ASIA School of Business

in collaboration with
MIT Sloan Management

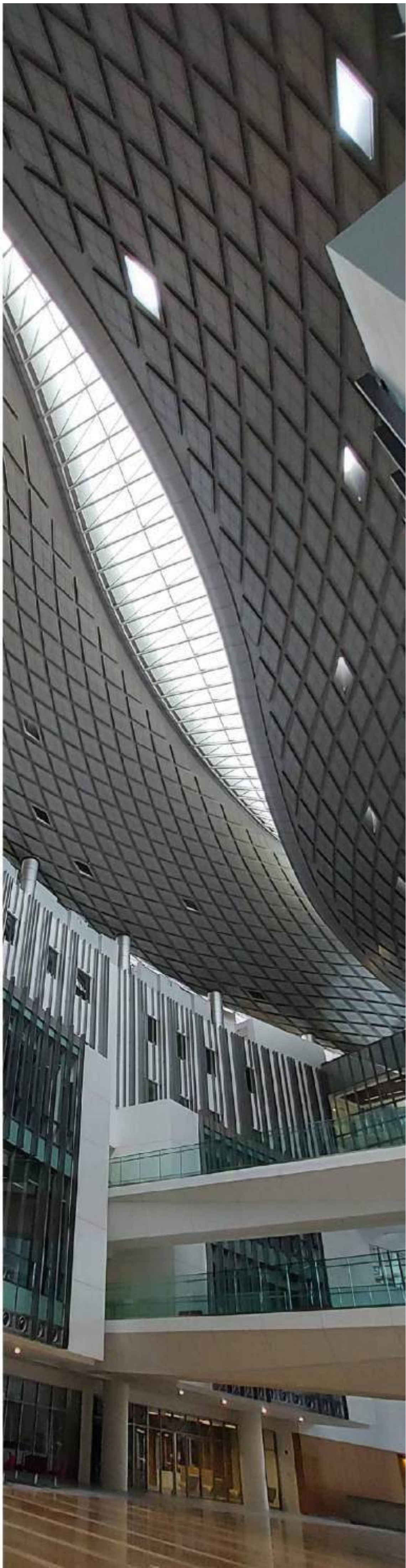
ASB Working Paper Series 04/2025

Center of Technology, Strategy and Sustainability

Charting New Currents: Legal Dimensions of Blockchain and Peer-to-peer Energy Trading in Malaysia

Karisma Karisma

November 2025



Attribution – Please cite the work as follows:

Karisma (2025). *Charting New Currents: Legal Dimensions of Blockchain and Peer-to-peer Energy Trading in Malaysia*. ASB Center of Technology, Strategy and Sustainability Working Paper Series 04/2025, Kuala Lumpur: Asia School of Business.

Please visit https://asb.edu.my/faculty-research/working-papers-database for further information on the ASB Center of Technology, Strategy and Sustainability Working Paper Series (CTSS).

1. Introduction

With its immense potential, blockchain technology is poised to revolutionise industries by enhancing their viability, operability, and functionality through its open, immutable, transparent, and decentralised characteristics. The increasing attention to this transformative power over existing business models is inspiring. Blockchain is making its mark in the renewable energy (RE) sector and reshaping peer-to-peer and community-based energy trading models. This unique role of blockchain in the energy sector is bolstering their effectiveness and presenting promising avenues for uplifting RE systems in Malaysia.

Analysing real-world RE projects provides valuable first-hand insights into the functionality of blockchain applications. Practical and current examples of blockchain include Dutch-based Powerpeers, France-based Sunchain, Japan-based Kepco, and Germany-based Tal.Markt. A common denominator is that the platforms advance user-friendly and seamless interfaces to facilitate trustless, equitable, and interoperable energy trading systems. However, while there are real-world applications and pilot projects, the current trajectory of blockchain in Malaysia remains uncertain due to the far-reaching implications to the legal and regulatory landscapes. In the Malaysian context, shifts towards blockchain integration are appealing and beneficial as 'prosumers', a term referring to consumers who also produce energy, can benefit from the increased flexibility and reliability of blockchain-based energy systems, which eradicate long-standing energy security issues.

Historically, Malaysia adopted a vertically integrated energy system. There has been a progressive shift towards liberalising the power sector by preventing entry barriers and encouraging competition. The government has since introduced the involvement of Independent Power Producers (IPP) to meet energy demands reliably. In recent years, there has been diversification of power generation, moving away from natural gas and coal supply, which is fossil fuel-based, ensuring energy security and positive environmental and economic effects.

The importance of carefully designed regulatory indicators cannot be overstated to guide the analysis of proper working initiatives in paving the way towards energy decentralisation in Malaysia. The author develops five key regulatory indicators that provide a framework for policymakers and regulators to develop appropriate tariff structures and methodologies to enable technology-centric peer-to-peer energy trading. These indicators allow policymakers to investigate their legal frameworks and are developed through desk-based qualitative study to assess the readiness of the power sector to address different stages of energy liberalisation fully and gradually mobilise and leverage key technology and infrastructure.

To guide the analysis of proper working initiatives in paving the way towards energy decentralisation in Malaysia, the regulatory indicators carefully designed can allow policymakers to investigate their legal frameworks. These indicators are developed through desk-based qualitative study to fully access the readiness of the power sector in addressing different stages of energy liberalisation and gradually mobilise and leverage key technology and infrastructure. Proper institutional arrangements are pivotal to ensure a conducive political and socio-economic landscape for blockchain-enabled energy trading in Malaysia. This includes tariff adjustments, defining the roles and responsibilities of new market actors, ensuring a set of privacy and security measures are in place, and non-discriminatory licensing frameworks.

2. Conceptual Framework

The primary objective is to examine the legal and regulatory industry-specific frictions confronting blockchain-enabled energy trading in Malaysia. These systems emerge within a legal landscape that remains under-inclusive, uncertain, and structurally outdated. The very paradigm shift catalysed by blockchain exposes the inertia of existing frameworks, highlighting their inability to accommodate novel practices and technologies.

The depletion of fossil fuels poses a challenge that contributes to an energy crisis, with far-reaching implications for energy security crucial to the well-being of a fair society. While blockchain is a potential entry point and a game changer in facilitating cleaner energy solutions, it is essential to overcome the carbon lock-in that ensures fossil fuels maintain a competitive advantage as the actual cost and externality severely deflate.

Addressing such ambiguities can ensure an efficient, equitable, and socially efficient energy transition, considering all stakeholders' needs and rights. First, addressing the definitional and conceptual ambiguity of individual and collective forms of prosumerism is essential. Unpacking these concepts promotes self-determination, allowing individuals to exercise autonomy and choice through the decision-making process on their energy behaviour, understanding the corresponding rights, roles, and obligations. With the immense potential of blockchain, the understanding is shifting towards the prosumer as a technology enabler with numerous commercial abilities. Legal instruments need to fortify collectively behind such intent.

Grid access is instrumental in facilitating transactive energy systems. Grid access plays a crucial role in facilitating transactive energy systems. This difficulty arises from the absence of a regulatory framework in non-discriminatory access, which constitutes the essential condition of energy democratisation, enabling prosumers to participate in the energy market at a limited access or wheeling charge. Further, the transition to technology-centric RE systems will benefit from efficient and cost-reflective tariff methodologies that support collaborative demand and supply-side activities. Network tariff designs should incentivise an active role in individuals participating in energy systems without unfairly burdening passive consumers who cannot invest in hard and soft technologies for active participation in the energy system.

This chapter advocates the development of a regulatory readiness assessment framework (RRAF) comprising regulatory indicators serving as a guide for policymakers and stakeholders in Malaysia to assess the country's readiness, driving comprehensive policies and regulations that enhance legal preparedness to address any industry-specific challenges.

3. Methodology

This Chapter adopts a qualitative research approach and undertakes a theoretical and doctrinal investigation to address the research questions set forth above. Further, the author employs deep desk research that provides distinctive insights into this multidisciplinary area. Through structured content analysis of primary and secondary data, information was collated on the legal and regulatory challenges in the widespread deployment of blockchain-enabled peer-to-peer energy trading and community-based models. This includes but is not limited to policy documents, government reports, energy industry reports, academic work, journal articles, commentaries, working papers, scientific web-based literature, technical reports and other relevant publications. We examine the broad challenges faced by both developed and developing nations in leveraging blockchain-enabled energy trading systems, delving into specific discussions to highlight how these issues manifest within the unique context of Malaysia.

