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Drivers and Challenges of Peer-to-Peer Energy Trading Development in Thailand

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Abstract: Recent developments in disruptive technologies along with the cost reduction of photovoltaics have been transforming business models in the electricity sector worldwide. The rise of prosumers has led to a more decentralized and open local green energy market through the emergence of peer-to-peer (P2P) energy trading, where consumers and prosumers can buy or sell electricity through an online trading platform. P2P energy trading has the potential to make green energy more accessible at the local level, provide a customer choice that aligns with community values, and promote the use of renewable energy (RE) for local consumption. Although P2P energy trading has already been adopted in some countries, its implementation remains challenging in other countries, including Thailand. In this work, we investigated the drivers and challenges of implementing P2P energy trading in Thailand based on the perspectives of P2P energy trading pilot project developers participating in the regulatory sandbox program. A strategic framework was used to identify the respondents' standpoints on the political, economic, social, technological, legal, and environmental (PESTLE) factors that can influence the implementation of P2P energy trading. This can help businesses, policymakers, and regulators better understand drivers and barriers of P2P energy trading, which is a potential local energy market. This paper also provides policy recommendations for regulatory changes for the future development of P2P energy trading, including opening a third-party access (TPA) regime, enabling a liberalized market in the electricity market, and integrating the role and responsibilities of the prosumer for P2P energy trading into existing law.

Keywords: peer-to-peer energy trading; drivers; challenges; solar rooftop; Thailand; business model

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1. Introduction

Climate change has recently become a major global issue and the use of renewable energy (RE) resources for the energy sector is being recognized as a possible solution to address this problem. In addition to a large scale of generation from clean energy, the deployment of distributed energy resources (DERs) from renewables is therefore growing rapidly around the world. Shifting power generation to RE is a key pillar of global efforts to reach carbon neutrality and sustainable development. In particular, global solar photovoltaic (PV) installations will continue to break new records, estimated to reach over 160 GW by 2020 [1]. In addition, the emergence of DERs has brought new players such as prosumers into the distribution network [2]. In the traditional grid, the end user had the option to be only a consumer, and the flow of electric power was one-way (i.e., from utility to consumer). The traditional power grid is changing drastically so that consumers can also become energy producers, called prosumers [3].

In Thailand, RE development has been encouraged through supporting policies and financial mechanisms. In the early stage of the market, the growth of solar PV installations had been driven through premium and regular feed-in tariff (FiT) programs under a single buyer market structure. With the continuous cost reduction of solar PV systems, prosumers have increased, although the recent government support program is not as attractive as in the past [4,5]. Currently, there is only a household solar program as a part of Thailand's power development plan (PDP) 2018 (Revision 1). This solar program is classified as a net billing (NB) program and aims to encourage the installation of rooftop PV systems for self-consumption with any excess electricity being compensated at 1.68 THB/kWh (0.05442 USD/kWh) [6]. However, other PV system sizes are allowed to be installed and connected to the grid, but the excess energy from the PV systems is not allowed to flow to the grids. Thus, new business models are required to incentivize the self-consumption of PV systems and increase monetary benefits for prosumers.

Peer-to-peer (P2P) energy trading can be a part of the existing electricity market where prosumers are allowed to trade electricity with their neighbors. The concept of P2P energy trading is inspired by the sharing economy, with well-known examples such as Uber and Airbnb [7]. The basic concept of P2P energy trading is that sellers offer energy at a higher price than the export price or buy price of the main grid, while the buyers buy it at a lower price than the retail price. A trade price is settled between the export price and the retail price. In this way, prosumers are encouraged to share their excess electricity directly with their neighbors [8]. P2P energy trading can be designed to serve specific needs of the community such as saving electric billing, promoting clean energy, and sharing surplus energy for those who need it in a community. In addition, traders can take an active role in managing their local energy systems by managing their energy consumption based on their preferences and in line with their community values.

P2P energy trading is considered a branch of transactive energy that encourages prosumers to participate in the energy market while ensuring the secure and efficient operation of the system [7]. Moreover, energy transactions can vary in quantity, timing, and acceptability, and are also network-specific [9]. The scale of customers can range from a single household to a neighborhood, microgrid, and local distribution network [10]. P2P energy trading has been proposed for various structures [7,10–12]. For example, structures may be changed completely with an autonomous P2P network, which enables prosumers and consumers to share, buy, and sell self-generated electricity and other services such as flexibility or demand response in an open electricity market through the regulated distribution grid, or P2P energy trading may be a part of the traditional power market [13].

The trend of P2P energy trading has attracted interest in several countries including Thailand. Due to the constraint of the Thai electricity market structure that is based on a single-buyer model, the Thai Energy Regulatory Commission (ERC) has launched the ERC sandbox program in 2019 where participants are allowed to test innovative concepts, such as P2P energy trading, with cutting-edge technologies in the marketplace under relaxed regulatory requirements [14]. From a total of 34 projects approved by the program, 8 projects were based on the assessment of the P2P energy trading model [15]. Most of the participants were project developers from different sectors, such as private companies, universities, and power utilities. The end goal of the ERC sandbox program is to establish rules and regulations for the full implementation of P2P energy trading in the future.

In addition, as P2P energy trading is a new business model in the power industry, we investigated the drivers and challenges for the development of P2P energy trading in Thailand based on the viewpoints of the project developers participating in the ERC sandbox program. PESTLE analysis was applied to identify the key drivers and challenges in terms of political, economic, social, technological, legal, and environmental aspects. The results can help businesses, policy makers, and regulators understand drivers leading to the adoption and barriers in implementing the business. We provided policy recommendations and implications for regulatory changes for P2P energy trading in Thailand.

This paper is organized as follows: Section 2 presents a literature review of P2P trends and policies and existing P2P projects. Section 3 presents the methodology used in this work. Section 4 provides results and discussions, and Section 5 highlights conclusions and policy recommendations.

2. Literature Review

2.1. Trends and Policies toward P2P

DERs and, more specifically, distributed solar PV (DPV) systems have proliferated in recent years around the world. The growth of DPV systems has been driven by government support mechanisms and instruments, such as solar mandates, FiT, net metering, NB, as well as measures to encourage community aggregation and promote utility activities and investments [16]. At a large scale, this support has traditionally taken the form of FiT (e.g., in Europe and the UK), tax incentives, and quotas and obligations (e.g., in India and the US). At a small scale, net metering (e.g., in the US), NB, and tax and other fiscal incentives have been the main support tools [17,18].

Based on this background, the evolution of the supporting mechanisms of the DPV systems can be divided into three categories: FiT, net metering, and NB [18]. FiT, net metering, and NB schemes have been widely used to drive the growth of DPV deployment over the past several years by encouraging customers to install more DPV systems through high monetary incentives [19]. Under FiT, owners of rooftop solar systems can sell all PV generation to the grid and purchase all electricity from the grid [20]. FiT programs are attractive and create new business models, such as system leasing and rooftop renting [21]. However, they also lead to the government obligation to support subsidies [22] and therefore have been discontinued in many parts of the world, e.g., Spain [23], the UK [24], and Japan [25].

After FiT programs, the DPV supporting schemes included self-consumption policies to encourage the use of PV electricity by compensating excess generation through various forms of compensation mechanisms, such as net metering and NB. As the cost of locally generated PV electricity is lower than the retail electricity price in some countries, PV electricity generation for self-consumption is becoming increasingly profitable without subsidies [26]. In addition, the net metering scheme usually offers more economic benefits to customers than the NB scheme as excess electricity generation under the net metering scheme is valued at the retail electricity price, while that under NB is assigned by the policymaker, which could be lower than the retail electricity price [27]. Therefore, countries with an implementation of the net metering scheme are likely to experience high DPV penetration, which increases distribution grid charges or taxes [4]. This led to the phaseout of the net metering scheme in some countries [17,28,29], whereas net metering regulations were revised in others such as Mexico and Indonesia [17].

