports from other countries [23].

5) UNITED KINGDOM (UK) ELECTRICITY MARKET STRUCTURE

With the introduction of the Electricity Act of 1989, the UK Government embarked on the market liberalization of electricity supply. Through the Act, the electricity market was restructured by creating separate generation, distribution, and transmission entities and removing the old Central Electricity Generation Board. Under the Gas and Electricity Markets Authority (GEMA), the Office of Gas and Electricity Markets (OFGEM) was established as the regulatory body for gas and electricity in Great Britain. OFGEM regulates the wholesale, transmission, distribution, and retail markets to ensure competitiveness, transparency, fairness, and protect consumers' interests [24]. Full competition was introduced in 1999, whereby consumers could choose to purchase their electricity packages from any of the retailers.

The national grid electricity system operator (ESO) manages the wholesale market, whereby generation, that is, wind farms and solar farms, are transacted to retailers. Through the infrastructure owned by the three transmission companies (National Grid Electricity Transmission, Scottish, and Southern Energy and SP Energy Networks), electricity is transported through any of the six distribution network operators (DNOs) across Great Britain [25]. DNO networks provide electricity to customers who are billed by retailers. The energy generation mix is comprised of 40.6% gas, 37.1% RE, 17.3% nuclear, 2.1% coal, and 2.9% oil plus other sources [26].

6) SINGAPORE ELECTRICITY MARKET STRUCTURE

In 1998, Singapore became the first country in Southeast Asia to introduce the wholesale electricity trading market [27]. The power generation companies in Singapore competed to sell their electricity to single buyers. Over time, the Singapore electricity market became even more competitive with liberalization efforts throughout the value chain. The Energy Market Authority (EMA) under the Ministry of Trade and Industry Singapore was established in April 2001 to ensure a reliable and secure energy supply, promote effective competition in the energy market, and develop a dynamic energy sector in Singapore [28]. The move to further liberalize the retail sector commenced in 2003. In April 2018, the EMA had soft launched the Open Electricity Market to allow contestable customers to enjoy more choices and flexibility when purchasing electricity from retailers [29]. Non-contestable customers can still choose to remain with their electricity plans under regulated tariff rates. Although the electricity market structure in Singapore has undergone further liberalization, it is still being overlooked and controlled by the EMA. With this, the potential to introduce new services such as demand response and P2P energy trading would be accepted. In 2019, Singapore was powered by 95.76% of natural gas, 0.36% of

petroleum products, and 3.88% of other resources, including solar and biomass [30].

C. NOTABLE P2P ENERGY TRADING

In this section, the notable P2P energy trading in selected countries are reviewed based on the market design, trading mechanism, and technology used in the implementation.

1) P2P IN MALAYSIA

Malaysia first embarked on P2P energy trading through a pilot regulatory sandbox mode, conducted from November 2019 to June 2020. This initiative was led by the Sustainable Energy Development Authority (SEDA), and was supported by the national energy utility, with participation from four prosumers as well as eight consumers [9]. According to SEDA, P2P energy trading is one of the strategies to be explored under the Renewable Energy Transition Roadmap (RETR) 2035 study being undertaken to augment the solar PV rooftop market [9]. The platform provider for this pilot sandbox adopted the blockchain technology.

From the market design perspective, the pilot is run under the centralized model whereby SEDA oversees the energy flow between the prosumers and consumers. The prosumers and consumers who participated were in a wide geographical location in Peninsular Malaysia. The benefit for prosumers under this pilot is that they sell the excess energy generated from the solar rooftop to the grid at 10% above the industrial tariff rate at RM 0.355/kWh [9]. Consumers buying energy from these targeted prosumers will purchase energy delivered at 11% lower than the prevailing commercial tariff at RM 0.509/kWh. This includes the network charges set for the pilot at RM 0.063/kWh, while no retailer fees are imposed [9].

The trading mechanism in the pilot is not extensively tested as, based on the energy export obtained from all the prosumers, it is more than the consumer usage throughout the pilot. Energy spillage was found to be between 4% and 54%, and this excess energy was not sold. The pilot utilizes the existing grid infrastructure, meter, and billing system by the national energy utility, whereas the prosumers provide the excess energy generated from the rooftop solar.

2) P2P IN SOUTH KOREA

In 2016, South Korea launched a demonstration project of the P2P Electricity Trading Platform (ETP) with physical infrastructure such as solar panels and energy storage systems in two small towns, to foster energy prosumers' business and activate the P2P electricity trade through new trading platforms. However, this project was still in the early stages of examining the feasibility of P2P ETP and has therefore not been actively promoted in South Korea [31]. The transactions were conducted by the Korea Electric Power Corporation (KEPCO). Solar PV has the characteristics of intermittent generation and high generation cost compared with other traditional generation methods. This is one of the reasons why the P2P electricity trading market is not actively operated in South Korea. As highlighted [31], average electricity charge of households in 2017 is KRW 110/kWh as compared to average photovoltaic generation cost at KRW 182/kWh. Apart from that, Energy Storage System (ESS) cost in South Korea is also very high, hence the excess energy is either sold via Power Purchase Agreement (PPA) or net energy metering with KEPCO [32].

In addition, Electron, a blockchain startup from the UK, has also started pilot P2P energy trading in South Korea [33]. Under the name of project Artemis, Electron collaborates with GridWiz, an energy aggregator startup in South Korea to kickstart the platform from November 2018 to September 2020. This notable trial involved six industrial companies, including the casting producer Daedong Metals, Hanwha Total Petrochemical, and the car component manufacturer Castec Korea. Companies are contracted to Gridwiz to reduce their energy demand when grid congestion occurs. The participants, who had committed themselves under the demand response, were able to trade with other prosumers who had surplus energy through Electron's platform. With this, they can avoid being penalized under the demand response contract, and the prosumers can earn extra revenue from the energy traded [34].