4. Taxonomy of Blockchain Systems

Blockchain is a shared and decentralized ledger that stores data records within a set of blocks in a transparent, distributed, secure manner (Gawusu et al., 2022; Yapa et al., 2021). Given blockchain immutability, data on the ledger are tamper-proof and resistant to deletion (Rajasekaran et al., 2022). Cryptographic hash functions are elements of blockchain immutability. Hash functions transform the input of any arbitrary length into a unique fixed-length output of an “alpha-numeric string,” known as a hash (Jena & Dash, 2021). Cryptographic hash functions have essential properties, such as being deterministic, where if the input entered is the same, the resulting output produced would be the same (Saez et al., 2019). However, the output value changes entirely if there is even a minor variation in the input value.

Further, every block in a blockchain network has a timestamp and is cryptographically connected to the previous block, creating a linked sequence of blocks containing the previous block’s hash (Andoni et al., 2019). The ingrained feature of cryptography prevents data manipulation and falsification, in addition to facilitating traceability and accessibility of previously recorded transactions (Yang et al., 2020). A blockchain database continuously expands whenever a new transaction is added to the ledger (Lei et al., 2021). Participating nodes maintain and store an identical local copy of the blockchain ledger. Blockchain eliminates information asymmetry between multiple participants on a blockchain network, ensuring data integrity and transparency between nodes (Niknejad et al., 2021). This in turn demonstrates blockchain's potential in maximising efficiency and advances cost-effective measures for secure transactive systems.

Blockchain is a revolutionary technology grounded in decentralisation and autonomy, intertwining with freedom and democratisation concepts. There are four domains, public, private, consortium, and hybrid blockchains. Each of these domains has a different impact on business processes based on their specific parameters of governance and architecture. The type of blockchain utilised may vary depending on the specific use cases and applications.

However, the technology offers numerous advantages as an integrative platform for advancing transactive energy markets. With its high throughput and superior security, blockchain presents highly favourable outcomes. It is not mere hype or utterance as various pilot projects and user-friendly platforms have since been developed, lived, and experienced by prosumers, societies and energy communities. Exploring blockchain-based energy trading has seen various international examples, yet large-scale adoption remains limited. The hesitance is mainly due to the unchartered territory of blockchain technology within the energy sector, where a comprehensive legal and regulatory framework is still lacking. Notable projects such as Brooklyn Microgrid in the United States, Sunchain in France, and Quartierstrom in Switzerland have emerged as small to medium-scale implementations but have not transitioned into wide-scale applications. The adoption and sustainability of blockchain-enabled energy trading projects hinge on clear regulations for enabling the growth of these platforms, as the absence of such clarity prevents projects from scaling effectively and disallows them from accommodating current market needs. Achieving public acceptability is crucial for widespread adoption, particularly in decentralised and community-driven systems. In most jurisdictions, this depends on robust community involvement and acceptance.

Therefore, this discourse sets the stage for blockchain being the panacea of peer-to-peer and community-based energy models as an interoperable, decentralised, and secure platform, facilitating data transfers, and recording energy production, consumption, and transaction data immutably (Yang et al., 2021). It is worthwhile to delve into blockchain's functionality, viability, and practicality within the parameters of the energy sector in Malaysia.

5. Blockchain in Transactive Energy Markets

The adoption of blockchain in the renewable energy sector prompts advanced exploration. The advent of decentralised energy systems signifies a paradigm seeking to bring energy in proximity to end-users and ensure a bottom-up transition. Relatively little practical knowledge has surfaced in the ambit of blockchain-enabled peer-to-peer and energy community models in Malaysia. Despite blockchain exhibiting immense potential as a trust-based model and engendering a significant transition from single central point to decentralised systems, much of the discussion has been premised on facilitating energy transitions to low carbon-intensive, such as solar and wind energy, replacing fossil fuels. Therefore, this disclosure is crucial in line with Malaysia's National Energy Transition Roadmap in driving technology-centric solutions to achieve energy security, equity, and justice (*National Energy Transition Roadmap*, 2023). Blockchain emerges as a potential catalyst, introducing a fresh perspective for decentralised renewable energy systems to assert their influence over the forthcoming electricity consumers. By leveraging blockchain, prosumers and consumers are able to carry out energy transactions smoothly without depending on a single central authority, which is usually prominent in centralised systems. The author explores the key benefits of blockchain implementation in transactive energy systems.

First, prosumers and consumers utilising distributed and decentralised energy systems grounded on the blockchain can trade energy in real-time, allowing greater energy consumption and transaction autonomy. RE transition is effective at a lower cost (Ahl et al., 2020). It negates the monopoly of power industries and reduces energy losses at transmission and distribution networks. Second, apart from the autonomy over their energy choices, prosumers and consumers can perform energy transactions in real-time, with interoperability and transparency features (Xie et al., 2021). Third, more importantly, peer-to-peer energy transaction information is recorded on a tamper-proof ledger, facilitating energy bids and offers to match and allowing demand and supply to be processed in real-time and broadcast among prosumers to enable direct trading between participants (Andoni et al., 2019). Such a system ensures flexibility and robustness while mitigating the inherent challenges of centralised systems.

Blockchain simplifies, transforms, and streamlines billing and settlement processes in real-time in fully peer-to-peer and community-based energy models. Automated billing and settlement processes can prevent shortcomings of centralised billing systems, such as the associated administrative and intermediary costs and the inability to accommodate energy transactions in light of the move towards distributed, decentralised, and decarbonised systems (Andoni et al., 2019).

The rising utilisation of RE sources and infrastructure has resulted in more complex grid management. In energy networks, grid management is crucial for enabling the grid to operate at peak performance. However, centralised systems cannot effectively assist in network management, particularly with the proliferation of DERs. A blockchain-enabled grid can facilitate secure and reliable grid management operations and ensure effective coordination and balancing of supply and demand (Adeyemi et al., 2020). The increasing resilience and reliability in grid management can alleviate network congestion and facilitate transactive energy systems in real time by reducing the inherent complexity present in network processes (Hua et al., 2022).

Blockchain automating grid operations is a significant step in controlling grid devices. Further, according to scholars, integrating smart contracts within blockchain landscapes can enable the formulation of a "responsive self-healing grid" that detects, identifies, and resolves grid-related aberrations autonomously without intervention (Adeyemi et al., 2020). Further, increased transparency, reliability, and resilience of blockchain-enabled grid management solutions can heighten peer-to-peer energy trading transactions (Teufel et al., 2019). Moreover, blockchain can synchronise data from various sources and platforms, ensuring optimum voltage and frequency regulation (Aklilu & Ding, 2022). Further, as peer-to-peer energy trading is gaining momentum as a promising framework, blockchain can facilitate the diverse types, attributes, and ownerships of DERs and ensure bidirectional energy flow to enhance the overall performance of energy systems feasibly and cost-effectively. As such, blockchain offers a range of benefits, from real-time integration of stakeholders, DERs and enterprise data to unlock new opportunities for innovation and efficiency.

6. Blockchain and Energy Security

Energy security, indicating continuity, adequacy, and quality of energy supply and services, require prioritising institutional and normative changes. In this section, the author explores the pertinence of blockchain in favourably impacting energy security, driving significant shifts across the industry.

a) Availability

Availability is a critical element of energy security, ensuring that electricity supply is continuous and sustainable to meet energy demands promptly. The harsh truth is that fossil fuels are running out, and the diminishing availability of resources traditionally relied on for electricity generation can threaten energy systems. As we diminish our reliance on fossil fuels and shift towards renewable energy sources, blockchain technology potentially enhances energy ecosystems. It can efficiently and flexibly optimise virtual peer-to-peer trading, incorporating features such as interoperability and transparency.