Policies to support the adoption of DPV systems have been adjusted and developed to respond to the trends and drivers. One of the concepts that have been discussed is P2P energy trading. With the emerging trends of digitalization and customization, P2P energy trading can enable prosumers to actively participate in the energy market either by selling their surplus generation [30] or reducing energy demand, i.e., demand reduction or negative watts [12]. As prosumers have control over setting the transaction terms and delivery of goods and services [8,13], the benefits they can harvest by participating in P2P trading are expected to be significant [31]. This concept provides benefits to the locality in which it operates, such as employment and investment in community assets [32]. Such a model can promote the use of renewable energy in energy communities such as cooperatives that allow residents to collectively benefit from renewable energy systems [33]. At the same time, the grid—comprising generators, retailers, and distribution system operators (DSOs)—can also benefit in terms of reduced peak demand [34], lowered capital and operating costs [35], minimized reserve requirements [36], and improved reliability of the power system [13]. In addition, the P2P model has the potential to change some existing roles and lead to the emergence of new roles, brokers, and representatives in future P2P trading in the context of current electricity markets [37].

With recent technological advancements, the security of transactions in P2P energy trading is being introduced through the use of distributed ledger techniques such as blockchain technology (BT). It is best known as an application that supports Bitcoin, Ethereum, and other popular cryptocurrencies [38]. BT is a decentralized, distributed open ledger that contains transaction data. It enables P2P transactions by using a consensus algorithm such as Proof of Work (PoW), Proof of Stake (PoS), Proof of Authority (PoA), without the involvement of a central authority. BT has proven to be viable for P2P transactions in terms of security, transparency, and immutable records of transactions. These characteristics of BT make it a suitable candidate for implementing P2P trading in the electricity market [39]. In addition, this type of technology has been applied in various areas. Matsuda et al. [38] demonstrated the coordination of a blockchain-based P2P energy trading system with Plug-in Hybrid Electrical Vehicles (PHEVs) and Home Energy Management Systems (HEMS) in daily life. Khan and Byun [40] developed a P2P trading and charging payment system for electric vehicles based on BT. Vlachokostas et al. [41] explored BT as an option for ensuring the integrity of data that are shared by lighting and other building systems by utilizing a PoA consensus. Tiron-Tudor et al. [42] analyzed the strengths, weaknesses, opportunities, and threats (SWOT) of BT for accounting or auditing organizations. Varriale et al. [43] presented the benefits, challenges, and future research of BT for the supply chain, also suggesting how the features of BT can change the organizational aspects of the supply chain.

2.2. Existing P2P Projects

Various structures for P2P energy trading have been proposed [8,9]. The proposed P2P structure could be changed completely from the traditional power market structure, while it can also function as a part of the existing market structure. Depending on available data and information, we reviewed existing P2P pilot and commercial projects under the regulated and deregulated electricity market structures, as shown in Table 1. P2P energy trading models emerged as a result of the increasing deployment of DERs connected to distribution networks and the intention to provide more incentives to encourage the further use of these resources.

Based on the reviewed projects, one of the key factors that can commercialize P2P energy trading under a deregulated market is the regulation that allows retailers to procure electricity from prosumers. Generally, retailers can purchase electricity from energy suppliers; however, prosumers have distinct characteristics that distinguish them from energy suppliers, and regulations are required to define the scope of this distinction. For instance, the Netherlands has no definition of prosumers [44], and prosumers need to apply for supplier licenses to sell electricity [45]. However, the regulations allow prosumers with no capability to apply for those licenses to act as a reseller through a cooperation agreement with those who have supplier licenses [46]. P2P energy trading in the Netherlands can be a part of the retail market to offer more supplier choices for customers. For Germany, a self-generator is defined in the Electricity Tax Act as someone who generates electricity for self-consumption [44], and individuals who install no more than 2 MW for self-generators are exempted from supplier licenses if they sell electricity [47]. In the Netherlands and Germany, prosumers can trade electricity through retailers to increase their electricity supplier options. The regulations in the UK [48], the US [49], and Australia [50] do not allow the implementation of P2P energy trading.

P2P energy trading can be implemented under a regulated electricity market. For instance, in South Korea, the transmission system operator, DSO, and retailer are the same agency and are driven by the government policies in promoting prosumers [51]. Therefore, prosumers in South Korea are allowed to sell electricity through brokers in the wholesale market and to suppliers and neighbors in the retail market [52]. Malaysia also has a regulated electricity market, but it implemented P2P energy trading only as a pilot project under a sandbox program [53].

The technology used in P2P energy trading involves a trading platform where consumers and prosumers can trade electricity with each other. Platform-based P2P energy trading has been developed using advances in information and communication technology (ICT) devices, smart meters, broadband communication infrastructure, and supply and demand forecasting analytics [54]. Some P2P pilots in Malaysia, the US, and Australia used a blockchain-based trading platform to provide security and decentralized transactions, while other projects in South Korea and Germany encouraged prosumers to install solar PVs with a battery system to store surplus electricity and help to manage grid stability (Table 1).

Table 1. P2P energy trading pilot and commercial projects.

Country	Project	Year	Status	Main Contribution	Main Technologies Used in the Project
UK	Piclo [55,56]	2015	Completed, Pilot project	Matching the preferences of generators and consumers in the local community.	- Online trading platform - Smart meter
USA	Brooklyn Microgrid [35,57]	2016	Ongoing, Pilot project	Enabling a local energy marketplace of prosumers and consumers by trading excess electricity within a localized area.	- Blockchain-based P2P energy trading platform - Smart meterr - Simple and easy to participate in electricity trading mobile applications.
Germany	Sonnen [58]	2015	Ongoing, Commercial project	Stable power supply utilizing batteries and provision of surplus power pool.	- Battery technology to store excess electricity for trading within the Sonnen community. - Simple and easy to participate in online trading platform
Netherlands	Vandebron [59,60]	2014	Ongoing, Commercial project	Connecting the RE suppliers, prosumers, and generators via its own platform and establishing a local clean energy community.	- Simple and easy to participate in electricity trading through web and mobile applications.
South Korea	Neighbor trading [51,61]	2016	Ongoing, Commercial project	Enabling neighbor trading model between prosumer with a rooftop PV system and consumer through matched contract.	- Energy storage system to store the energy produced for own use or sell to other consumers - Smart meter
	Smart Energy Campus [62,63]	2018	Ongoing, Commercial project	Enabling P2P energy trading model within the microgrid, especially trading across universities.	- Energy storage system to store the energy produced for own use or sell to other consumers - Energy Management System (EMS)
	Sungdaegol Energy Cooperative [52,64]	2018	Ongoing, Commercial project	Enabling a community solar cooperative for local energy trading and in Smart Korea Energy Exchange.	- Energy storage system to store the energy produced for own use or sell to other consumers

Table 1. *Cont.*

Country	Project	Year	Status	Main Contribution	Main Technologies Used in the Project
Australia	Latrobe Valley Microgrid [65]	2016	Completed, pilot project	Enabling a local energy marketplace of dairy farms, residential and commercial/industrial customers to trade PV excess electricity and demand response within a localized area.	- Blockchain-based P2P energy trading platform - Simple and easy to participate in electricity trading through web and mobile applications - Smart meter
Malaysia	1st pilot project SEDA (Sandbox project) [53,66,67]	2019	Completed, pilot project	Enabling a local marketplace of prosumers and consumers by trading excess electricity within a localized area.	- Blockchain-based P2P energy trading platform - Smart meter

2.3. Challenges of the Implementation of P2P Energy Trading

Several studies have identified challenges in P2P energy trading. In the context of this paper, PESTLE analysis was used to examine the external factors affecting the P2P energy trading business in political (P), economical (E), social (S), technological (T), legal (L), and environmental (E). PESTLE analysis is an analytical tool for strategic business planning that provides a strategic framework for understanding the external influences on a business and helps organizations maximize P2P business development opportunities and minimize threats [68]. This type of analysis has been applied to diverse energy topics, including solar home systems in refugee camps in Rwanda [69], port energy management systems [70], and RE in Malawi [71]. The analysis of PESTLE includes six factors: the political factor refers to the extent to which government and government policy can influence an organization or a particular industry. Economic factors refer to the performance of an economy, which directly affects an organization and has long-term consequences. Social factors help organizations better understand the needs and wants of consumers in a social environment. Technological factors consider the level of technological innovation and development that could affect a market or industry. Legal factors take into account certain laws that affect the business environment in a particular country, while there are certain policies that companies maintain for themselves. Environmental factors include all factors that influence or are determined by the environment [72]. According to PESTLE analysis, the challenges are classified into six main categories as follows.