3) P2P IN GERMANY

One of the notable P2P energy trading pilots in Germany is the SonnenCommunity [35]. The key difference between sonnenCommunity P2P energy trading as compared to others is that it couples solar PV prosumers with advanced battery storage technology. The sonnenCommunity is a community of sonnenBatterie owners with solar PV installed to share self-produced energy with other members of the sonnenCommunity. The excess energy is not fed into the conventional power grid, but into a virtual energy pool that can serve others in the community. There is a need to be registered as a member of the sonnenCommunity, through a monthly membership fee of EUR 19.99 and the energy exchange cost from EUR 0.23 per kWh. sonnenCommunity has grown its market not only in Germany but also in other countries such as Austria, Switzerland, and Italy [35].

PeerEnergyCloud is another P2P project in Germany. It is developed based on cloud-based technologies for a local virtual marketplace to deal with local excess energy production [36]. The microgrid in the city of Saarlouis (Germany) is considered, which consists of approximately 500 residential units, and among them are prosumers with solar PV systems. The residential units are connected to the local energy provider (Stadtwerke Saarlouis) via a dedicated secured fiber-optic cable, which allows the processing of data in real time. The market model is much decentralized as there is no central control between prosumers and consumers through the virtual marketplace.

4) P2P IN THAILAND

In Bangkok, the state-run Metropolitan Electricity Authority (MEA) cooperated with Power Ledger for pilot P2P energy trading utilizing a blockchain platform in 2018 [37]. The pilot

involved several large prosumers, including a community mall, a school, and an apartment, while a dental hospital became the only consumer. The RE generator utilized for this pilot was solar PV installed on community mall, school, and apartment with a total capacity of 635 kWp.

The P2P market design was highly centralized and was overseen by the energy utility, MEA. Bidirectional smart meters were installed at the participant meters to record energy imports and exports. When there is excess energy from prosumers, they can export energy to other consumers. Throughout the first eleventh month of the P2P pilot trial, the total energy consumption from the conventional generators was significantly reduced by 18%, potentially saving about USD 22,276 [37]. However, it has yet to involve actual monetary transactions, as the outcome is purely based on a simulation. From a technical perspective, no critical impact such as voltage failure, has been observed on the grid. This P2P trial provides an example of the potential of P2P in the urban environment of one of the largest cities in the world.

5) P2P IN UNITED KINGDOM

Piclo is the first online P2P marketplace in the United Kingdom (UK) to sell and buy smart grid flexibility services and trading energy among peers [38]. It is one of the earliest notable P2P energy trading platform providers globally. Piclo launched its P2P energy marketplace in October 2015 under the sponsorship of the United Kingdom Department of Energy and Climate Change (DECC) and the Energy Fund of Nominet Trust [38]. Due to this, there were no fees for participants to use the Piclo platform. 37 prosumers and consumers participated in this trial. Piclo-matched energy consumers and prosumers every half-hour using meter data, power generation costs, and consumer preference information. Both consumers and prosumers can use Piclo online services through computers and smartphones, and electricity trading takes place when the consumers' desired prices and the prosumers' transaction conditions are both met. Piclo is also supported by ''Good Energy,'' a 100% renewable energy supplier, to balance the market. Piclo flex was introduced thereafter to assist customers with flexible assets, such as electric vehicles and batteries, to participate in energy trading. The charging methodology used by Piclo includes common distribution charging methodology (CDCM) and distribution use of system (DUoS), in addition to price-based incentive models that are widely adopted in the UK [39].

6) P2P IN SINGAPORE

Electrify has kickstarted the first retail pilot P2P energy trading marketplace in Singapore with its synergy platform under the Alpha phase [40]. A total of 15 participants, consisting of three prosumers and 12 consumers, participated in the Synergy Alpha marketplace across Singapore's national grid. It has achieved its technical test objective, which was to simulate an end-to-end use case for P2P energy trading through Singapore's main electricity grid while complying with the energy regulation there. Electrify uses smart contracts where

consumers can buy electricity from retailers or from their peers to reduce fees and transaction costs. Electrify has a proprietary matching algorithm and has two tiers of matching modes. Electrify is moving the synergy alpha into beta for a larger number of participants and coverage across Singapore.

III. CHALLENGES AND ISSUES OF P2P ENERGY TRADING IMPLEMENTATION

There have been various challenges in the adoption of P2P energy trading by countries around the world. Until now, to the best of our knowledge, there has not been a significant P2P energy trading that has been fully implemented throughout the nation. Most of the countries are still embarking on pilots and getting a hold on the potential challenges while evaluating the techno-commercial impact to ensure successful implementation and roll out at a larger scale. Several researchers worldwide have classified P2P energy trading into various categories [10], [41], [42]. Among these, the similarities in the categories are market design, trading platform mechanism, physical and information and communications technology (ICT) infrastructure, and policy. These are the core areas to be analyzed further within the selected countries.