Blockchain-enabled energy systems facilitate sufficient and sustained energy supplies by effectively managing and enhancing the operability and functionality of diversified distributed energy resources (DERs). As an architecture of trust, blockchain eases the functions of peer-to-peer energy trading platforms by eliminating intermediaries and promoting direct interactions between prosumers and consumers. Further, blockchain enhances energy security by removing the single point of failure (Wang et al., 2022).

b) Affordability

Another crucial aspect of energy security is affordability. Affordability involves access to electricity sources at lower costs. The volatility of energy prices due to the rapid and unpredictable fluctuations of fossil fuel prices triggers instability and prevents equity of access (Hughes, 2012; Ren & Sovacool, 2014). The sudden spike in electricity prices may not significantly deter affluent electricity customers. However, for individuals with limited financial resources, an upward shift in electricity prices can have an immediate and profound consequence. The increase in electricity prices from the top-down electricity structure further worsens the social inequalities that already exist in society. The transition to renewable energy sources and decentralised and distributed technologies ensures energy affordability, contributing to a more sustainable and inclusive energy landscape. Blockchain-enabled energy systems obliterate the cost of intermediaries when facilitating the supply and trade of energy access. Further, blockchain is a reliable technology for effective price signals using real-time data.

c) Acceptability

Sustainability, or acceptability, goes beyond environmental impacts such as carbon emissions rates. It includes the existence or absence of effective national and international governance measures designed to regulate the energy sector cohesively and ensure compliance with international norms, exemplified by the Paris Agreement.

Using blockchain in energy systems and incorporating prosumer-centric technologies and bottom-up transitions provide promising paths for achieving Sustainable Development Goals (SDGs) and decarbonisation. Decentralised energy systems (DESs) enabled by blockchain will support renewable energy (RE) landscapes crucial for SDGs.

The robustness of national energy systems regarding stability, safety, and reliability across geological, political, and economic realms becomes apparent through accessibility. Accessible energy refers to internal and external conditions that influence access to energy resources. Distributed generation and DESs allow universal energy access, bringing electricity to rural areas and facilitating surplus energy trading by connecting smaller generating units directly to the point of consumption.

d) Accessibility

Developing institutional and governance measures to facilitate blockchain adoption in energy trading systems is crucial for progressive transitions towards achieving energy security. Energy democratisation and liberalisation are overarching goals reflected in institutional ecologies adapting to blockchain's diverse aspects within the energy sphere (Lavrijssen & Parra, 2017). Adopting blockchain-enabled peer-to-peer (P2P) energy trading schemes require restructuring existing energy structures, involving conceptual and political considerations.

Blockchain implementation in energy systems poses challenges, from technical hurdles to addressing legal and regulatory barriers. It is crucial to timely assess whether blockchain implementation outweighs the costs before committing to this technology. Exploring blockchain's capabilities is essential, delving into decentralisation, decarbonisation, and digitalisation components and understanding how blockchain can catalyse shifts in the energy sector within these realms.

The growing demand for electricity in Malaysia has increased reliance on coal to meet the country's energy needs. In addition to coal, natural gas plays a significant role, accounting for two-thirds of the total electricity generation. Environmental concerns, such as the negative externalities from fossil fuels associated with extraction and utilisation, are significant motivators to transition towards prosumer-centric energy initiatives. The harsh truth is that fossil fuels are running out. Given their longstanding role in electricity generation, the decline in fossil fuels raises serious concerns for energy security and broader impacts for the nation.

In recent years, the energy mix has been increasingly diversified to meet the demands of residential and industrial consumers in light of the limited reserves of fossil fuels. The Malaysian Government has strengthened its commitment to low-carbon renewable energy (RE) transitions, aimed at addressing energy poverty and climate challenges, including the National Energy Policy 2022-2040, National Renewable Policy and Action Plan 2010, and National Energy Efficiency Action Plan 2015.

As Malaysia continues diversifying its energy sources and integrating RE to meet the nation's energy demands, the deeply ingrained human rights to access electricity engulf our attempts to explore the strategic realities of blockchain-enabled energy trading systems. As a pathdependent architecture, these systems hold immense potential to achieve energy policy goals while effectively tackling climate change, instilling a sense of hope and optimism for the future of energy in Malaysia.

Few energy democratisation models permit prosumers to actively participate in RE production, consumption, storage, and trading. Further, decentralised and distributed energy systems need to be more recognised for their role in strengthening energy security. This Chapter explores Malaysia's imminent challenges in integrating blockchain-based energy systems. By highlighting these challenges, policymakers and energy industry stakeholders can feel more aware and prepared for the task.

In expediting blockchain adoption, regulators and policymakers must address prevailing challenges to ensure the complete realisation of blockchain benefits through an enabling policy environment. Here, we explore the considerable benefits of blockchain in P2P and community based RE models.

7. Industry-specific Challenges

The author discusses the legal and regulatory bottlenecks that prevent the operationalization and functionality of blockchain-enabled energy trading systems. Engaging in the essential challenge is imperative to unlock the full potential of blockchain-enhanced energy trading systems.

a) Lack of consensus, consistency, and legal certainty in the domain of prosumerism

As market participants, prosumers are increasingly crucial in transitioning from centralised to decentralised energy systems. Energy democratisation refers to the active involvement of prosumers in managing adjusting, and regulating their energy production, consumption, storage, and transaction activities. To facilitate democratic deliberation over their energy mix and strengthen democratic representation in energy systems, policymakers should clearly define, recognise, address, and accommodate prosumers as technology enablers and facilitate their participation in P2P-centric activities. This concept is intriguing and crucial for stakeholders to understand and engage.

We address the definitional and conceptual ambiguities of the prosumer concept and the corresponding roles, rights, and obligations of prosumers. In the Malaysian context, disambiguating this concept proves beneficial, drawing particular attention to the defining characteristics of prosumers. As defining the prosumer concept remains a preoccupation in Malaysia, the European Union (EU) Directives serve as a starting point in conceptualising and developing this concept. EU Directive 2018/2001 and EU Directive 2019/944 (the Directives) define renewable self-consumers and active customers, respectively, by prescribing specific actions, such as (a) energy production, (b) energy consumption, (c) sale and storage of surplus energy, and (d) engagement in demand response and flexibility schemes ("Directive 2018/2001 on the Promotion of the Use of Energy from Renewable Sources," 2018; "Directive 2019/944 on Common Rules for the Internal Market for Electricity and Amending Directive

2012/27/EU ", 2019).

The aim is to transform social parameters by recognising prosumers as indispensable for the widespread P2P energy trading applications and enabling economic, environmental, social, and sustainability goals. The regulatory barriers impede the institutionalisation of prosumers. Instead of maximising prosumer welfare, the entanglement and lock-in of capital and funding to fossil fuels demonstrate the essentially "traditionalist approach" that the Government adopts, putting the position of energy companies at the forefront of energy systems (Inderberg et al., 2020).

Legislative recognition empowers energy participants to engage actively in local energy markets and sets out the rights and responsibilities of market players (Englberger et al., 2021; Fell, 2021; Morstyn et al., 2021). In such instances, a workable legal definition can prevent the problem of laws being too limited by realising a more comprehensive range of energy prosumers (Lavrijssen & Parra, 2017). On the one hand, establishing a clear and cohesive definition of prosumers can provide energy stakeholders with a solid foundation for engaging in analytical discussions to address the gaps in both individual and collective forms of prosumerism. Additionally, it is essential to ensure plurality, heterogeneity, and inclusiveness, coupled with considering both normative and institutional dynamics when formulating representative governance regimes.

In ensuring the active integration of citizens in the energy supply chain, regulators should emphasise the importance of national idiosyncrasies, such as geographic, social, and cultural factors, when formulating prosumer definitions. Traditional energy frameworks are built around large, monopolistic power stations. Malaysia must embrace and integrate prosumer initiatives with comprehensive legal definitions of active customers. Currently, P2P energy trading models exist only as a utopian wish list (Ruotsalainen et al., 2017; Wilkinson et al., 2020). Recalibrating policies that embrace prosumer-based models can remedy the regulatory disconnection caused by the lag in realising this utopian vision and facilitating effective diffusion and direct P2P energy trading.