2.3.1. Political Challenges

- As a prosumer is a key player in P2P energy trading, prosumers should be allowed and promoted by the government first before moving forward to adopt P2P energy trading. P2P energy trading is likely to be adopted in countries where policies to support prosumers are certain, such as the Netherlands, Germany [45], and South Korea [61]. In the Netherlands and Germany, all prosumers are legally allowed to sell electricity [44,47], while in South Korea, the national policy includes prosumer promotion [61]. The government can encourage the development of P2P energy trading in terms of the efficient use of RE resources and associated environmental benefits.
- As with other novel businesses that have never existed before, policies and regulations related to P2P energy trading lagging behind technological developments [73] hinder the implementation of P2P energy trading. If the government foresees that P2P energy trading can be deployed to support the adoption of RE, the policies should validate

P2P models in theory and practice in the early stage. Consequently, authorities and policymakers know the benefits and implications of the models in detail to plan for infrastructure investments and make the necessary regulatory changes. Sandbox programs can be used to investigate the impacts of P2P energy trading, as performed in the US [35], Malaysia [53], and Thailand [74]. In addition, it is important to fit the P2P energy market into the current policies, which requires clarifying what market designs are permissible, how taxes and fees are allocated, and the relationship between P2P energy trading markets and traditional electricity markets.

- Embedding the P2P model as part of the public grid infrastructure comes with significant caveats and complexities [5–7,75] as it is unclear whether the direction of P2P energy trading is an end goal of an electricity market or just one of the business models under the current market structure. In the early stage, local, microgrid, or P2P energy markets would need to be integrated into current regulatory practices [36]. However, they have the potential to drastically change the established roles of entities under the current market structure. For the countries that foresee a local energy market such as P2P energy trading as a potential, regulators should grant permits for pilot projects testing such novel marketplaces or regulatory sandboxes to explore potential benefits for consumers and the operation of the energy system [76]. Concrete details on the direction of policy development in P2P energy trading must be developed, including clearer ownership and partnership models, prosumer licensing, and associated requirements and market roles.

2.3.2. Economic Challenges

- As P2P energy trading is a new business under existing electricity market structures, business models can be designed differently based on the community's needs or interests, but such designs require testing to ensure that P2P models can benefit participants and stakeholders. It is crucial to ensure that prosumers are actively involved in the trading mechanism and can reap the benefits of P2P energy trading. Business models are expected to equitably distribute costs and benefits among a large number of self-interested market participants [77]. Existing studies examined the new business models and market designs for prosumers in the post-subsidy era of the existing energy system [78]. An autonomous P2P model was also investigated [7] but is still the furthest from the current electricity market design and requires policies to support the emerging prosumer business model [78].
- As P2P energy trading is usually applied for a community, pricing mechanisms, including auction and bidding, should be designed to be prosumer-centric [79]. In other words, pricing mechanisms should consider not only practical decision-making but also human behavior with motivational psychology [19,31]. A large number of proposed techniques are multi-class energy management [79], motivational psychology [31], bilateral contract theory [80,81], reinforcement learning [82], game theory [22,75], prediction-integrated double auction [83], consensus-based approach [84], aggregated battery control [81,85], and optimal energy scheduling for prosumers [22]. Existing studies suggest that game theories such as noncooperative, cooperative, and evolutionary games are effective tools to model user behavior and design pricing schemes that help them to cooperate in P2P networks [85,86]. However, due to the complexity of user behavior in the real world and few studies on motivational psychology combined with game theory, the design of pricing mechanisms remains challenging [22,31]. Project developers must calculate appropriate rates for P2P participation while attracting more participants to the P2P system.
- The development of a P2P energy trading project requires high initial investments, including a digital trading platform, ICT devices, smart meters, and broadband communication infrastructure, which may incur additional costs for participants and make P2P participation less attractive. Two types of investments are required to implement a P2P trading platform: the initial investment to build a monitoring center, a web server,

and a workstation to run the server and trading system, and the investment to cover operation and maintenance costs to maintain all monitoring and server functions [87]. Additional investments for platform-based P2P energy trading include smart meters, ICT devices, communication infrastructure, and forecasting analytics systems. In doing so, participants may incur additional fees, such as service and transaction fees, to cover the total cost of the facility. In addition, to promote P2P participation, subsidies are needed for the uptake of solar PV systems as the main technology in the P2P system [77].

2.3.3. Social Challenges

- As P2P energy trading is usually implemented to support local energy trade, its trading platform must be designed based on not only market-driven trading but also the values, pain points, and social justice issues of the community. In a study performed under the RE and Water Nexus project in Australia, it was found that participants preferred to be able to select suppliers and sell to selected individuals within the community and were dissatisfied with the overly market-driven trading design. Participants agreed to pay more in the P2P scheme as part of the pilot to demonstrate the benefits of P2P energy trading in the community with the expectation that this would lead to lower costs in the longer term [77].
- As with the adoption of other recent technologies, P2P energy trading platforms should have a friendly user interface. A platform with a complex user interface or trading mechanism is likely to hinder participants to join the trade. In addition, less tech-savvy people may be less likely to be able to trade effectively, leading to further disadvantages, although the shrinking "digital divide" may reduce this disadvantage over time [88].
- The P2P energy trading concept still lacks social awareness and acceptance [89]. As P2P energy trading is the new concept of local electricity trading and new technologies such as smart meters and blockchain are being introduced, building trust between stakeholders in the adoption of this new technology is a very important issue [88]. In addition, the implementation of the P2P model will influence the lifestyle and cultural practices related to the supply and demand of electricity in the local community [90–92]. A social trust should be created to improve transparency, reduce fraudulent transactions [77], and increase a sense of attachment to that community [10,93].

2.3.4. Technological and Technical Challenges

- The increasing number of prosumers participating in P2P energy trading leads to technical issues on the grid [94], such as overvoltage [9,95,96], undesired reverse power flow [79], network capacity overload [97], and loss of system inertia [98]. The concerns over the fully decentralized P2P energy trading implementation could not control the technical limit of the network within the safety range during multiple transactions [30,99]. Prosumers, which favor generating electricity from RE and are connected to the distribution grid, have transformed grid operation to monitor and control electricity injected to the grid. The change from passive customers only purchasing electricity with a predictable load profile to active prosumers and consumers in P2P energy trading with small knowledge on their behaviors leads to challenges in managing and operating grids for distribution utilities. During trading, power loss could happen [98], and to some extent, that loss must be included in P2P pricing [8]. In addition, the increase in inverter-based generation (e.g., DPV systems) may lead to the loss of system inertia as the share of synchronous generators is not sufficient to re-stabilize power systems after voltage/frequency disturbances [8,98]. P2P energy trading must contribute to balancing local supply and demand and avoiding peak demand simultaneously [77].
- It is necessary to ensure the privacy of individual participants and that all private information is secured. Under P2P energy trading, financial transactions and data re-

lated to those transactions are numerous as trading transactions are settled in real-time along with the continuous power supply. The availability of accurate and statistically useful energy transaction and consumption data between consumers and prosumers is important for the algorithms of supply and demand forecasting and price settling. These data related to transactions are required for a P2P trading platform and help to operate the platform and network; thus, a demonstrably private transformation of prosumers' energy data is needed to facilitate data access while ensuring sufficient statistical accuracy for querying the data [100], and methods and techniques must be developed to ensure the security of the network [36]. Cybersecurity is required to implement countermeasures to ensure information security [101]. Although distributed ledger techniques such as blockchain have been developed for transaction security, BT is still at an initial stage and needs improved data transmission and computational speed to be used in real-time [39,102].