Tushar *et al.* [10] segregated the market structure into fully decentralized, community-based, and composite markets, while Zhou *et al.* [41] classified market design into centralized, decentralized, and distributed markets. Although different terminologies are used, the classification is similar in nature, whereby the level of decentralization and topology differentiates between each of them, as described by Sousa *et al.* [12]. In terms of trading platform mechanisms, blockchain, game theory, and auction theory are widely used for P2P energy trading simulations. Physical infrastructure such as advanced metering infrastructure (AMI) and ICT infrastructure are the key enablers for the implementation of P2P energy trading. P2P platform providers have increased in recent years to manage transactions between prosumers and consumers, giving them the assurance of the trade. In addition, the policies adopted technically and commercially are critical to the success of large-scale rollouts. A comparison between the countries implementing P2P energy trading, based on the categories used in the literature, is shown in Table 2. The following subsection provides further deliberation on the issues, challenges, and existing scenarios in implementing P2P energy trading in these countries.

A. MARKET STRUCTURE IMPACT ON P2P IMPLEMENTATION

Most of the notable pilot P2P energy trading adopted by countries ranked in the top 20 eases of getting electricity are under a fully or partially liberalized electricity market structure. It is observed that the countries that achieved a fully liberalized electricity market structure earlier, such as Germany and the United Kingdom, have implemented pilot P2P energy trading much earlier.

López-García *et al.* [42] described similarities in P2P energy trading development in a deregulated market, whereby

TABLE 2. Comparison of P2P energy trading based on the common categories.

Country	Notable no. of pilot P2P Energy Trading Rollout	Years started pilot P2P	P2P Market Design	Trading Platform Mechanism	National P2P Policy	References
South Korea	> 2	2016	Centralized	Blockchain	N/A	[31, 33, 42]
Malaysia	1	2019	Centralized	Blockchain	N/A	[9]
Germany	> 5	2011	Centralized, Decentralized	Cloud-based web marketplace, Blockchain	N/A	[35, 36, 42, 55]
Thailand	1	2018	Centralized	Blockchain	N/A	[37]
United Kingdom	> 4	2014	Centralized, Decentralized	Blockchain	N/A	[38, 42, 55]
Singapore	1	2019	Decentralized	Blockchain	N/A	[40]

a more decentralized model was adopted. Various efforts have been made by private firms with retailers trying to set up a P2P energy trading platform for pilots. The first pilot P2P energy trading began as early as 2010 in Germany with a project named Lichtblick Swarm Energy [43]. A more liberalized electricity market structure will see more P2P energy trading implementation, such as Germany and the UK. Thereafter, South Korea, Thailand, Singapore, and Malaysia followed their P2P energy trading initiatives in pilots.

B. PHYSICAL INFRASTRUCTURE READINESS
One of the key levers of P2P energy trading is physical infrastructure readiness to support the entire rollout. Components of infrastructure readiness include the utility network, smart meters, RE generators, energy storage systems, trading platforms, and communication support. With a strong readiness for physical infrastructure, such as smart metering, P2P energy trading can be implemented at greater ease for these countries. These physical infrastructure issues are also pertinent, especially for countries that adopt time of use (ToU) electricity billing. A comparison of P2P energy trading infrastructure enablers in terms of smart meters, ToU, and energy storage systems for consumers is shown in Table 3. Solar PV is the most common RE generator adopted in P2P pilots across countries. With the reduced acquiring cost and ease of maintenance, solar PV can provide prosumers with excess green energy to participate in the P2P energy trading market. A trading platform with the right trading mechanism that benefits the prosumers, consumers, and grid operators would also be equally important. Various countries such as the United Kingdom, South Korea, and Singapore have seen P2P implementation initiated by platform service provider [58].

C. THIRD PARTY ACCESS (TPA) IN THE GRID
The P2P energy-trading framework requires a third-party access mechanism for the grid. This has been a key challenge that needs to be addressed across countries. The electricity tariff is structured in such a way that it accounts for the total cost of the electricity ecosystem across geography: broad-based from generation, transmission, and distribution before the customer's end. The unbundling of tariffs to a specific location is far more challenging and restrictive, especially for countries that have yet to fully liberalize the electricity market structure. Forming the framework for third-party access is vital for countries such as Malaysia to allow the efficient implementation of P2P energy trading. From this, wheeling charges or network charges will need to be determined as precisely as possible to ensure fairness to the grid operators and appropriate pass through of cost to the end customers.

On a larger scale of P2P energy trading, there has been an increase in the TPA in the grid in recent years through the renewable energy corporate power purchase agreement (CPPA) mechanism in America, Europe, and Asia Pacific [59]. CPPA is a long-term contract under which a business agrees to purchase electricity directly from an energy generator. The buyer purchases renewable electricity at a pre-established price for a pre-agreed period. The agreement contains the commercial terms of the electricity sale: contractual length, point of delivery, delivery date/times, volume, and rate. The sleeve corporate power purchase agreement (SCPPA) involves a connection to the grid, whereby the grid utility is the intermediary between the RE generator and the end customer [60]. The contracted SCPPA rates include network charges and sleeving fees. The determination of the fees and associated costs could be complex from country to country because of the electricity market structure.

TABLE 3. Comparison of P2P energy trading infrastructure enablers.