As prosumers are key energy market actors in blockchain-enabled energy systems, representation and inclusive definition facilitate blockchain-based energy systems by enabling supportive landscapes for citizens to explore prosumer-related activities. Regulators should actively promote and reinforce the concept and identity of prosumers, aligning with their abilities to contribute to energy operations through blockchain and other technological applications.

b) Absence of non-discriminatory grid access

Establishing a third-party grid access framework is a pivotal precondition for achieving decentralised energy systems. Third-party access to grid infrastructures facilitates new entrants to engage in P2P energy trading systems, promoting energy liberalisation and democratisation. Institutional decisions concerning grid access should be taken at the early stages, particularly with the immense potential energy decarbonisation, decentralisation, and digitalisation have on energy landscapes. We argue that the lack of equitable grid access creates barriers to energy transition efforts. Access to public grid facilities is necessary for prosumers who wish to engage in P2P energy trading to engage in these activities through the private grid. Developing and scaling up a new distribution network is economically ineffective and impractical.

In most jurisdictions, prosumers who generate surplus energy are eligible for feed-in tariffs when they export excess electricity to the grid. However, selling the excess to market peers can offer more advantages than feeding it into the primary grid. In P2P models, peers can trade surplus energy directly with each other as they adopt a horizontal structure, are decentralised, are flexible, and can transform the energy market. Energy peers have complete control over their trading activities, including the amount of energy transacted based on energy availability and the selling price.

In this chapter, we explore P2P energy trading systems as facilitating a virtual rather than physical transfer of electricity. Public electricity networks function as a reservoir for electricity injection and withdrawal by market actors. While individual households may not physically export electricity directly to their neighbours, access to the grid is essential to ensuring the smooth and efficient operation of P2P energy trading, allowing the transfer of surplus electricity into the shared pool (Zhou et al., 2020).

The primary obstacle in East and West Malaysia involves access to the public grid in light of a vertically integrated energy structure. The forthcoming introduction of a third-party access framework represents an advancement in leveraging prosumer engagement to meet renewable energy goals and allow bi-directional energy flows.

In fostering competition in energy landscapes and placing prosumers on a more level playing field with conventional energy players, access to the public grid should constitute an inherent right of prosumers possessing generation units. Malaysia should introduce non-discriminatory access to public grids as the central pillar to facilitate P2P energy trading and transactive energy markets. Regulators can tie up such access by obliging contractual agreements that set out reasonable wheeling or access charges and tariffs to recoup capital and operational expenditures and ensure the stability of energy infrastructure.

c) Lack of appropriate tariff regimes to support peer-to-peer and energy community models

Addressing network usage tariffs is crucial in both horizontal and competitive energy markets, which demand flexible tariff structures. Many countries still need to define suitable tariff methodologies amidst the advent of decentralised energy system and energy prosumerism.That being said, to prevent grid congestion and ensure the grid's efficient operation, countries should consider implementing various tariff strategies, such as time-of-use, real-time pricing, and critical peak pricing. These strategies address the diverse behaviour of prosumers participating in decentralized systems, effectively managing their activities to optimise grid performance. Scholars have stressed the importance of government oversight in the development of local energy markets and the discussion of tariff structures, which play a crucial role in maintaining grid stability and delivering value to stakeholders actively engaged in local energy markets.

This chapter offers a comprehensive overview of the prevalent challenges that hinder the adoption of blockchain-enabled energy trading systems within energy markets, focusing specifically on this subject. Additionally, this chapter highlights the importance of adopting legal and regulatory frameworks that can significantly influence the widespread deployment of energy trading systems.

To underscore the significance of regulatory implications, it is essential to highlight the role of network system operators. As intermediaries, they will continue to play a pivotal role within the dynamic landscapes of local energy markets. Consequently, complete disintermediation is not feasible, since system operators are responsible for ensuring the secure and reliable operation of public grids, as well as the proper functioning of interconnected public network facilities and infrastructure.

The current tariff methodology poses an obstacle in blockchain-enhanced peer-to-peer energy trading offering a weak stimulus for dynamic efficiency in the behaviour of individual and collective prosumers when pursuing efficient practices (Felice et al., 2022). In this portion, we explore conventional volumetric and fixed tariffs and their implications in incentivising the deployment of blockchain-enabled energy trading systems.

i. Volumetric tariffs.

There are inherent limitations to applying volumetric tariffs, especially considering that capital and operational expenditures are not evenly distributed, particularly when these costs pertain to capacity. Inefficient tariff designs place undue pressure on the grid, necessitating grid reinforcements.

Volumetric tariffs, the most widely utilised, charge consumers based on the total amount of energy consumed over a specified period. Prosumers, with their diverse and heterogeneous energy profiles, render the current framework obsolete. With the immense potential of distribution energy resources, volumetric tariff triggers a cross-subsidisation conundrum in the electricity grid as it shifts the cost burden from active prosumers to passive consumers (Reneses et al., 2011). Generally, as part of the solution for energy security, network tariff methodologies should incentivize active, technology-focused prosumers, without unfairly burdening passive consumers.

Moreover, as peer-to-peer energy trading gains traction in facilitating the bilateral use of the public grid, it presents several challenges stemming from the inefficacy of existing tariff methodologies. Most notably, the surge in energy exports via public grids has led to significant network congestions, peak loads, and phase imbalances, primarily due to the absence of price and economic signals (Dudjak et al., 2021; Rocha et al., 2019; Silva-Rodriguez et al., 2022).

This generally leads to increased investments and reinforcements in the grid, causing financial instability owing to maintenance and operational costs (Hoarau & Perez, 2019). In a post-modern context, the emergence of blockchain-enhanced energy trading has made the development of network tariff structures significantly more complex. Decentralizing energy systems leads to extra grid costs that cannot be recouped through a volumetric tariff structure focusing on consumption rather than capacity (Srianandarajah et al., 2022). In essence, volumetric tariffs fundamentally fail to encourage prosumers to reduce their peak loads and to ensure efficient utilization of the network. They do not take into account critical factors such as price, time, and the location of bidirectional energy imports and exports. In conclusion, volumetric methodologies fail to provide precise pricing and economic cues in light of modular energy technologies in peer-to-peer or community-based business models.

ii. Fixed tariffs

Distribution System Operators (DSOs) are inclined to implement network tariffs that primarily focus on recovering costs associated with capacity. The uniform application of fixed tariffs across all network user groups diminishes the motivation and incentive for prosumers to actively participate in bidirectional energy trading systems within the public grid (Brown et al., 2020). In line with economic efficiency and cost-reflectivitiy, system operators are unable to fully recover the cost incurred. Further, imposing the same fixed charge on both passive consumers and active prosumers who participate in peer-to-peer energy trading shifts the financial burden disproportionately onto the less affluent, despite the fact that grid usage is notably higher among active prosumers (Schittekatte & Meeus, 2018). The flexibility and efficiency of decentralized energy systems are not adequately represented in current tariff methodologies (Brown et al., 2020). Therefore, it may not be prudent to charge prosumers for using the grid for both energy imports and exports. Typically, non-dynamic methodologies do not account for consumption time or load curves during peak and non-peak periods, nor do they consider the stress or congestion levels of the network that can ultimately affect the reliability of power systems.

iii. Capacity-tariffs

By advancing capacity-based tariffs, these tariffs effectively address the challenges posed by volumetric tariffs in realizing the inevitable liberalisation of energy systems. Although not an ideal representation of tariff methodologies for energy trading systems in local markets, capacity-based tariffs encourage consumers to reduce their consumption during peak hours, thereby aligning energy trading activities with pricing and economic signals (Tomar et al., 2021; Willems & Zhou, 2020). By incentivising prosumers to lower their individual peak demand, system operators can efficiently recoup both capital and operational expenses.

Current regulatory frameworks are ill-suited to address the fluid and dynamic nature of energy landscapes, such as heterogeneous network users with different energy profiles and flexibility mechanisms. Governance and regulatory regimes must introduce tariff designs that better reflect renewable energy transitions, chiming with the utilisation of distributed energy resources and blockchain platforms as drivers for the exponential growth of clean energy. Capacity-based tariffs are preferable over volumetric and fixed tariffs for importing and exporting electricity due to their superior alignment with price and economic signals, promotion of network efficiencies, and mitigation of strain and congestion on network systems (Willems & Zhou, 2020).