- Successful implementation of large commercial platforms, such as cities, states, or countries, is also a challenge [9]. More prototypes, laboratory platforms, and tools are needed to enable the research society to validate the performance of models that can support P2P trading implementation on a large scale. However, for the trading platform that aims to extend the covered area, scalability must be primarily considered when designing a trading structure and platform [73,103,104]. The platform requires the considerations of technical and financial issues, such as data security and privacy, speed of financial transactions, resilience, and energy balance, to support the increasing number of customers participating in P2P markets [105]. If a trading platform deploys BT, high computational costs of blockchain consensus mechanisms and scalability difficulties must be addressed [35,36,106].

2.3.5. Legal Challenges

- As with other novel technologies and business models, the P2P model is still not supported by existing regulatory structures. The regulatory instrument needs to be amended to enable P2P energy trading. For instance, the status or scope of the prosumer must be defined in law [107], and the third-party access (TPA) regime must be established to allow prosumers, or third parties, to access the grid [107,108]. Moving forward, it will be required to amend the laws to accommodate P2P energy trading [109]. Efforts are being made to consider how regulatory schemes should facilitate the development of P2P energy trading and deal with the associated challenges [13,85,85,110].
- In the P2P market, contractual arrangements between prosumers and consumers are no longer conceived as bilateral contracts, as the P2P market implies multi-bilateral arrangements among agents. The contractual relationships are still undefined among prosumers who operate in the same energy trading platform and share the electricity generated by their self-production units. This legal issue is crucial for designing a P2P trading platform and regulating the energy transition [10]. New contract types are needed to describe agreements between prosumers and consumers, especially when counterparties use the public grid [108]. In addition, this would require new market rules and mechanisms [95]. Designing smart contracts that integrate consumers, prosumers, service providers, and utilities requires a paradigm shift as the energy market for P2P trading must be dynamic. Most importantly, the new framework requires new and potentially more flexible electricity tariffs, which are currently highly regulated [10,108].
- For the P2P platform deploying BT, the lack of legal frameworks inhibits innovation, so blockchain implementation and broader adoption are hindered [109,110]. In distributed system architectures such as blockchain, it is not clear who bears legal and technical responsibilities for the negative consequences of the actions of different parties [111]. For example, if a large-scale attack is successfully conducted due to a software or hardware error in the system, there is no central authority to which

consumers can turn with their complaints [112]. It is important to ensure privacy, confidentiality, and identity management when all trade and transaction information is recorded by multiple participants in shared ledgers [107]. Moreover, smart contracts should be regulated in the existing legal context to ensure compliance with the laws and consumer protection [113].

2.3.6. Environmental Challenges

- P2P energy trading has the potential to deliver environmental benefits, but it is challenging to build environmental awareness for customers and transform them into prosumers [114]. Customers who decide to become prosumers are likely to have environmental awareness, while other factors also influence such decisions [115]. A lack of environmental awareness may result from a lack of understanding of the benefits and costs of RE [116]. Customers should be educated on the share of fuels used in generating electricity they consume so that they become aware of the importance of RE in the electricity supply [117].

3. Methodology

To investigate the key drivers and challenges related to P2P energy trading, PESTLE analysis was applied, which is an analytical tool for evaluating the impact of existing and future external factors that most influence the development of business activities or projects at the macro level [72]. In this work, PESTLE was used to understand the current trends and changes affecting the market environment for businesses and organizations by focusing on the key drivers and challenges for the development of the P2P energy trading project in Thailand considering political, economic, social, technological, legal, and environmental aspects.

3.1. Data Collection

Drivers and challenges were collected by conducting semi-structured interviews with project developers of 7 approved P2P energy trading projects under the ERC sandbox program in Thailand. Each developer was interviewed separately between May and September 2020. Each interview lasted between 45 and 60 min, and interviewees were audio-recorded. Figure 1 shows the details of P2P project developers and their projects in the ERC sandbox program. There were five groups of P2P project developers in the ERC sandbox, including real estate developers, electric utilities, universities, chemical manufacturers, and engineering, procurement, and construction (EPC) developers. Each project has a different type of business model, players, and roles. For example, a project led by a real estate developer aims to create a local trading between buildings within its community through a blockchain-based trading platform. A project led by utilities aims to develop an energy trading platform that allows prosumers and consumers in their service areas to trade the excess PV electricity. For industry-led projects, they aim to increase the use of RE, enable energy trading in their industrial areas, and conduct carbon credits between industries through trading platforms. The type of P2P business model for energy trading as pilot projects in the ERC Sandbox program can be divided into two main types: the first is a direct P2P energy trading through a blockchain-based trading platform, and the second is a direct P2P energy trading through a trading platform based on a bilateral agreement. In this type of trading, the trading pair between prosumers and consumers must be matched and reach an agreement before participating in a P2P energy trading platform. There are five P2P projects that use a trading platform based on BT to enable P2P transactions. The other two projects do not use BT, because transactions between prosumers and consumers are based on the agreement on the trading pair contract. For project areas, the scope of trade areas can be categorized into 4 types: small community, industrial area, campus area, and large community, as shown in Figure 1.

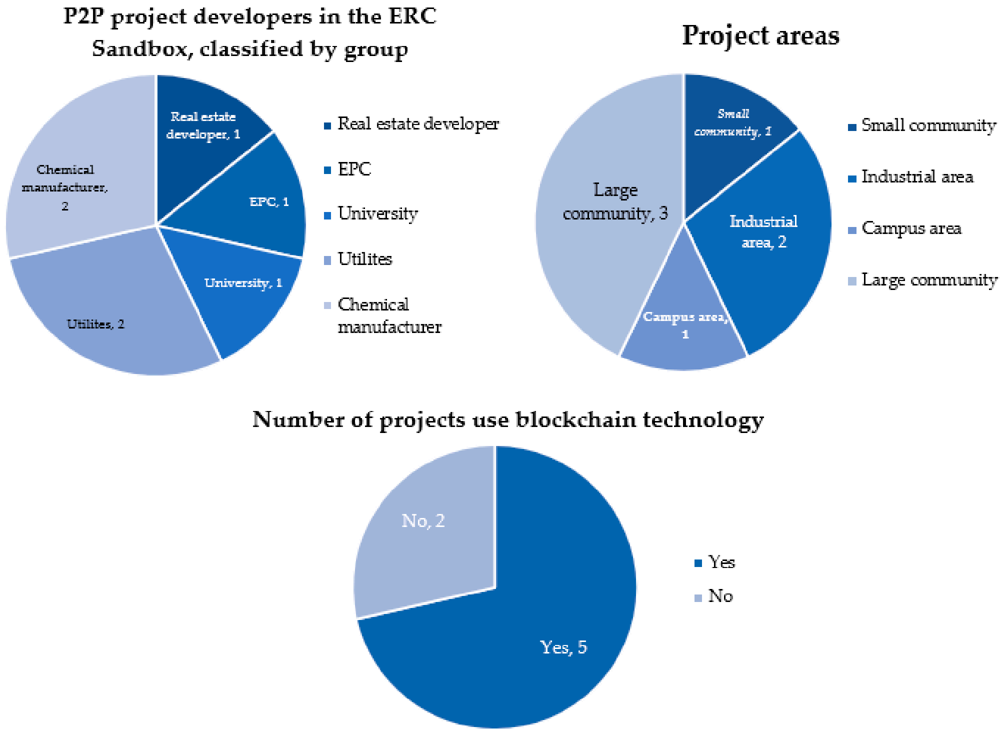

Figure 1. Overview of P2P projects in the ERC sandbox program in Thailand classified by project developer, project area, and the use of BT.