Location	Smart Meter (Installation Target)	Time of Use (ToU) Scheme	Energy Storage System for Consumers	References
South Korea	Yes (22 million)	Customers except Residential	Yes	[44, 45, 46]
Malaysia	Yes (9 million)	Low Voltage Industrial, Medium Voltage & High Voltage Customers	New & Growing market, limited installation and info	[15, 47, 48]
Germany	Yes (47.6 million*)	Yes	Yes	[44, 49, 50, 51]
Thailand	Yes (N/A)	Yes	Yes	[44, 52, 53]
United Kingdom	Yes (53 million*)	Yes	Yes	[44, 49, 54, 55]
Singapore	Yes (1.4 million)	Yes	Utility-scale and distribution level	[44, 56, 57]

does not disaggregate between electricity and gas smart meters

D. GRID CHALLENGES

P2P energy trading is very useful in areas with high grid congestion. This is significant, especially during peak hours, and the excess energy delivered by prosumers will help ease network congestion. In areas that are not congested, surplus energy is required to meet consumer demand. Hence, the grid needs to be smart and well equipped with technology to identify congestion areas. Data accuracy is vital to support the energy trading. The benefits obtained from grid congestion could be plowed back to the prosumers of P2P energy trading during the matching period between prosumers and consumers. Balancing out the technical viability, the trading period (peak and off-peak), and the commercial rates of the trades will be one of the key focus areas in adopting P2P energy trading. Parallel to P2P energy trading, energy utility practices demand response mechanisms to reduce grid congestion. This requires a form of compensation for participants who are willing to reduce their energy consumption or isolate completely from the grid. At times, participants are unable to shed their load to reduce grid congestion, which could lead to penalties incurred. In South Korea, the collaboration between Electron and Gridwiz has widened the potential of P2P energy trading coupled with demand response programs, as highlighted in Section 2.3.2 [34]. The P2P energy trading scheme assisted the demand response participants to avoid penalties from the inability to reduce their demands, thus showcasing innovation in energy solutions.

In addition, the potential technical loss reduction in the total system should also be evaluated from the impact of implementing P2P energy trading. Theoretically, the total system losses should be reduced owing to the reduction in cable and transformer losses. However, Azim *et al.* [61] conducted an in-depth study on the power losses in grid-tied networks due to P2P energy trading, which showed indifferences in the results. The simulation showed that there is no significant variation in losses between P2P and non-P2P scenarios for a typical 24h day for a large-sized distribution network with notable residential customers. This could be another area that can be further researched to cover the entire total system losses impact throughout the grid system should P2P energy trading scales up throughout the nation.

E. RIGHT MODEL TO MEET ALL STAKEHOLDERS INTEREST

Until now, no country has yet to set any form of governance or Act for P2P energy trading. As this mechanism is relatively new, pilots have been tested for rapid prototyping in terms of technical aspects and potential commercial benefits. However, a more inclusive and holistic approach is required to ensure that the implementation of P2P energy trading on a large scale would balance the benefits to prosumers, consumers, grid operators, and government. Different countries have different costs of electricity supply, generation mix, energy policy, economic conditions, and electricity market structure. Moreover, the outbreak of the Covid-19 global pandemic since the end of 2019 has impacted countries all over the world in various ways in its energy policies. There has been a strong push and rising importance for environmental, social, and governance (ESG) practices, which could hasten the implementation of P2P energy trading.

The right business model to cater for all demands is vital to ensure fairness. Pichler *et al.* [51] investigated a user-centered business model in Germany that resulted in the existence of energy communities in Germany, such as SonnenCommunity and EnBWsolar+, to provide ease of energy trading to the participants. In addition, Lee *et al.* [31] proposed that the normalization of the electricity price scheme in South Korea for

P2P needs to comprehensively reflect greenhouse gas (GHG) emissions and fairness in the tax regime across all energy sources. Nevertheless, with the ever-increasing RE penetration into the grid and the rise of green electricity adoption, there is a need to outline how carbon credit ownership will be transferred, especially in P2P energy trading. This is vital as more companies and organizations, especially those that are associated with the RE100 global corporate renewable energy, are seeking ways to ensure that they can source 100% of their energy from renewable sources [62]. In Malaysia, P2P energy trading has seen its importance to be set up as the next level of RE scheme post-FiT and NEM schemes that were introduced before with its available quota being completely taken up [9].

F. QUANTIFYING P2P ENERGY TRADING BENEFITS

There is no doubt that P2P energy trading will be one of the key drivers of more renewable energy penetration in the electricity ecosystem and further decentralize energy generation. This mechanism could bring more cost savings to consumers and potential income generation for prosumers. Most pilot rollouts of P2P energy trading across these countries have reported various forms of savings from the reduction of energy costs from the incumbent electricity providers and supported by other prosumers. For instance, the P2P rollout in Bangkok has seen a significant reduction of 18% in electricity consumption from the grid and high savings [37]. Jongbaek *et al.* [32] used a P2P business model evaluation software to analyze and calculate the potential savings from residential buildings in seven metropolitan cities in South Korea. The findings from the evaluation have led to prosumers deciding whether to self-consume the energy generated or sold under P2P energy trading. In Malaysia, through the pilot P2P energy trading done by SEDA, it is seen that the consumer can achieve a reduction of 11% compared to the regulated tariff [9]. Lüth *et al.* [63] found that housing communities in London, United Kingdom utilizing storage and P2P can result in savings of up to 31% of electricity costs. The true potential benefits must be quantified with more in-depth findings so that P2P energy trading model implemented will benefit all the parties involved in the long run.

IV. PROPOSED IMPLEMENTATION OF P2P ENERGY TRADING IN MALAYSIA

Subsequent to the analysis and review in the previous section, this section briefly highlights several proposed implementations of P2P energy trading in Malaysia based on six key areas: market design, trading mechanism, physical infrastructure, virtual infrastructure, policy and governance, and social science perspective.