Capacity-based tariffs are contingent on peak demand within specific time intervals, typically ranging from hourly to fifteen-minute increments, across various timeframes such as daily, monthly, seasonally, or annually, incentivising network users who reduce their load during peak periods. Many countries are progressing towards capacity-based tariffs from purely volumetric tariffs as they are cost-reflective and represent the actual cost of network utilisation (Tomar et al., 2021). However, capacity-based tariffs create a paradoxical scenario where consumers without flexible equipment bear higher network fees than those who can invest in and utilise such technologies (Schittekatte & Meeus, 2018). Introducing hybrid tariffs is a viable transition strategy that allows network users to gradually move towards cost-reflective tariffs without significantly disrupting energy landscapes.

iv. Dynamic tariffs

Dynamic tariffs represent network pricing regimes with high temporal and geographical granularity, conveying price and economic signals at shorter intervals (Abdelmotteleb et al., 2022). In addition, it reduces grid congestion by promoting the efficient use of network tariffs and achieving a fair and efficient energy export and import. Dynamic tariffs effectively communicate price and economic signals, prompting active consumer response to market conditions and encouraging investment in DERs. This approach also promotes load-shifting to off-peak periods, thus driving changes in energy production, consumption, and trading and preventing network congestion (Abdelmotteleb et al., 2022). By implementing dynamic and cost-reflective tariffs for locally produced and consumed energy, utilising community-owned assets at different times and locations, and establishing a comprehensive smart metering infrastructure, we can foster the growth of peer-to-peer models in the energy sector.

While such progressive tariffs promote efficient and optimised network usage and incentivise prosumers to invest in DER operations, complicated designs impede prosumer engagement in technology-centric business models (Brown et al., 2019; Hennig et al., 2022). The increasing granularity in energy prices in light of heterogeneous energy profiles generates complexities and intricacies, discouraging active prosumers as simplicity carries weight in promoting public acceptability.

Authorities derive domestic tariff rates from the total energy consumption, including a standard monthly charge that does not fluctuate with energy consumption. Apart from fixed and volumetric tariffs for commercial and industrial entities, capacity-based charges constitute an important component of network pricing (Tenaga Nasional Berhad, n.d.). Three prevailing tariff design structures in Malaysia are prominent: fixed, capacity-based, and volumetric-oriented (Kumar et al., 2021).

Industrial and commercial entities stand to gain from time-of-use, peak, and off-peak tariffs, providing customised pricing and operational flexibility. In contrast, households are generally subject to fixed tariffs relative to tiered or categorical classifications (Tenaga Nasional Berhad, n.d.). The NRAs set and monitor the imposition of these tariffs, taking into account feedback from DSOs and other stakeholders DSOs and other relevant parties. In addition, the Minister of Energy, Water, and Communications formally endorse these electricity tariffs per Section 26 of the Electricity Supply Act 1990 ("Electricity Supply Act 1990,"). To ensure meaningful participation, smart metering infrastructure and platform-based soft and hard technologies can work in parallel when articulating price and economic signals provide the actual reflection of costs. Proper tariff designs drive network usage, ensuring efficient congestion management, voltage control, and resource optimisation.

8. Key Regulatory Indicators Paving the Way to Energy Decentralisation in Malaysia

In the next section, the author develops five key regulatory indicators that provide a framework and scope for regulators to construct tariff models and methodologies that are contextually appropriate to enable blockchain-enabled peer-to-peer energy trading.

These indicators are benchmarks and encompass a range of institutional design considerations to accommodate innovative technologies. They do not aim to be exhaustive or definitive but provide valuable insights when mapping the path of decentralised, technology-centric energy transitions.

a) Intelligibility

Intelligibility forms the primary and basic tenet in facilitating the transition for successful governance of blockchain-enabled energy landscapes.

Do tariff methodologies demonstrate intelligibility while remaining aligned with other fundamental principles?

Intelligibility forms the primary and basic tenet in facilitating the transition for successful governance of blockchain-enabled energy landscapes. Network utilisation fees must be clear and comprehensible to transmit price and economic signals effectively (Lummi et al., 2018). By shifting social structures towards the effective use of renewable energy systems through technology-centred approaches, we recognise the importance of creating tariff designs that encourage prosumer-centric behaviours.

While conventional tariffs, such as volumetric and fixed-based tariffs, offer the element of intelligibility, they place undue pressure on the grid and do not limit daily peak loads. Further, as explored above, it creates the cross-subsidisation conundrum between active prosumers and passive customers when network usage is more pronounced amongst the former to trade surplus electricity.

An inefficiently utilised network leads to rising reinforcement costs for distribution system operators. Implementing cost-reflective tariffs that consider time, location, and capacity may bring about inherently challenging complexities. While dynamic tariffs aim to reduce peak loads and congestion, they may fail to effectively involve prosumers in decentralised energy systems and the network as a whole. Adaptive behaviour focused on optimising network utilisation can only emerge with clear and established network tariff methodologies. The transition to decentralised energy systems is smooth with the technological infrastructure to configure tariff breakdowns accurately and simplistically for a user-centric experience.

In Malaysia, the utility company Tenaga Nasional Berhad is leading the way with its deployment of smart meters. With an estimated 9.1 million households projected to have smart meters installed by 2026, Malaysia is well on its way to embracing technology-centric energy systems. Although the hardware is present, smart meters are not utilised to their full potential in energy landscapes. Underutilisation hinders maximising the benefits of smart meter technology, which empowers consumers to adjust their consumption in response to the system's marginal price. To address this gap, it is crucial to establish precise regulatory standards and guidelines for the installation and maintenance of smart meters.

The introduction and roll-out of smart meters can promote intelligibility. They offer the potential to enable real-time monitoring and measurement of electricity generation and consumption, thus providing the necessary precision and clarity in billing statements (International Renewable Energy Agency, 2019). Smart meters facilitate the implementation of dynamic and variable tariffs by effectively conveying price and economic signals to prosumers and consumers (Hennig et al., 2022; Vijayapriya et al., 2010). Integrating smart metering technology with communication infrastructure is crucial for energy production, consumption, and transaction data. While there are pre-existing silos surrounding smart meters, Malaysia is progressing towards the installation of digital infrastructures to propel success in decentralised energy systems.

The rapid adoption of smart meters and communication infrastructure is crucial to enabling transactive energy systems. Streamlining network tariffs can pave the way for regulatory sandboxes. With clear participant guidelines, these sandboxes will assess the viability of dynamic tariffs in fostering blockchain-based peer-to-peer energy trading in Malaysia. In 2019, Malaysia's Sustainable Energy Development Authority (SEDA) introduced a blockchain-enabled peer-to-peer energy trading pilot programme, partnering with Australia's Power Ledger. The pilot programme enabled prosumers and consumers to sell surplus energy over the grid (Sustainable Energy Development Authority, 2020).

Here, even though consumers are said to bear the entire network costs, there is an 11% cost savings when purchasing energy on energy trading platforms (Sustainable Energy Development Authority, 2020). Given that there is no one-size-fits-all solution in developing tariff methodologies, regulatory sandboxes serve as a vital precursor to devising effective legal and regulatory solutions. They foster discussions and consultations with regulators in the deployment of innovative transactive energy systems. Therefore, the high granularity of dynamic tariffs directly conflicts with the principles of simplicity. Smart meter and communication network efficiency hinges on synchronised tariff methodologies. Regulatory sandboxes, crucial for pinpointing Malaysia's optimal tariff design, can be developed and implemented to address these issues.

b) Non-discrimination

Non-discrimination entails equal treatment of all market participants in decentralised transactive energy systems.

Are network tariff constructions in DESs explained and justified by temporal granularity and load flexibility in light of the plurality of energy profiles and network utilisation of prosumers and consumers?

Prosumers, to ensure seamless peer-to-peer energy trading systems, should be granted non-discriminatory access to distribution grids, an essential prerequisite for addressing diverse societal concerns surrounding centralised energy systems.

The widespread use of Distributed Energy Resources (DERs) to lower peak demand and alleviate network congestion has led to the implementation of capacity-based and dynamic tariffs. These tariffs are not only cost-reflective but also increasingly discriminatory. Scholars Hennig et al. have thoroughly explained the difference between due and undue discrimination regarding the tariff charges applied to network users (Hennig et al., 2022). Establishing regulations that eliminate unjustified or undue discriminatory tariff practices through legal and policy measures is of utmost importance.