The interviews consisted of 4 parts, and the details of the questions are given in Appendix A. First, we asked questions about the background of the developer's company and project, including objectives, the scope of work, financial resources, project status, and technology used. Secondly, interviewees were asked to identify their drivers for the development of the P2P energy trading project. Third, we asked project developers to discuss their challenges in implementing P2P energy trading projects in the ERC sandbox program. For the second and third parts, we used the PESTLE analysis framework, which includes political, economic, social, technological, legal, and environmental aspects. This analysis provides a comprehensive overview of the entire P2P business in the macro environment. It will help determine the current external influences impacting P2P business adoption and help organizations maximize the opportunities of and minimize the threats to P2P business development. Before moving to the next part, trends/drivers and challenges that we had reviewed were presented to the interviewees to help them to recall if they missed some points. In the last part, interviewees were asked to formulate and discuss policy recommendations to unlock future regulations and support the full implementation of P2P energy trading in Thailand.

3.2. Analysis

The information from the second and third parts was analyzed to categorize the drivers and challenges in implementing P2P energy trading projects according to the PESTLE aspects. Keywords related to drivers and challenges that were frequently mentioned were extracted and then categorized into the PESTLE framework. The projects that involved those keywords were counted to identify the issues in each aspect where the project developers expressed similar or diverse views and experiences.

4. Results and Discussion

4.1. Drivers

4.1.1. Results

Figure 2 shows an overview of the perceived drivers for the development of P2P energy trading projects from the perspective of PESTLE aspects. The group of economic, social, and technological drivers has the most factors identified by project developers. The most frequently mentioned factors for the development of P2P energy trading projects are related to the national plans (PDP, AEDP, solar household scheme) (P), energy cost reduction (Ec), deployment of smart meters (T), implementation of the regulatory sandbox program (L), and climate change and greenhouse gas emissions reduction (En). The factors discussed by most project developers were considered to be the most important drivers for the development of P2P energy trading projects. The details of drivers in all aspects are discussed below.

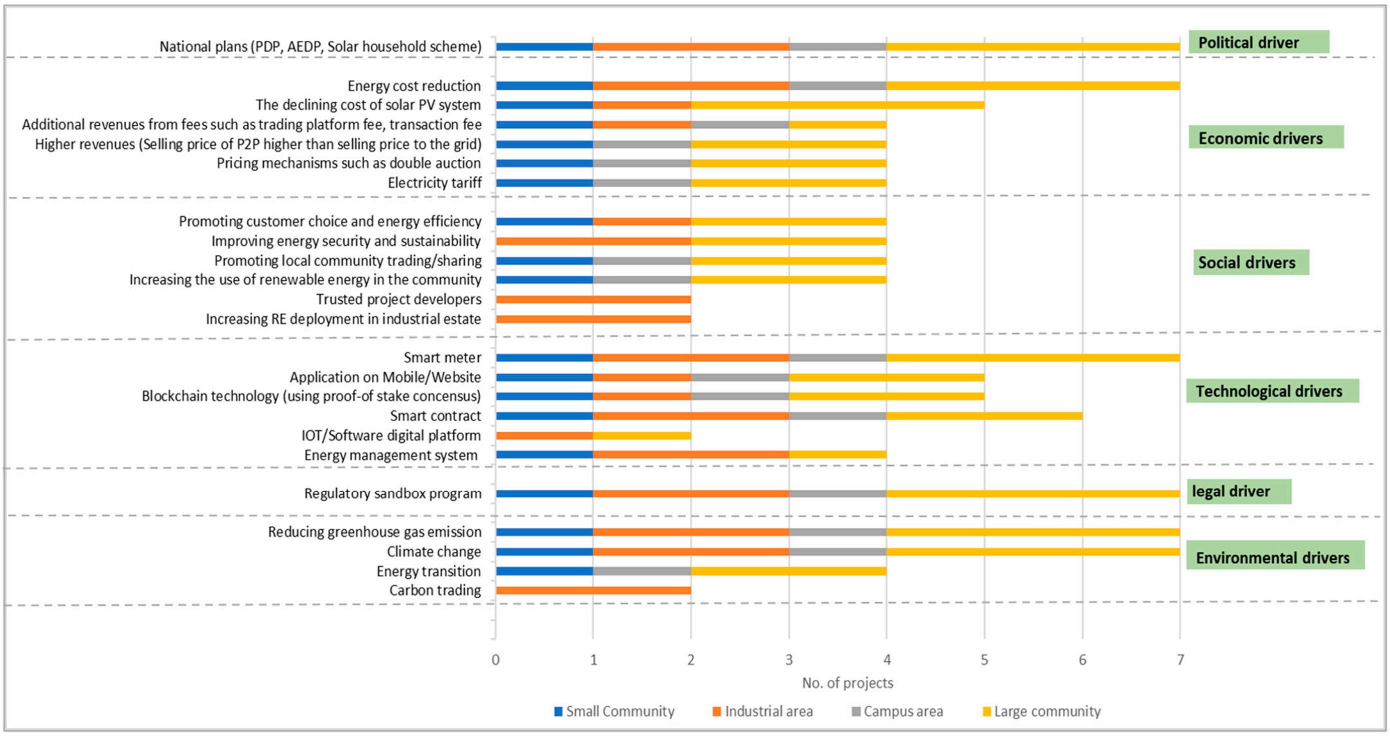

Figure 2. Perceived drivers for P2P energy trading project development under the PESTEL framework.

- Political

National energy policy and plans such as PDP, Alternative Energy Development Plan (AEDP), and the National Greenhouse Gas Roadmap were perceived by all interviewed project developers as political drivers for the development of P2P energy trading projects in Thailand. These plans aim to increase the share of RE in generation, and end users particularly in the industry sector have become prosumers with some surplus energy that is not allowed to flow to the grid. From the developers' perspective, instead of curtailing this excess energy, the P2P energy trading model can be a tool to add value to this excess energy while promoting the adoption of RE in the household and commercial/industrial sectors. The project developers agreed that Thailand has clear policies and plans of increasing the share of RE and reducing greenhouse gas emissions, and these clear policies and plans have motivated them to explore the P2P energy trading.

- Economic

The energy cost reduction was identified by all interviewed projects as the main drivers for the development of P2P energy trading projects. They agreed that P2P energy trading offers benefits in terms of bill savings that encourage prosumers and end users to participate in the P2P energy trading platform. Prosumers can earn additional revenue by selling excess electricity in the P2P system instead of feeding it into the grid for free. In addition, the declining cost of solar PV systems was also highlighted as the important driver for the development of P2P energy trading projects. Most project developers viewed this trend as a business opportunity for developing a local P2P energy trading platform and utilizing excess electricity generation from the solar system for the maximum benefit of the prosumer. If the solar PV system is used under such conditions, it can help reduce household electricity costs and establish efficient energy management in the community. In addition, implementing P2P energy trading projects can generate additional revenues such as trading platform fees and transaction fees as mentioned by some project developers. Pricing mechanisms and electricity tariffs were also considered economic drivers, as pricing mechanisms such as double auctions allow prosumers and consumers to bid/offer the price of electricity in the P2P market. Prosumers can thus benefit from this advantage by setting the selling price below the electricity tariff, while consumers can purchase P2P electricity cheaper than from the grid.

- Social

Local community sharing/trading, increasing the use of RE in the community, increasing energy choices for consumers, and improving energy security and sustainability were seen by most project developers as social drivers for the development of P2P energy trading projects. These drivers can build relationships One developer from the real estate sector emphasized that the concept of P2P energy trading can increase customer choices, maintain a sustainable living, and encourage the use of DPVs and other DERs for local consumption. This concept of P2P energy trading can lead to a smart, green energy community that can, for example, use solar technology to generate clean energy for up to 20% of the community's total electricity consumption, increase energy security and sustainability in the community, and lead to positive social change. Similarly, a project developer from the industrial sector expressed a desire to develop P2P energy trading, as there is a need for the use of RE by end users in the industrial area. Implementing the P2P energy trading concept can help increase the use of green energy, improve energy security, and reduce carbon emissions in the industrial sector.