A. MARKET DESIGN

The market design for Malaysia is based on a centralized model [64], as illustrated in Figure 2. Malaysia's energy market structure is still highly regulated by the Energy Commission (EC) of Malaysia. Furthermore, the tariff setting

in Malaysia is cross subsidized across the country, such as urban, suburban, city, or rural areas. The centralized model will be good for shaping the P2P energy trading mechanism for the start, as consumers will have higher trust in participating with the incumbent energy provider. A central coordinator plays a role in managing the participants, known as peers. This coordinator will be best coming from the national electric utility, who presently manages the grid and distribution network system. The predefined principles such as the grid charges, wheeling charges, calculation, and settlement could be decided with EC, and the Malaysian energy utility will be the implementation to distribute the revenue to the entire P2P community.

Malaysia's grid voltage level ranges from the high voltage at 500 kV, 275 kV and 132 kV to medium voltage at 33 kV and 11 kV and lowest at a 400V low voltage as per Figure 3. To address and formulate the potential grid charges and wheeling charges, it is proposed that the P2P energy trading mechanism is to be based on an incremental execution methodology to start within the lowest voltage level from the output of a substation transformer at medium voltage. Thereafter, the P2P mechanism moves up to medium-voltage level energy trading and finally to a high voltage level. At low voltages, there are three major segments of customers: residential, commercial, and industrial customers. These customers pay the electricity tariffs determined by the EC at Tariff A (residential), B (commercial), and D (industrial) [65]. When P2P energy trading takes place within this community, the energy transaction makes value sense as the electricity is traded as though it travels short distances and wheeling charges can be determined better. The output of a transformer at low voltage is rated at 1600A. This could cater to several houses and shop lots in a community. At the medium-voltage level, there are two major customer segments in Malaysia: commercial and industrial. Commercial customers will pay at the commercial rate at Tariff C1 and C2, while industrial customers are at Tariff E1 and E2.

At this voltage level, it is recommended that P2P energy trading can be traded to low-voltage A, B, and D customers apart from medium-and high-voltage customers. At a high voltage level, commercial customers will pay Tariff C3, while industrial customers pay Tariff E3. For high-voltage customers, the P2P mechanism is proposed to allow trading to happen only between the C3 and E3 customers and a level lower, which are the medium voltages C1, C2, E1, and E2 customers. The incremental implementation based on the voltage level will bring stability for P2P to be implemented in the long run.

B. TRADING MECHANISM

There are several technical approaches to enable the trading mechanism of P2P energy trading, such as game theory, auction theory, and constrained optimization [10]. It is proposed that the canonical coalition game theory, which is a cooperative model, is implemented for the start in Malaysia over a non-cooperative game. The canonical coalition game will
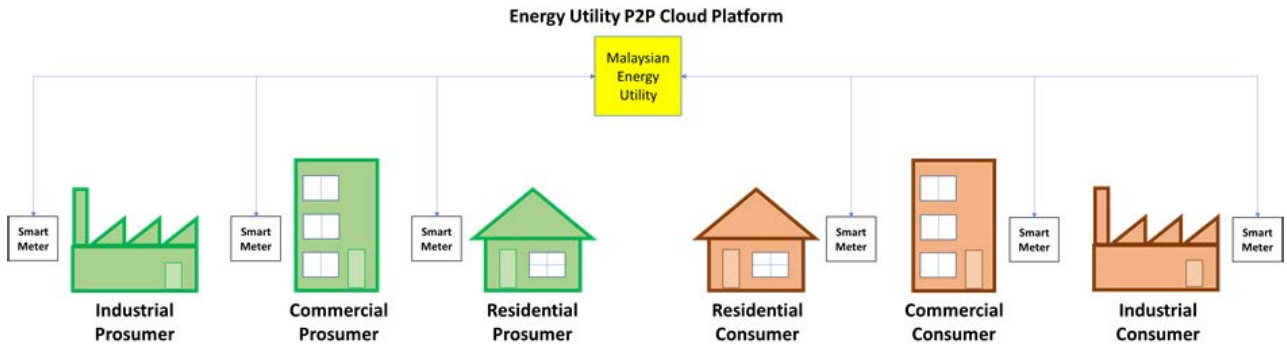
FIGURE 2. Proposed centralized model to Kickstart P2P energy trading in Malaysia.
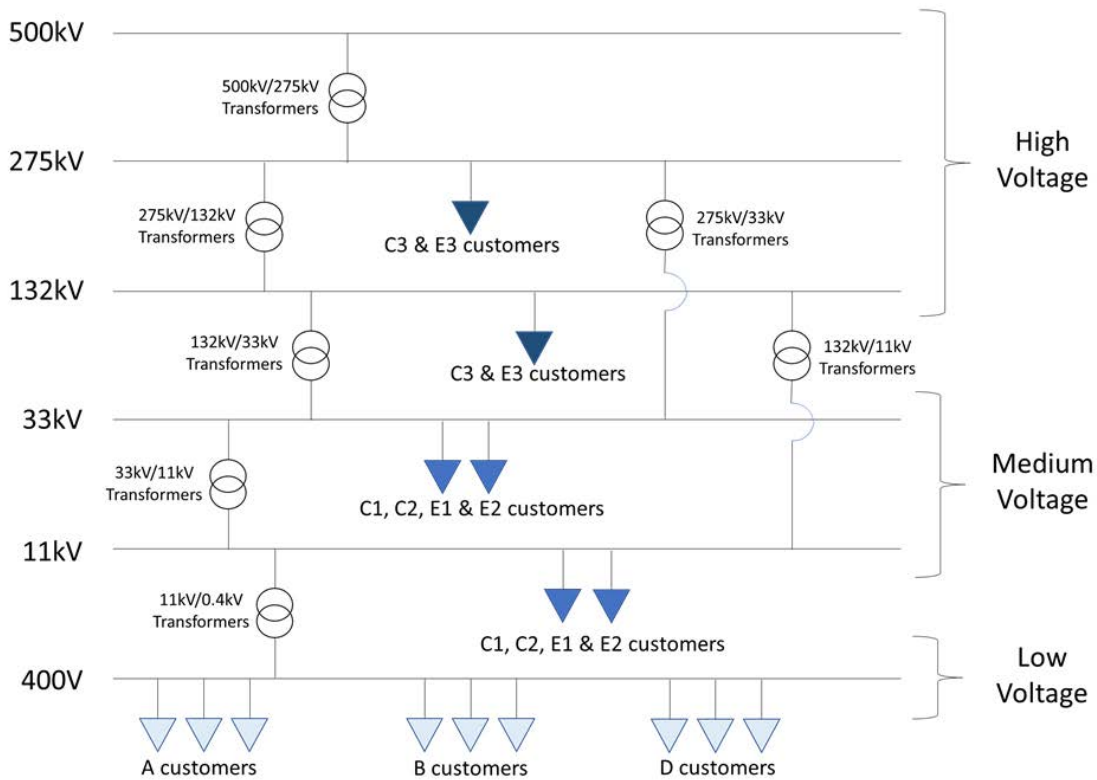