On the other hand, rational and explained differences in network tariffs based on temporal granularity and flexibility of loads are permissible. Network tariff methodologies should consider the diverse characteristics and capabilities of network users and their pluralistic needs. This consideration is particularly relevant when quickly scaling up different DERs. The regulatory indicator catalyses encouraging the transition towards Distributed Energy Systems (DESs) and the swift implementation of DERs.

c) Cost-reflectiveness and cost-recovery

Cost reflectivity refers to assigning network operators' costs to the users who caused them. It is the second most important principle when developing tariff methodologies.

Are the network tariffs in DESs allocated to reflect the network costs as closely as possible?

Cost-reflective tariffs ensure that system operators can recoup network infrastructures' capital and operational expenditures, thus ensuring their financial viability.

These tariffs perfectly align with the economic and price signals resulting from the gradual flattening of the load curve, the reduction in peak demand, and the efficient utilisation of the grid. Cost-reflective tariffs are pivotal in the design of regulations, as they offer valuable incentives for efficient investments in distributed energy resources (DERs). Cost-reflective tariffs are essential in shaping the structure and effectiveness of blockchain-enabled peer-to-peer and community-energy models by encouraging the scaling up of such investments (Dupont et al., 2014; Passey et al., 2017; Picciariello et al., 2015).

The cost-reflective tariff encourages network users to respond effectively to economic signals and make efficient decisions about their network usage. Ultimately, this approach minimises system operators' capital and operational expenditures. Adopting blockchain-enabled peer-to-peer trading and distributed energy resources (DERs) eliminates inefficiencies. It reduces the expenses associated with the grid by providing greater flexibility in generating and consuming renewable energy. Additionally, it accounts for real-time load prediction, reducing peak load and energy loss during transmission (Saxena et al., 2019). These improvements benefit the grid and are cost-effective for bi-directional energy structures.

However, since Malaysia's current tariff methodologies do not reflect network costs or the heterogeneity of network participants characterized by varying load profiles and flexibility mechanisms, they deter prosumers and consumers from engaging in blockchain-driven energy markets. Blockchain and peer-to-peer trading face significant regulatory obstacles, limiting the widespread adoption of the infrastructure needed for network support. The current conventional tariffs are not sustainable due to the increasing influx of private investments in DERs (Roberts et al., 2019).

Policymakers must remain mindful of the gestation phase - the interval between the adoption of cost-reflective tariffs and rollout of peer-to-peer energy trading models. An extended gestation period indicates a significant lack of investment in DERs, which hampers prosumers' ability to respond effectively to tariff changes. In such situations, regulators in Malaysia can turn to regulatory sandboxes to design and implement suitable tariff designs that can, in turn, heighten bi-directional energy trading.

For higher-voltage grids to adhere to cost reflectivity, market participants must be exempt from network tariffs. This exemption will prevent market participants from bearing the costs of unused or new transmission and distribution grid components. However, evaluating whether complete cost exemptions may generate negative externalities for passive consumers in conventional networks is pertinent, such as the unfair distribution of grid fees.

The rising number of DERs and the emergence of blockchain-based peer-to-peer business models impact the recovery of grid costs under current tariff designs.

Do tariff methodologies ensure the recovery all the efficient costs incurred by system operators?

Without a private microgrid to facilitate the transaction of locally generated electricity, system operators must accede to statutory responsibilities, technical hurdles, and network expenditures emanating from bidirectional energy flow in public distribution networks. In situations like these, it is essential to formulate tariff methodologies that allow distribution system operators to fully recover the costs they incur due to energy sharing and trading activities at the local level. This practice is vital to ensure the seamless provision of utility services.

Electricity networks bear a significant portion of transmission and distribution costs, and imposing volumetric tariffs that do not reflect network user profiles may hinder system operators from fully recovering the expenses incurred, especially with the rise of decentralised power systems. This situation may affect system operators' financial sustainability, leading to an inevitable death spiral. Regulators must develop effective strategies to ensure network tariff designs are established at cost-recovery levels, allowing for the recovery of all network costs. This endeavour includes residual or sunk costs associated with infrastructure investments and the costs of operation and maintenance incurred by system operators, especially in the context of blockchain-enabled peer-to-peer energy trading systems (Dupont et al., 2014; Passey et al., 2017; Picciariello et al., 2015).

d) Transparency

The methodological design process in developing tariffs should be allocated transparently to all network users.

Are tariff methodologies unambiguous and transparent in enabling network users to understand the cost breakdown of grid utilization during bidirectional energy trading?

Due to technological advancements and the advent of new business models, the variability within energy landscapes creates excessive opacity, making it difficult for network users to understand what they are paying for, mainly if there is no emphasis on transparency in methodologies and tariff design processes (Derakhshan et al., 2016). Although blockchain improves the transparency and traceability of energy generation and consumption by informing network users of the cost breakdown and energy mix, it rapidly outpaces facilitative regulatory instruments (Andoni et al., 2019). Smart meters and other communication infrastructures can ensure transparency via the collection and transmission of data. Such measures can foster the era of decentralisation, increasing engagement amongst prosumers and strengthening energy democratisation. Implementing security and privacy by design measures is crucial for preventing any trade-offs between transparency and privacy or security.

e) Gradualism

Regulators and policymakers should adopt a gradualist approach to regulating network tariffs. This strategy incorporates gradual, non-radical, and harmonised reforms, allowing a smooth transition towards more efficient peer-to-peer energy trading and community-based models.

Are tariff methodologies in decentralised energy systems subject to adjustments to allow network users to adapt to incremental changes and minimise transitional costs?

Network tariffs should change gradually to reflect the nature of DERs and hard and soft technologies (i.e., blockchain). There are valid arguments for adopting a gradual reform path. Gradualism helps minimise the disruptive impact of changes in regulatory frameworks and the rising energy costs on passive consumers who cannot utilise such technology. A phase-out approach reduces adaptation and adjustment costs from policy changes. While the blockchain fosters innovative business models, gradualism in imposing network tariffs encourages users to respond or reckon positively to market liberalisation without resulting in a disadvantage to passive consumers.

In Malaysia, regulators can allow opt-in or opt-out schemes to implement dynamic tariffs equitably and synchronously. Opt-in schemes empower consumers to make proactive choices that align with their needs and preferences, ultimately leading to a more equitable and consumer-focused system. In this context, the opt-in approach ensures a deep sense of fairness among network users, giving them equal access to respond to dynamic tariffs. Regulators should also explore the implementation of opt-out schemes, whereby consumers are automatically enrolled in default dynamic tariffs but can switch to non-dynamic tariffs. Unlike opt-in schemes, this approach can effectively expedite the progress of tariff reforms. It provides sufficient lead time for prosumers, system operators, and other market actors to adopt innovative-centric infrastructures, such as smart meters and communication infrastructures, to harness the potential of decentralised energy systems.

9. Conclusion

Blockchain is an incipient field constantly evolving, while fully peer-to-peer and community-based energy trading models are nuanced and intricate. Integrating these two concepts as an ongoing decentralisation and digitalisation process in Malaysia is anything but straightforward. However, the potential benefits of blockchain-enabled energy trading are clear: decentralising the energy grid reduces costs, improves efficiency, increases transparency, heightens energy democratisation and competition and goes linear in creating a more resilient and sustainable energy system. This chapter posits that industry-specific regulatory challenges associated with blockchain-enabled energy trading are significant but manageable, and by working together, governments, industry, and academia can develop the necessary frameworks to deploy this innovative technology safely and effectively.

In essence, this chapter makes three significant contributions:

1. Utilising the current electricity distribution networks is essential for blockchain-based energy trading platforms, since building entirely new microgrids or distribution lines solely for peer-to-peer exchange is neither economical nor realistic. The dominance of public distribution systems creates significant barriers for independent producers seeking to enter the market, hindering the process of liberalisation. Moreover, stringent regulatory frameworks, such as high connection charges and ambiguous exemptions in existing policies, discourage prosumers from accessing the power grid equitably, thereby undermining fair competition within retail electricity markets.

2. Traditional tariff methodologies present obstacles in adopting distributed energy resources and trading via individual and collective forms of prosumerism. The current tariff designs, such as volumetric and fixed tariffs, do not effectively convey price and economic signals through legal and regulatory mechanisms. Further, existing frameworks are ill-equipped to address the dynamic and rapidly evolving nature of the energy sector, such as heterogeneous network users with different energy profiles and flexibility mechanisms. Dynamic tariffs represent network pricing regimes with high temporal and geographical granularity, conveying price and economic signals at shorter intervals.