- Technological/Technical

Smart meters were seen by all project developers as the most important technological drivers for the development of P2P energy trading projects. This is because all electricity trading data from both consumers and prosumers on the trading platform are recorded in smart meters, which can help monitor energy consumption and the quality of electricity delivered to consumers. In addition, Thailand has a smart grid plan to replace smart meters. Other digitization trends, such as smart contracts and BT, were seen as the key technology drivers that facilitate P2P energy trading platforms and enable trading between consumers and prosumers. In particular, blockchain-based smart contracts have been deployed in various industries such as finance, real estate, healthcare, and insurance. In addition, most project developers indicated that using a platform based on BT can provide a high level of trust and security in energy trading transactions. This can enhance trust between energy trading participants through smart contracts. In addition, they emphasized the role of BT in enabling various types of transactions without intermediaries in the energy sector, especially in energy trading between consumers and prosumers by providing an automated market trading platform.

- Legal

The regulatory sandbox program was seen by all project developers as the main legal driver for piloting P2P energy trading projects. This program allows them to test the operation of P2P energy trading, which is not foreseen in the legislation, in a real environment with a small number of customers in a limited time period. All project developers agreed that the findings and results of the Sandbox Program can help all stakeholders, such as the government, regulators, and the private sector, to amend the regulation and remove barriers that hinder development so that the pilots can potentially be implemented on a larger scale once the post-Sandbox is in place.

- Environmental

Climate change and reducing greenhouse gas (GHG) emissions were perceived by all project developers as the main drivers to develop P2P energy trading projects. All interviewees agreed that the concept of P2P energy trading can help increase the use of RE in households, communities, and industrial areas, especially from solar PV systems for self-generation and self-consumption, where the systems do not cause air pollution or GHG emissions. This can help meet emissions targets and mitigate the negative impacts of climate change. As mentioned by the interviewed projects from industrial areas, the intention of developing a P2P energy trading project is not only to conduct P2P energy trading in their industrial areas, but also to operate carbon credits by converting unused land into solar farms.

4.1.2. Discussion

Based on the results, there are two main policy and regulatory approaches driving the development of P2P energy trading in Thailand: regulatory sandbox program and national energy policies. The sandbox program can be used to study the impacts, as has been done in Malaysia [53] and UK [48]. At the current precompetitive stage that P2P energy trading is in, sandboxes are a preferable approach to regulation because they allow for the testing of new ideas and subsequent development under relaxed regulations [118]. However, due to the limited scope and timeframe, it is not certain that all impacts arising from new business models will be considered to alert policymakers. Therefore, it is important to integrate P2P energy trading into current regulatory practices [36] and establish concrete details on the direction of policy development in P2P energy trading to increase the share of RE in electricity generation.

In addition, P2P energy trading was found to provide local benefits in the form of energy cost reduction and economic incentives to participants by making electricity cheaper than buying it from the grid. Sæther et al. [11] showed that P2P electricity trading can bring significant economic benefits to both the industrial site and the individual customer, saving 6.8% annually for the entire industrial site. Similarly, participants in the Quartierstrom pilot project in Switzerland emphasized the lower cost of energy as the most important factor for the willingness to participate in the P2P market upon entry, as this pilot allows them to set the selling price between the export rate and the electricity tariff to gain more benefits and attract more buyers [119].

However, Scuri et al. [120] found that economic incentives do not appear to be a strong motivator for P2P energy trading. Participants in the PowerShare application P2P energy trading can develop new and existing social relationships through the sharing/trading of electricity within communities [32]. A sense of community was perceived by participants at three pilot sites in Portugal to be enhanced by P2P energy sharing activities [121]. Similar to the Australian pilot studied by Wilkinson et al. [77], some participants revealed their intention to participate in the trial as the concept of supporting the local community. The social values of P2P energy trading are influenced by many factors. Brisbois [122] identified that the social values that emerge from P2P energy trading are likely to be strongly shaped by the cultural, economic, and institutional context from which the business model emerges. In addition, demographic factors such as young and educated people are an important factor associated with interest in participating in P2P energy trading.

Furthermore, the technological analysis revealed that current technological trends are available for the development of P2P energy trading. This analysis also highlighted the importance of preparing for technological changes in the energy trading market by developing a centralized energy trading platform for community groups or local power producers to sell electricity in the local area. Smart meter infrastructure is being deployed in many areas of the world [123] and in P2P pilots, as shown in Table 1.

Another environmental factor driving the development of P2P energy trading is climate change. Similar to the UK survey, it showed that the most important demographic factor associated with interest in participation was concern about climate change [124]. In addition, participants in the Australian P2P pilots expressed a high level of interest in the decarbonized transition in energy systems and knowledge of RE [77].

4.2. Challenges

4.2.1. Results

Figure 3 presents the main challenges in implementing P2P energy trading projects under the ERC sandbox program from the perspective of project developers. The group of technological and technical, legal, and economic challenges has the most issues identified by project developers in the implementation of P2P energy trading projects. The most frequently mentioned issues include the issue of the wheeling charge under the sandbox program and lack of policy commitment (P), high cost of technologies (Ec), power losses due to P2P transactions, voltage and capacity constraints, and concerns about power outages due to power quality and system reliability in the project area (T). The issues mentioned by most project developers were considered the most significant challenges to implementing P2P energy trading projects. The details of challenges in all aspects were discussed below.