FIGURE 3. Malaysia's general grid voltage level & customers representation.

benefit players by distributing the gains that result from the coalition in a fair manner [66]. This would benefit all stakeholders in terms of reducing energy costs by balancing local generation and demand, fairness in deciding the trading price, and increased participation of prosumers in P2P trading.

The proposed mechanism is based on the motivation for prosumers to trade their excess energy as well as the purchase intention of consumers in Malaysia. Figure 4 shows the proposed model for P2P energy trading at low voltages. The customers of Tariff A, B, and D are motivated to purchase electricity from peers if the traded price is lower than the regulated tariff. The prosumers of Tariff A, B, and D are

highly likely to demand a selling price above that which they can offset from the grid under the latest NEM 3.0 scheme.

For prosumers of category A, it will be an offset based on the published A tariff, while for B and D prosumers, the offset will be based on the average monthly system marginal price (SMP) published monthly by 14th by Single Buyer [8]. SMP is the energy price of the most expensive thermal generator dispatched to meet the demand in the half-hour period. The SMP is influenced by a combination of factors, including the fuel price, system demand, and generation system conditions. Customers in category A are presently categorized into 5-tier tariffs while B and D customers have a single tariff rate.
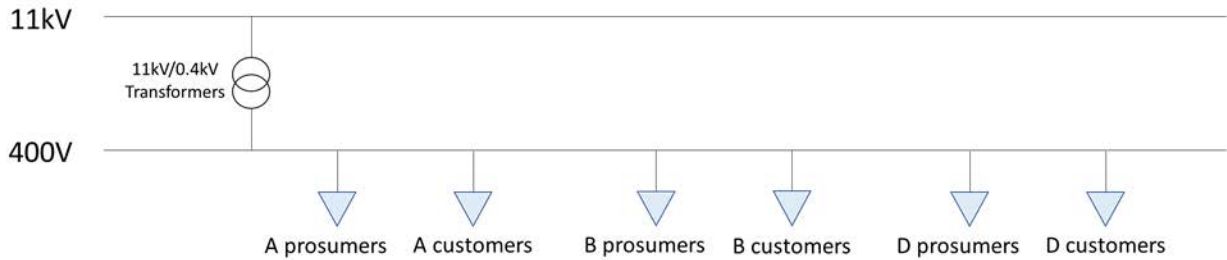
FIGURE 4. P2P energy trading at low voltage grid level.

TABLE 4. Motivated buying and selling price range for low voltage customers or prosumers in Malaysia.

Customer Category by Tariff Rates	A1	A2	A3	A4	A5	B	D
Customers: Motivation to buy from peers under P2P energy trading	< RM 0.218/kWh	< RM 0.334/kWh	< RM 0.516/kWh	< RM 0.546/kWh	< RM 0.571/kWh	< RM 0.509/kWh	< RM 0.441/kWh
Prosumers: Motivation to sell to peers under P2P energy trading	> RM 0.218/kWh	> RM 0.334/kWh	> RM 0.516/kWh	> RM 0.546/kWh	> RM 0.571/kWh	> Average SMP	> Average SMP

The rate at which prosumers or consumers are motivated to participate in P2P energy trading is shown in Table 4.

From the table, we can see that both B and D tariff customers could purchase electricity from their peers in the network, which are in categories A1, A2, B, or D. As for residential A tariff customers, as they are segmented into 5-tier tariffs, they could purchase based on the listed range, as shown in Table 4 (i.e., A2 customers are motivated to purchase from A1 prosumers in the range <RM0.334/kWh and >RM0.218/kWh). This deliberation on potential P2P energy trading models has highlighted the trading mechanism based on the canonical coalition game theory application whereby the potential buying and selling rates are in the range that is fair to all participants. This is also because the buying and selling motivations are highly based on the regulated tariff and the existing prevailing NEM scheme for offsets from the grid. In the future, the trading mechanism could be combined with the double auction theory and potentially with linear optimization to develop a mathematical model that can be proposed for P2P energy trading in Malaysia. A more centralized market model tends to adopt an auction format, as it is managed centrally with the buy and sell order [67].