3. Universally agreed-upon regulatory principles and prominent instruments ensure sustainable transformation within energy trading communities. These principles are (a) intelligibility, (b) non-discrimination, (c) cost-reflectiveness and cost-recovery, (d) transparency, and (e) gradualism, which influence energy users to embrace innovative frameworks and pursue objectives concerning energy security. By conceptualising these principles into indicators, regulators can engage in detailed discussions on the multifaceted and nuanced considerations surrounding decentralised energy systems within their diverse geographical and institutional landscapes.

Bibliography

Abdelmotteleb, I., Fumagalli, E., & Gibescu, M. (2022). Assessing Customer Engagement in Electricity Distribution-Level Flexibility Product Provision: The Norwegian Case. *Sustainable Energy, Grids and Networks*, *29*, 100564. https://doi.org/https://doi.org/10.1016/j.segan.2021.100564

Adeyemi, A., Yan, M., Shahidehpour, M., Botero, C., Guerra, A. V., Gurung, N., . . . Paaso, A. (2020). Blockchain Technology Applications in Power Distribution Systems. *The Electricity Journal*, *33*(8), 106817. https://doi.org/10.1016/j.tej.2020.106817

Ahl, A., Yarime, M., Goto, M., Chopra, S. S., Kumar, N. M., Tanaka, K., & Sagawa, D. (2020). Exploring Blockchain for the Energy Transition: Opportunities and Challenges Based on a Case Study in Japan [Article]. *Renewable and Sustainable Energy Reviews*, *117*, 109488, Article 109488. https://doi.org/10.1016/j.rser.2019.109488

Aklilu, Y. T., & Ding, J. (2022). Survey on Blockchain for Smart Grid Management, Control, and Operation. *Energies*, *15*(1), 193. https://doi.org/10.3390/en15010193

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., . . . Peacock, A. (2019). Blockchain Technology in the Energy Sector: A Systematic Review of Challenges and Opportunities [Review]. *Renewable and Sustainable Energy Reviews*, *100*, 143-174. https://doi.org/10.1016/j.rser.2018.10.014

Brown, D., Ehrtmann, M., Holstenkamp, L., Hall, S., & Davis, M. (2020). *Policies for Prosumer Business Models in the EU* (Prosumers for the Energy Union: Mainstreaming Active Participation of Citizens in the Energy Transition, Issue. https://proseu.eu/sites/default/files/Resources/PROSEU

Brown, D., Hall, S., & Davis, M. E. (2019). Prosumers in the Post Subsidy Era: An Exploration of New Prosumer Business Models in the UK. *Energy Policy*, *135*, 110984. https://doi.org/https://doi.org/10.1016/j.enpol.2019.110984

Derakhshan, G., Shayanfar, H. A., & Kazemi, A. (2016). The Optimization of Demand Response Programs in Smart Grids. *Energy Policy*, *94*, 295-306. https://doi.org/https://doi.org/10.1016/j.enpol.2016.04.009

Directive 2018/2001 on the Promotion of the Use of Energy from Renewable Sources, (2018). http://data.europa.eu/eli/dir/2018/2001/oj

Directive 2019/944 on Common Rules for the Internal Market for Electricity and Amending Directive 2012/27/EU (2019). http://data.europa.eu/eli/dir/2019/944/oj

Dudjak, V., Neves, D., Alskaif, T., Khadem, S., Pena-Bello, A., Saggese, P., . . . Zhou, Y. (2021). Impact of Local Energy Markets on the Distribution Systems: A Comprehensive Review. *arXiv preprint arXiv:2103.16137*.

Dupont, B., De Jonghe, C., Olmos, L., & Belmans, R. (2014). Demand Response with Locational Dynamic Pricing to Support the Integration of Renewables. *Energy Policy*, *67*, 344-354. https://doi.org/https://doi.org/10.1016/j.enpol.2013.12.058

Electricity Supply Act 1990. https://www.st.gov.my/contents/2020/AKTA/Electric/Act%20447%20-

%20Electricity%20Supply%20Act%201990.pdf

Englberger, S., Chapman, A. C., Tushar, W., Almomani, T., Snow, S., Witzmann, R., . . . Hesse, H. (2021). Evaluating the Interdependency between Peer-to-Peer Networks and Energy Storages: A Techno-Economic Proof for Prosumers. *Advances in Applied Energy*, *3*, 100059. https://doi.org/https://doi.org/10.1016/j.adapen.2021.100059

Felice, A., Rakocevic, L., Peeters, L., Messagie, M., Coosemans, T., & Ramirez Camargo, L. (2022). Renewable Energy Communities: Do they have a Business Case in Flanders? *Applied Energy*, *322*, 119419. https://doi.org/https://doi.org/10.1016/j.apenergy.2022.119419

Fell, M. J. (2021). Anticipating Distributional Impacts of Peer-to-Peer Energy Trading: Inference from a Realist Review of Evidence on Airbnb. *Cleaner and Responsible Consumption*, *2*, 100013. https://doi.org/https://doi.org/10.1016/j.clrc.2021.100013

Gawusu, S., Zhang, X., Ahmed, A., Jamatutu, S. A., Miensah, E. D., Amadu, A. A., & Osei, F. A. J. (2022). Renewable Energy Sources from the Perspective of Blockchain Integration: From Theory to Application. *Sustainable Energy Technologies and Assessments*, *52*, 102108. https://doi.org/https://doi.org/10.1016/j.seta.2022.102108

Hennig, R. J., Ribó-Pérez, D., de Vries, L. J., & Tindemans, S. H. (2022). What is a Good Distribution Network Tariff?—Developing Indicators for Performance Assessment. *Applied Energy*, *318*, 119186. https://doi.org/https://doi.org/10.1016/j.apenergy.2022.119186

Hoarau, Q., & Perez, Y. (2019). Network Tariff Design with Prosumers and Electromobility: Who Wins, Who Loses? *Energy Economics*, *83*, 26-39. https://doi.org/https://doi.org/10.1016/j.eneco.2019.05.009

Hua, W., Chen, Y., Qadrdan, M., Jiang, J., Sun, H., & Wu, J. (2022). Applications of Blockchain and Artificial Intelligence Technologies for Enabling Prosumers in Smart Grids: A review. *Renewable and Sustainable Energy Reviews*, *161*, 112308. https://doi.org/10.1016/j.rser.2022.112308

Hughes, L. (2012). A Generic Framework for the Description and Analysis of Energy Security in an Energy System. *Energy Policy*, *42*, 221-231. https://doi.org/https://doi.org/10.1016/j.enpol.2011.11.079

Inderberg, T. H. J., Sæle, H., Westskog, H., & Winther, T. (2020). The Dynamics of Solar Prosuming: Exploring Interconnections between Actor Groups in Norway. *Energy Research & Social Science*, *70*, 101816.

International Renewable Energy Agency. (2019). *Solutions to Integrate Variable Renewables. Summary for Policy Makers.* (Innovation Landscape for a Renewable-Powered Future, Issue. https://www.irena.org/publications/2019/Feb/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovation_Landscape_2019_summary_EN.pdf?la=en&hash=A0E3FDF6B67DD91D103BB3B4D8ED25FE23A02D1E

Jena, A. K., & Dash, S. P. (2021). Blockchain Technology: Introduction, Applications, Challenges. In *Blockchain Technology: Applications and Challenges* (pp. 1-11). Springer.

Kumar, M., Poudineh, R., & Shamsuddin, A. (2021). *Electricity Supply Industry Reform and Design of Competitive Electricity Market in Malaysia*.

Lavrijssen, S., & Parra, A. C. (2017). Radical Prosumer Innovations in the Electricity Sector and the Impact on Prosumer Regulation. *Sustainability*, *9*(7), Article 1207. https://doi.org/10.3390/su9071207

Lei, N., Masanet, E., & Koomey, J. (2021). Best Practices for Analyzing the Direct Energy Use of Blockchain Technology Systems: Review and Policy Recommendations. *Energy Policy*, *156*, 112422. https://doi.org/10.1016/j.enpol.2021.112422

Lummi, K., Rautiainen, A., Peltonen, L., Repo, S., Jarventausta, P., & Rintala, J. (2018, 27 June 2018). *Microgrids as Part of Electrical Energy System-Pricing Scheme for Network Tariff of DSO* International Conference on the European Energy Market (EEM), Łódź, Poland.