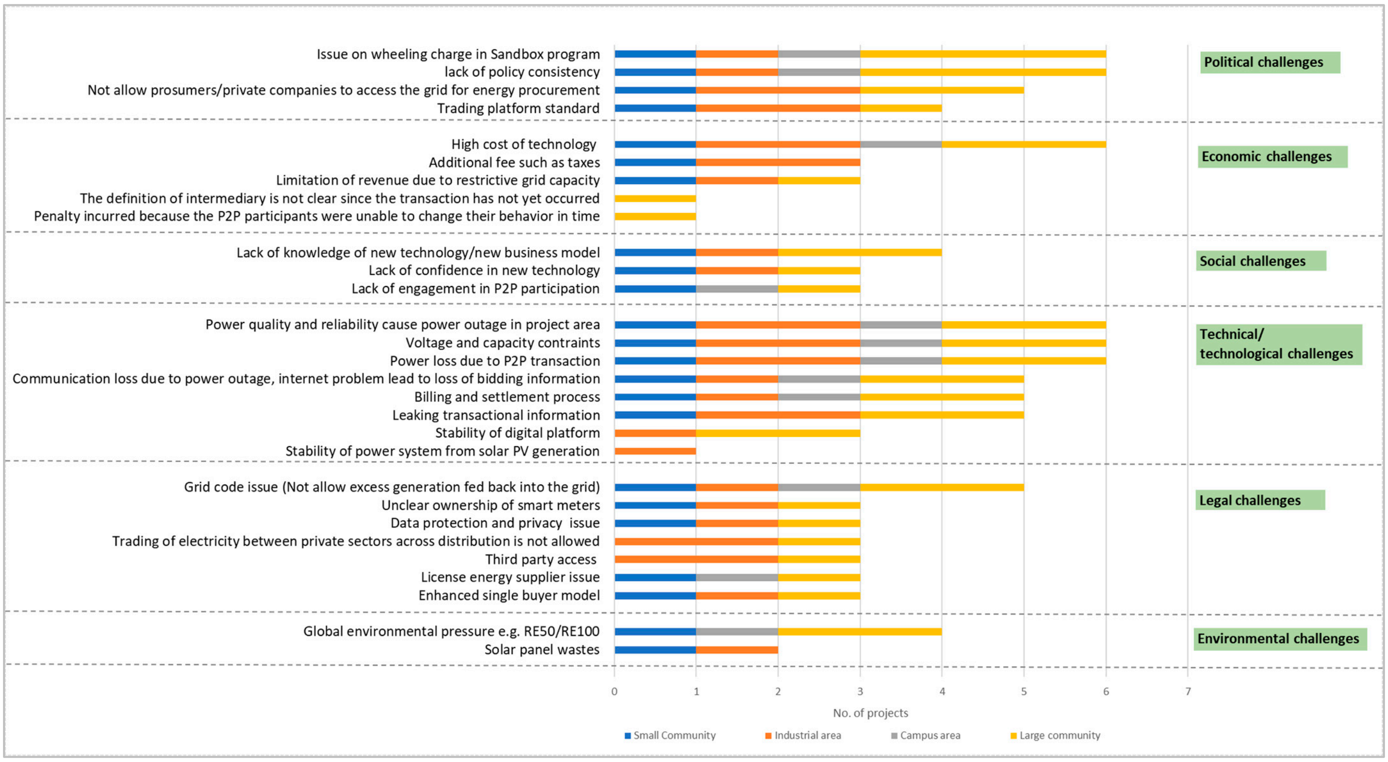

Figure 3. Perceived challenges of project developers to P2P energy trading project development under the PESTEL analysis.

- Political

The lack of policies related to P2P energy trading was seen as the main challenge to the development of P2P energy trading projects, leading to uncertainty in markets and investment. Most project developers indicated that the government should provide a clear, consistent, and practical policy direction for P2P energy trading. Under the current market structure, neither consumers nor private companies can trade power through the grid, as third-party open access is not allowed and wheeling charges have not settled at the attractive level for consumers and private companies. In addition, current grid connection rules for DPV systems do not allow excess electricity generation to be fed back into the distribution grid without installing a reverse power relay to connect to the higher voltage. On the other hand, one of the projects under the industrial area has seen that third-party open access for prosumers and private companies and trading platform standards are the major challenges as this interviewee focuses on how to make the business work as fast as possible.

- Economic

Most of the interviewed projects agree that the high cost of technology investments, such as DPV systems, digital trading platforms, smart meters, communication systems, and ICT devices, pose a challenge for calculating the appropriate rates for P2P participation to achieve the expected profit while attracting more participants to the P2P system. In addition, the development of P2P energy trading requires high investment to operate and maintain the reliability of the trading service.

One of the projects under the industrial area has seen that the additional fee is a main challenge. This is because the additional fees that occur from P2P energy trading participation may cause less attraction. The project developers mentioned this challenge as they provide trading platforms for external users, so they experienced a difficulty in estimating the appropriate charging rate to the remaining participants in the trading platform as the rate depends on the number of participants in platforms. Regarding taxes, there could be discrepancies if an incorrect price is charged, and this could lead to double taxation and penalization of any financial transactions by participants and shake confidence in the trading system.

- Social

The lack of knowledge of new technology and new business models were seen as the main social drivers in developing P2P energy trading projects in small communities, industrial areas, and large communities. For the project in a small community, developers are required to provide knowledge on the technology and business model to the community to build confidence of the participants in that community. To enhance social trust, it is important to design the P2P energy trading platform to support social engagement and promote community values. Trust between P2P market participants should be established by improving transparency and reducing fraudulent transactions. The P2P project in the campus experienced the challenge of engaging participants as the main objective is being a test bed of P2P trading where participants are campus buildings with a low incentive to join the project.

For the P2P projects in industrial areas and large communities, participants in P2P energy trading are usually industries and tend to have some basic knowledge about the concept of P2P energy trading. However, the complexity of business models could lead to a lack of good understanding and confidence in this P2P energy trading as some developer projects mentioned these challenges, as shown in Figure 3.

The interviewees from the P2P projects using BT agreed that the use of a blockchain-based platform can increase trust between participants. In addition, one interviewee pointed out that P2P energy trading platforms need to foster greater social connections and cohesion within local communities while preventing any negative interactions between members or participants. Through the P2P market, they must ensure further engagement of new and existing participants.

- Technological/technical

Voltage and grid capacity constraints, power losses due to P2P transactions, and power quality and reliability imbalance were the primary technical challenges in implementing P2P energy trading projects from most of the interviewed P2P projects. Most interviewees indicated that active participation in P2P energy trading may increase the risk of overvoltage and reverse power flow into the power grid. Typically, an increased penetration of solar PV systems could result in an overvoltage at various nodes and reverse power to the grid. Power exchange between consumers and prosumers via P2P trading can overload the grid, inevitably leading to power losses in the network [9]. The excess PV feed-in to the low-voltage grid could also affect the power quality if the electricity generation from the P2P system does not meet the power standard.

The billing and settlement process was seen by interviewees as another challenge in P2P transactions. As all electricity flowing through a customer's meter is purchased from one utility, double-counting could occur if this issue is not resolved. This challenge can also cause loss of communication due to unexpected events, such as power outages or internet problems, which can lead to a loss of bid or transaction information. Finally, P2P transactions must protect transaction data and avoid leakage, which is considered another major concern by project developers.

- Legal

The grid code issue was seen as the most legal challenge by most project developers for the development of P2P energy trading projects. As the grid code requirement of solar PV installations does not allow excess PV generation to be fed back into the grid without the installation of a reverse power flow relay, this creates additional investment costs for project developers. Furthermore, several legal challenges, including the enhanced single buyer model, license energy supplier issue, third-party access, data protection and privacy issues, and the unclear ownership of the smart meter were considered to be legal challenges at the same level in the implementation of P2P energy trading projects.

From the perspective of project developers, the enhanced single model is considered more challenging than other factors because private companies or prosumers are not allowed to access the distribution network for electricity trading without the involvement of utilities in this structure. They suggested that the main regulatory tool that allows private companies and prosumers to access the grid is the regulation that ensures TPA with the provision of an appropriate wheeling charge.

In addition, unclear ownership and data access of smart meters for the implementation of P2P energy trading was seen as the legal challenge by small community, industrial areas, and large community project developers. Typically, the ownership and installation of meters are the responsibility of DSOs. However, in a sandbox project, most project developers are invested in smart meters themselves, so this raised their concern that it will be unclear who will invest in smart meters or if duplication of investments may occur. Furthermore, under the existing law, third parties are not permitted to access meter data, but an implementation of P2P requires data access to smart meters. Due to the unclear ownership of smart meters, permission of data access cannot be settled.

Another legal challenge is the issue of the energy supplier license for prosumers. Currently, the legal status of prosumers, including the scope, role, and responsibilities, in P2P energy trading is unclear in terms of whether prosumers should apply for a supplier license or only obtain permits to sell electricity. Some interviewed projects suggested that the government should integrate prosumers into the existing legal framework to enable P2P energy trading.

- Environmental

Pressure to reduce GHG emissions and pressure from business partners to meet the requirements of RE50 or RE100 were perceived as environmental challenges by some P2P projects since the global calling for action to tackle climate change. Most of the developers from private companies indicated that pressure from business partners to meet the requirements of RE50 or RE 100 was perceived as an environmental challenge to developing P2P energy trading projects. This requires companies to commit to using 50% or 100% of their electricity from renewable sources for production, business operations, and export. In addition, most project developers from the industrial sector were concerned that the use of RE is limited due to its intermittent energy sources and that batteries are required to affirm these sources.

Moreover, the issue of solar panel waste was raised as a concern by most interviewees. The waste generated by solar panels that reach the end of their service life negatively impacts the environment as it involves small amounts of heavy metals. Therefore, the disposal of solar modules at the end of their life needs to be addressed through policy action.