The inclusion of network conditions in the trading mechanism framework further enhances the reliability of P2P energy trading. Guerrero *et al.* [68] developed a continuous double-auction trading framework with network constraints to block high-risk trading that could disrupt voltage and power flow fluctuations. Accounting for uncertainty elements in the trading mechanism would also add value to the P2P energy trading execution, given the intermittency of PV and potential integration of flexible loads such as electric vehicles and energy storage [69].

Another key area of importance to be highlighted under the P2P energy trading mechanism in Malaysia is the transfer of carbon credit ownership. There has been increased interest in green electricity in Malaysia, especially for large power consumers. Subsequently, Malaysia saw the launch of the myGreen+ scheme and Malaysia Green Attribute Tracking System (mGATS) in October 2019 which enabled customers to purchase bundled green electricity or the internationally recognized renewable energy certificate (REC) to achieve the RE100 target [70]. With more organizations and companies moving toward ESG adoption and investment in sustainability initiatives, P2P energy trading can definitely contribute to more green electricity in the pool. In 2020, both myGreen+ and REC in Malaysia have seen a high uptake rate, whereby 483,400 MWh of RECs have been sold and 190 MWh of myGreen+ has been subscribed [15]. This shows that consumers in Malaysia are willing to pay a premium on top of the electricity rates for green electricity. The cost of green that carries carbon credit ownership should be considered in P2P trading mechanism pricing.

C. PHYSICAL INFRASTRUCTURE

Being ranked 4th in the world for ease of getting electricity supply, Malaysia's electrical infrastructure is seen to be much more advanced. The smart meters installation could play an important role for a successful implementation of P2P energy trading in Malaysia. Bidirectional communication utilizing advanced metering infrastructure is vital, especially in the

real-time mode of P2P energy trading. Having real-time information capabilities is critical for resolving one of the main challenges in executing P2P energy trading [63].

In addition, there is no centralized energy management or control imposed on all residents in Malaysia. As such, the P2P energy trading source will depend solely on the excess of distributed generated energy from prosumers without control, limited by the maximum capacity of the RE allowed to be installed. Areas to be explored for P2P implementation are best targeted at congested grid network points that can be identified by the grid system operator (GSO) and distribution system operator (DSO). Focusing on these P2P areas will benefit the technical ecosystem, potentially providing cost reduction and further encouraging demand response. The showcase pilot conducted by GridWiz and Electron in South Korea has shown an exemplary example of coupling P2P energy trading and demand response to support reduction in grid congestion [33]. Zhang *et al.* [71] provided insights on the use of ancillary services such as voltage control and congestion management by the DSO to safeguard the grid without technical violations.

An energy storage system (ESS) coupled with a solar PV is a good setup for P2P energy trading participants. With the integration of the ESS, participants can control and decide the best export time to obtain the most return while supporting the grid. The ESS model with a RE generator has been shown to be effective in P2P energy trading implementation by the SonnenCommunity in Germany [35]. After the end of the net energy metering (NEM) scheme in Malaysia, the P2P energy trading to be adopted soon would indirectly impact the demand for ESSs. However, the present cost of battery storage is still relatively high to reduce its payback period as compared to the cost of electricity in Malaysia. Several efforts have been made to kickstart and implement ESSs in Malaysia. Lim *et al.* [48] published a real case study on the first utility-scale grid-integrated energy storage system installed in Universiti Tunku Abdul Rahman (UTAR) with a sizing of 667 kWh. The national energy utility has also showcased the battery storage for residential customer segment under the Maverick home pilot project as well as in its research center building and intending to expand more investment for ESS in the future [14, 72]. As reported under the Peninsular Malaysia Generation Development Plan 2020 (2021-2039) by the Energy Commission of Malaysia, a target of 100 MW grid-connected capacity is set to be installed by 2030 [2]. The growth of more ESS penetration and its affordability over time will be key to drive further implementation of P2P energy trading in Malaysia.

D. VIRTUAL INFRASTRUCTURE

The blockchain technology platform is a suitable virtual infrastructure to support P2P energy trading by Malaysian energy utility. Blockchains ensure that the energy supply is traceable and that demand in one area is met by locally sourced renewable energy [73]. As the complication of energy trading at all voltage levels could be massive

coupled with high-volume information from the smart meters of participants, the advantage of using blockchain here is clearly demonstrated [74]. The underlying technology of blockchain's proof of stake protocol can be adopted for trading, settlement, smart contracting, and collection rules. A comprehensive compilation and systematic review of more than 140 blockchain research projects and startups in energy space was conducted by Andoni *et al.* [58]. The classification [58] has shown that in the energy sector, 61% of blockchain applications have largely been used for decentralized energy trading, cryptocurrencies, tokens, investment and metering, billing, and security.

In addition, various researchers have coupled the use of blockchain with unique transaction methodologies, such as distributed double auctions, continuous double auctions, and multi-layer coalitions. Table 5 shows the research on the use of blockchain with various transaction methodologies or techniques in a decentralized market. These research outcomes further implicate the advancement of blockchain adoption in P2P energy trading, especially in a decentralized market. The blockchain platform is envisioned to execute the market design and trading mechanism proposed for Malaysia's scenario. The availability of this platform will be a major breakthrough in the decentralization of electricity in Malaysia. Transactions through this platform must be protected with appropriate cyber security measures to protect all relevant data and information from theft and damage.