Morstyn, T., Savelli, I., & Hepburn, C. (2021). Multiscale Design for System-wide Peer-to-Peer Energy Trading. *One Earth*, *4*(5), 629-638. https://doi.org/https://doi.org/10.1016/j.oneear.2021.04.018

National Energy Transition Roadmap. (2023). Ministry of Economy. Retrieved 25 January from https://www.ekonomi.gov.my/sites/default/files/2023-09/National%20Energy%20Transition%20Roadmap_0.pdf

Niknejad, N., Ismail, W., Bahari, M., Hendradi, R., & Salleh, A. Z. (2021). Mapping the Research Trends on Blockchain Technology in Food and Agriculture Industry: A Bibliometric Analysis. *Environmental Technology & Innovation*, *21*, 101272. https://doi.org/10.1016/j.eti.2020.101272

Passey, R., Haghdadi, N., Bruce, A., & MacGill, I. (2017). Designing More Cost Reflective Electricity Network Tariffs with Demand Charges. *Energy Policy*, *109*, 642-649. https://doi.org/https://doi.org/10.1016/j.enpol.2017.07.045

Picciariello, A., Reneses, J., Frías Marín, P., & Söder, L. (2015). Distributed Generation and Distribution Pricing: Why Do We Need New Tariff Design Methodologies? *Electric Power Systems Research*, *119*, 370-376. https://doi.org/https://doi.org/10.1016/j.epsr.2014.10.021

Rajasekaran, A. S., Azees, M., & Al-Turjman, F. (2022). A Comprehensive Survey on Blockchain Technology. *Sustainable Energy Technologies and Assessments*, *52*, 102039. https://doi.org/https://doi.org/10.1016/j.seta.2022.102039

Ren, J., & Sovacool, B. K. (2014). Quantifying, Measuring, and Strategizing Energy Security: Determining the Most Meaningful Dimensions and Metrics. *Energy*, *76*, 838-849. https://doi.org/https://doi.org/10.1016/j.energy.2014.08.083

Reneses, J., Gómez, T., Rivier, J., & Angarita, J. L. (2011). Electricity Tariff Design for Transition Economies: Application to the Libyan Power System. *Energy Economics*, *33*(1), 33-43. https://doi.org/https://doi.org/10.1016/j.eneco.2010.04.005

Roberts, M. B., Bruce, A., & MacGill, I. (2019). Opportunities and Barriers for Photovoltaics on Multi-Unit Residential Buildings: Reviewing the Australian Experience. *Renewable Sustainable Energy Reviews*, *104*, 95-110. https://doi.org/https://doi.org/10.1016/j.rser.2018.12.013

Rocha, R., Villar, J., & Bessa, R. J. (2019, 18 September 2019). *Business Models for Peer-to-Peer Energy Markets* International Conference on the European Energy Market (EEM),

Ruotsalainen, J., Karjalainen, J., Child, M., & Heinonen, S. (2017). Culture, Values, Lifestyles, and Power in Energy Futures: A Critical Peer-to-Peer Vision for Renewable Energy. *Energy Research & Social Science*, *34*, 231-239.

Saez, Y., Estebanez, C., Quintana, D., & Isasi, P. (2019). Evolutionary Hash Functions for Specific Domains. *Applied Soft Computing*, *78*, 58-69. https://doi.org/https://doi.org/10.1016/j.asoc.2019.02.014

Saxena, S., Farag, H., Brookson, A., Turesson, H., & Kim, H. (2019). *Design and field implementation of blockchain based renewable energy trading in residential communities* 2nd International Conference on Smart Grid and Renewable Energy (SGRE), Doha, Qatar.

Schittekatte, T., & Meeus, L. (2018). *Limits of traditional distribution network tariff design and options to move beyond*. Florence School of Regulation.

Silva-Rodriguez, L., Sanjab, A., Fumagalli, E., Virag, A., & Gibescu, M. (2022). Short Term Wholesale Electricity Market Designs: A Review of Identified Challenges and Promising Solutions. *Renewable and Sustainable Energy Reviews*, *160*, 112228. https://doi.org/https://doi.org/10.1016/j.rser.2022.112228

Srianandarajah, N., Wilson, S. J., & Chapman, A. C. (2022). From Green to Amber: Is Australia's National Electricity Market Signalling a Financial Warning for Wind and Solar Power? *Energy Policy*, *167*, 113052. https://doi.org/https://doi.org/10.1016/j.enpol.2022.113052

Sustainable Energy Development Authority. (2020, 5 November 2020). *Malaysia's 1st Pilot Run of Peer-to-Peer (P2P) Energy Trading*. https://www.seda.gov.my/2020/11/malaysias-1st-pilot-run-of-peer-to-peer-p2p-energy-trading/

Tenaga Nasional Berhad. (n.d.). *Electricity Tariff Classification*. Retrieved 31 January from https://www.tnb.com.my/residential/pricing-tariffs

Teufel, B., Sentic, A., & Barmet, M. (2019). Blockchain Energy: Blockchain in Future Energy Systems. *Journal of Electronic Science and Technology*, *17*(4), 100011.

Tomar, A., Shafiullah, D. S., Nguyen, P. H., & Eijgelaar, M. (2021). An Integrated Flexibility Optimizer for Economic Gains of Local Energy Communities — A Case Study for a University Campus. *Sustainable Energy, Grids and Networks*, *27*, 100518. https://doi.org/https://doi.org/10.1016/j.segan.2021.100518

Vijayapriya, P., Bapna, G., & Kothari, D. P. (2010). Smart Tariff for Smart Meters in Smart Grid. *International Journal of Engineering and Technology*, *2*(5), 310-315.

Wang, T., Hua, H., Wei, Z., & Cao, J. (2022). Challenges of Blockchain in New Generation Energy Systems and Future Outlooks. *International Journal of Electrical Power & Energy Systems*, *135*, 107499. https://doi.org/10.1016/j.ijepes.2021.107499

Wilkinson, S., Hojckova, K., Eon, C., Morrison, G. M., & Sandén, B. (2020). Is Peer-to-Peer Electricity Trading Empowering Users? Evidence on Motivations and Roles in a Prosumer Business Model Trial in Australia. *Energy Research & Social Science*, *66*, 101500. https://doi.org/https://doi.org/10.1016/j.erss.2020.101500

Willems, B., & Zhou, J. (2020). The Clean Energy Package and Demand Response: Setting Correct Incentives. *Energies*, *13*(21), 5672. https://doi.org/https://doi.org/10.3390/en13215672

Xie, Y.-s., Chang, X.-q., Yin, X., & Zheng, H. (2021). Research on the Transaction Mode and

Mechanism of Grid-side Shared Energy Storage Market Based on Blockchain. *Energy Reports*, *8*, 224-229. https://doi.org/10.1016/j.egyr.2021.11.044

Yang, J., Paudel, A., Gooi, H. B., & Nguyen, H. D. (2021). A Proof-of-Stake Public Blockchain based Pricing Scheme for Peer-to-Peer Energy Trading. *Applied Energy*, *298*, 117154. https://doi.org/https://doi.org/10.1016/j.apenergy.2021.117154

Yang, R., Wakefield, R., Lyu, S., Jayasuriya, S., Han, F., Yi, X., . . . Chen, S. (2020). Public and Private Blockchain in Construction Business Process and Information Integration. *Automation in Construction*, *118*, 103276. https://doi.org/https://doi.org/10.1016/j.autcon.2020.103276

Yapa, C., de Alwis, C., Liyanage, M., & Ekanayake, J. (2021). Survey on Blockchain for Future Smart Grids: Technical Aspects, Applications, Integration Challenges and Future Research. *Energy Reports*, *7*, 6530-6564.

Zhou, Y., Wu, J., Long, C., & Ming, W. (2020). State-of-the-Art Analysis and Perspectives for Peer-to-Peer Energy Trading. *Engineering*, *6*(7), 739-753. https://doi.org/https://doi.org/10.1016/j.eng.2020.06.002