4.2.2. Discussion

By considering the number of factors mentioned in each PESTLE component, the main challenges in implementing the P2P business model in Thailand are the technical issues, the legal framework, the economic barriers, and the political challenges. Technical issues include power losses due to P2P transactions, voltage and capacity constraints, and power outages due to power quality and system reliability imbalances in the project area. Technical limitations have also been identified in the implementation of P2P energy trading in a low-voltage grid [9,94–96,98]. Typically, solar PV systems are mostly connected to a low-voltage grid. The increased solar penetration could lead to overvoltage at different nodes and reverse power to the grid. If fully decentralized P2P energy trading is implemented, this could result in the inability to control the technical limit of the grid within the safety range during multiple transactions [30,99], which could lead to transaction losses [98]. Furthermore, the billing and settlement process, leaking transactional information, and communication loss due to a power outage or internet problem were found to be significantly associated with the loss of P2P transactions. Cybersecurity is required to implement countermeasures to ensure information security [101]. Although digitization trends are available to facilitate P2P energy trading, these technologies are very expensive and require high initial investments. Initial technological investments for the development of P2P energy trading include a digital trading platform, ICT devices, smart meters, and broadband communication infrastructure, as described by Heo et al. [88]. To ensure the stability of the trading platform, operation and maintenance costs are also required to implement the trading platform. In addition, the platform must consider technical and financial aspects, such as data security and privacy, speed of financial transactions, resilience, and energy balance, to support the growing number of customers participating in P2P markets [106]. This may result in additional fees such as platform fees, service fees, and taxes for participants to cover the total investment costs of project developers.

Similar to other countries, the regulatory framework remains the primary obstacle in most countries around the world [35,53], as direct P2P energy trading is commonly prohibited. Government initiatives are needed to develop appropriate regulations. The grid code requirements should be revised to allow excess PV generation to be fed back into the grid without the need to install reverse power protection. This issue has significant implications for the economic feasibility of solar PV systems and may limit revenues and make participation in P2P energy trading less attractive. In addition, the P2P model is still not supported by existing regulatory structures. The regulatory tool needs to be changed to enable P2P energy trading by allowing prosumers or third parties to access the grid through an open TPA regime [108,109].

5. Conclusions and Policy Recommendations

We identified the drivers and challenges in developing P2P energy trading projects by seeking the perspective of project developers. As the current state of the P2P business model is still in its preliminary stages in Thailand, it is important to identify external factors to identify weaknesses and opportunities in order to understand and address the main obstacles to the successful implementation of P2P energy trading. Such consideration would enable government, regulators, and policymakers to not only better understand the details of P2P energy trading, but also prepare for possible adjustments to the sustainable business model in the future.

By using a PESTLE framework, the drivers leading to the adoption of the P2P energy trading model in Thailand are the national energy plans, energy cost reduction, smart meters, the regulatory sandbox program, greenhouse gas reduction, and climate change.

The results show that Thailand has the same development path for P2P energy trading as other countries. P2P energy trading can be implemented in the current regulated electricity market under the regulatory sandbox program as in Malaysia [53]. Local benefits in the form of energy cost reductions and economic incentives are the main drivers for P2P energy trading development, as confirmed by the study in Switzerland, and can create social relationships through electricity sharing/trading within communities.

The challenges in implementing the P2P energy trading project in Thailand are mainly in technical constraints, which is related to power losses due to P2P transactions, voltage and capacity constraints, and power outages due to power quality and system reliability in the project area. Meanwhile, the high cost of technology, issue of the wheeling charge, and lack of policy consistency were also identified as the main challenges in developing P2P energy trading projects. Similar to other countries, the regulatory framework remains the main barrier to P2P energy trading adoption [53,55,56], especially in countries that are highly regulated, for instance, in Malaysia [53]. One of the key factors that can commercialize P2P energy trading under a deregulated market is the regulation that allows retailers to procure electricity from prosumers. One of the key factors in the commercialization of P2P energy trading is regulation that allows retailers to buy electricity from prosumers, as in the Netherlands and Germany. However, P2P energy trading can be implemented under a regulated electricity market as in South Korea [51,61].

P2P energy trading requires further work to be implemented in the real world. According to the findings, the main challenge for implementing the P2P business model in Thailand is technical constraints. To address this issue, utilities and regulators should revise and relax the current grid code requirement for solar system interconnection by allowing excess electricity generation to be fed back into the distribution grid without installing a reverse power relay. In addition, the permitting process should be less time-consuming by streamlining the process for obtaining a building permit. Due to the inconvenient permitting process, prosumers are likely to avoid such processes by installing a reverse power relay to curtail excess energy injected into the grid, causing difficulties for utilities, regulators, and policymakers in operating and planning the energy system. To this end, the P2P energy trading platform can be a way to obtain information on prosumers, which is available to utilities, regulators, and policymakers.

Current regulations in the power sector are largely based on the paradigm of the conventional electricity system, which needs to be changed to fit the P2P business model into the future. The existing regulations are still restrictive for the implementation of the P2P market worldwide. The current structure of the Thai electricity market is under the enhanced single-buyer model. Under this structure, private companies or prosumers are not allowed to trade electricity among each other at the distribution grid. Policymakers and regulators should address the regulatory tool that allows prosumers and the private sector to access the grid by establishing the rules that ensure TPA through the provision of wheeling charges. The rate should reflect actual costs and consider a reasonable return on investment for project developers. In addition, the tariff should be consistent with the current electricity tariff. Another important challenge is that only the power producer can obtain a supplier license, while consumers and prosumers cannot apply for the supplier license.

In the future, the P2P energy trading model may create a future electricity market that is strongly community-centric and decentralizes energy supply by consuming the excess generation of prosumers in the local area. In this way, it will encourage the deployment of RE at the local level, make green energy more accessible, and provide customers with choices that align with community values. Therefore, regulatory reform for the future development of the P2P energy trading model in Thailand should include opening the TPA regime, allowing a liberalized market for competition in the electricity market, and defining the scope, role, and responsibilities of the prosumer for P2P energy trading in the current law. These regulatory changes will enable the development of the P2P energy trading model in Thailand and minimize concerns about the economic, technical, and environmental impacts that hinder its development.

This paper presents the main political, economic, social, technological, legal, and environmental drivers and challenges for a sustainable development of the P2P energy trading model in Thailand. These finding can help key stakeholders such as policymakers, regulators, utilities, and private companies in other countries to better understand and anticipate the potential barriers to the implementation of the P2P energy trading business model. As each country has its own context, the common value of P2P energy trading can support a local green energy market that serves the needs of the community and promotes the deployment of RE to accelerate the transition toward cleaner energy sources. Future work should conduct the financial feasibility of P2P energy trading for prosumers in Thailand.

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Appendix A

Interview questions

Part 1: Background information of the project

1. What is the main objective of the P2P energy trading pilot project?
2. How does the business of P2P trading work? What does the business model for P2P energy look like?
3. What is the main technology used in the P2P energy trading project?
4. What is the project area of the project?

Part 2: Drivers

1. What are the main political drivers in developing the P2P energy trading project?
2. What are the main economical drivers in developing the P2p energy trading project?
3. What are the main social drivers in developing the P2P energy trading project?
4. What are the main technological drivers in developing the P2P energy trading project?
5. What are the main legal drivers in developing the P2P energy trading project?
6. What are the main environmental drivers in developing the P2P energy trading project?

Part 3: Challenges

1. What are the major political challenges in implementing the P2P energy trading as pilot project?
2. What are the major economic challenges in implementing the P2P energy trading as pilot project?
3. What are the major social challenges in implementing the P2P energy trading as pilot project?

4. What are the major technological/technical challenges in implementing the P2P energy trading as pilot project?
5. What are the major legal challenges in implementing the P2P energy trading as pilot project?
6. What are the major environmental challenges in implementing the P2P energy trading as pilot project?

Part 4: Policy and regulation

1. What are the major challenges/concerns in developing P2P trading under the current market structure?
2. What changes are required in the regulation to enable the P2P business model in Thailand?

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