E. POLICY & GOVERNANCE

Presently, there has yet to be a benchmark for the country-wide adoption of P2P energy trading policy. Most of the studies were conducted at the pilot stage or in case studies. In Malaysia, the Energy Commission plays an important role in ensuring that the establishment of P2P energy trading in Malaysia will be fair, stable, and reliable. This can be achieved by executing a trading policy and good governance. Through the implementation of P2P energy trading, the country will benefit from higher renewable energy penetration, which will lead to an increase in sustainable energy sources in the total energy mix, management of the grid congestion areas, and improvement in the socio-economic status of the country.

Critically, policies on data privacy need to be addressed in line with the implementation of P2P energy trading. As the P2P mechanism involves data from all parties, the rights to use the data for energy trading need to be put in place. This is also critical when P2P energy trading execution can include the control management of participants' energy generation sources in the future. The rise of smart homes in the coming years will further increase control management capabilities for P2P energy trading [80]. In countries already adopting time of use (ToU), a smart home coupled with a smart meter will be a huge enabler to the establishment of P2P energy trading supported by good policy and governance. Thereafter, fairness and Pareto optimality could be further explored in the trading mechanism to ensure that one would not be worse off

TABLE 5. Various research on transaction methodology in blockchain for decentralized P2P energy trading.

No.	Transaction Methodology	Benefits/Outcome	References
1	Distributed Double Auction	• Quick convergence, minimizes energy losses and efficient	[75]
2	Continuous Double Auction	• Reasonable running costs and comparable technical management capabilities with respect to a physical, centralized managing authority	[76]
3	Multi-agent Coalition System	• Flexible structure, adaptable to prosumers with different types and heterogeneous energy resources, trusted and secure settlement	[77]
4	Empirical Agent-based Modeling Framework	• Application to manage emerging uncertainties by facilitating the testing and development of management strategies.	[78]
5	Common Distribution charging methodology (CDCM), Distribution use of system (DUoS) and Price Based Incentive Model	• Neglect retail suppliers and participants uses shared database in a network for direct energy trading	[39]
6	Advertise, Negotiate and Prioritize with Optimization Algorithm	• Proposed framework improves the welfare of trading agents and decrease system overheads	[79]
7	Decentralized Ant-Colony Optimization	• Maximize the social welfare of the prosumers within the time frame of the trading horizon and guarantees a near optimally efficient market solution	[74]

than others. Malaysia is expected to move toward adopting the ToU tariff for residential customers after the installation of nine million smart meters targeted by 2026 [15]. This has been mooted by the previous deputy energy, science, technology, environment, and climate change minister of Malaysia [81] and could happen in the coming years.

F. SOCIAL SCIENCE PERSPECTIVE

As trading of electricity between prosumers and consumers would heavily depend on their motivation to do so, it is important to understand the human behavior to develop an optimized P2P energy trading model in Malaysia. A customer-driven model would be one of the best business models that is sustainable in today's highly competitive society. Jiang *et al.* has included the maximization of social utility function into the 2-stage optimization approach on the decision of prosumers and consumers within a P2P energy trading community [82]. Nash bargaining, a branch of cooperative game theory is used by the authors with the decision variables to be the amount of energy traded and associated payoffs [82]. A balance of payoffs between the prosumer and consumer would be a good reflection to the maximization of social welfare.

Social practice theories can also be considered to improve the adoption of the P2P energy trading platform, which provides another dimension to its implementation rather than focusing on technical aspects [83]. Pumphrey *et al.* had highlighted five key social practices to be considered in the P2P energy trading platform, arranged by the highest priority; ease and automation, 3rd party expertise, cost of trading, trust in the trading mechanism and credibility of green trading image [83].

Apart from that, Georgarakis *et al.* had analyzed the energy trading preferences based on economic, environmental, social and technological parameters in the Netherlands [84]. From the 74 survey data findings [84], the environmental factor is seen to be the most important factor while economic attribute such as selling price came third instead. Though, a survey in Malaysia could be very much driven by the economic factor such as pricing and profitability factor that is to be further tested. These inputs would contribute to the development of an optimized P2P energy trading model.

V. CONCLUSION AND FUTURE RESEARCH

This paper presents an in-depth literature review and benchmark on the electricity market structure in countries with notable P2P energy trading adoption and listed in the top 20 ease of obtaining electricity by the World Bank: South Korea, Germany, Thailand, the United Kingdom, and Singapore. These countries had a mix of fully liberalized and partially liberalized markets. Countries that have a fully liberalized market have seen earlier implementation and tend to have a more decentralized P2P pilot model. Malaysia's energy landscape, its renewable energy growth initiatives, and the nascent P2P pilot rollout have also been reviewed. In Malaysia's highly regulated electricity market structure, several key areas need to be focused on prior to successful P2P implementation, such as third-party grid access, technical grid optimization, appropriate commercial pricing, and location of rollout. A list of proposals for P2P energy trading, tailored for the Malaysian energy landscape, has been proposed based on the six major areas of market design, trading mechanism, physical infrastructure, virtual infrastructure, policy & governance and social science.

Further research can be carried out in depth on the proposed implementation with case studies, inclusion of uncertainty elements, data simulation, and verification. Market models can be further developed, from a centralized to a hybrid P2P model, or fully decentralized, while an optimum trading mechanism can also be developed to suit Malaysia's scenario. On top of that, the model can be optimized based on social science perspective from customers and prosumers as the core entities of the P2P energy trading value chain. The inclusion of carbon credits in the trading mechanism will play a significant role in the setup, as there are increasing interests in obtaining greener and cleaner electricity that can be translated into zero electricity GHG emission factors.

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