MASTER

How can a comprehensive framework be developed to assess the readiness level of P2P-blockchain energy trading platforms in the Netherlands, considering key criteria?

Ylla Gelabert, Ines

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Inés Ylla Gelabert
1642502
i.ylla.gelabert@student.tue.nl

Supervisor:
Bert Sadowski

Second and third reader:
Geert Verbong
Georgios Papachristos

Company supervisor:
Menno Driesse
driesse@dialogic.nl
Hooghiemstraplein 33-36, 3514 AX Utrecht

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Summary

In the pursuit of a sustainable and decarbonized energy future, distributed generation has emerged as a key driver of energy transition at the end-consumer level generating energy near the point of consumption (AEMC, 2023). Distributed energy resources (DERs), such as photovoltaic panels (PVs), have witnessed significant growth, leading to the decentralization of energy systems and the emergence of new energy business models like peer-to-peer (P2P) energy trading. The Netherlands has become a prominent adopter of these models. Moreover, experts state that the use of blockchain technology can be a crucial enabler to help implement P2P energy trading as it decentralizes data verification and storage of energy exchange as well as improve its transparency and traceability (IRENA, 2020; Wu et al., 2019).

This thesis aims to develop a framework for assessing the readiness of P2P-blockchain energy trading platforms within the Dutch energy ecosystem. It begins with an extensive literature review on P2P-blockchain energy trading systems, focusing on the necessary requisites for successful implementation. The socio-technical lenes guides this review. The gathered insights are used to create the P2P-Blockchain Energy Trading Readiness Framework, which evaluates the operative P2P-blockchain energy trading platform of Distro energy company in the port of Rotterdam and re-evaluates the functionality of the analytical framework with feedback from interviews done to actors within the Dutch energy ecosystem.

The results highlight that the key criteria for evaluating the readiness of P2P-blockchain energy trading platforms are technological infrastructure, market dynamics, legislative and operations domains, and societal and user adoption domains. The evaluation highlights that Distro platform is still in its early stages of implementation, with the technological infrastructure being the most developed domain and user and societal adoption, as well as market dynamics, posing challenges. Governance aspects reveal that while the legislative framework has reached, Distro needed to use a lot of alternatives from what was expected to do so. The theoretical framework proves effective as it can successfully determine the level of readiness of P2P-blockchain energy trading platforms but requires changes which had been added at the end of the thesis, and further research and validation through assessment in other ongoing P2P-blockchain energy trading projects.

Regarding the readiness level of the socio-technical ecosystem in the Netherlands, definitive conclusions cannot be drawn from this thesis as it has just been assessed one case study. However, initial findings suggest that the technological infrastructure is well-established, the Dutch energy market remains centralized and unbundled, information on end-user integration is limited, and the legislative framework requires significant enhancements to support the implementation of this new business model in society.

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Chapter 1. Introduction

1.1. Background

In the quest for a sustainable and decarbonized energy future, distributed generation (DR) has emerged as one of the key drivers of this energy transition. It refers to the production of electricity through renewable energy sources located near the point of consumption, rather than relying solely on centralized power plants (AEMC, 2023). This decentralized approach to energy generation empowers individuals, communities, and businesses to actively participate in producing their clean energy, reducing reliance on fossil fuels and mitigating the environmental impact. Therefore, new energy business models are emerging to support the utilization of distributed energy resources (DER) such as photovoltaic systems (PVs).

Peer-to-peer (P2P) energy trading (P2P-ET) is one of the various business models that gain most popularity as it brings economic exist to the self-generation of energy (Domènech Monfort et al., 2022). It enables *prosumers* (individuals that both produce and consume electricity) to trade their surplus electricity with other peers. The energy and data exchange takes place on a digital platform, functioning as an online marketplace where consumers and prosumers can seamlessly trade electricity. (IRENA, 2020). P2P energy trading promotes sustainability and reduces environmental impact, among others (Tushar et al., 2020; Wongthongtham et al., 2021). It can benefit energy transitions in different ways. First, it can economically profit prosumers as they can monetize their surplus of energy. Second, it can be utilized to efficiently manage the energy demand by providing electricity when the demand peaks, as well as to generate clean energy mix in the local grid (Tushar et al., 2020). Third, it reduces consumers reliance on traditional centralized grid and increase their involvement in the energy system (Hext, 2022). Also, it benefits generators, retailers, and distribution network system providers as it lowers investment, operational costs, and minimizes the reserve requirements (Tushar et al., 2020).

According to research, The Netherlands leads Europe with the highest solar capacity per capita, standing at 1044 Watt/Capita, followed by Germany (816 Watt/Capita) and Denmark (675 Watt/Capita) (SolarPowerEurope, 2022). Furthermore, The Netherlands has experienced an increase in solar PV capacity in recent years (Statista, 2022a). This phenomenon helps to explain why The Netherlands is at the forefront of implementing P2P energy trading systems to capitalize the growing amount of self-generated capacity from solar PV (Park et al., 2022). However, the implementation of P2P energy trading in The Netherlands is hindered by the challenges posed by the existing centralized energy ecosystem and its conventional top-down approach to energy supply (de Almeida et al., 2021). Additionally, the country is currently working on developing new energy package regulations that align with the European Clean Energy Package (CEP) introduced in 2019 (Uhde, 2022). The package acknowledges P2P energy trading and 'energy communities' (EC) and defines the rights of consumers to participate in energy markets, through energy trading. However, The Netherlands has recognized the need to decentralize and unbundle its energy system and has positioned itself as a frontrunner in implementing this technological innovation (Uhde, 2022). The Dutch government has taken several actions to promote flexible energy systems, including widespread deployment of smart meters[1], research on electric vehicles smart charging as a resource, and pilot projects demonstrating the benefits of DER for grid operations (IEA, 2021).

Moreover, blockchain is a digital, decentralized ledger technology (DLT) that is used to record transactions across a network of computers. Each block in the chain contains a set of transactions and a unique cryptographic code that links it to the previous block in the chain, forming a continuous and tamper-evident record of all transactions (Chiarini & Compagnucci, 2022). As this technology is currently in early stages and is recognized as a disruptive technology, it is crucial to avoid being swayed solely by its hype and instead objectively assess its actual value in enhancing P2P energy trading (de Almeida et al., 2021). Literature states that blockchain links with P2P energy trading systems through similar decentralization characteristics as P2P energy trading aims to decentralize energy transactions, while blockchain aims to decentralize data verification and storage. Having these characteristics in mind, blockchain serves in the energy trading sector as (i) a way to track low-carbon energy and certify it from its origin to its end consumer, (ii) have public energy transactions and ensure the security of those, (iii) through to the use of *smart contracts*[2] help trade energy without the need of intermediaries, and (iv) provide substantial solutions to the scalability of P2P energy trading (Dua, 2023; Wongthongtham et al., 2021).

1.2. Problem statement

In recent years researchers have undertaken studies that integrate these two technological developments. Recent studies have encompassed literature reviews on P2P energy trading systems, integration of P2P-blockchain trading systems, and exploration of their design, dynamics, and mechanisms (Darmawan, 2019; Das et al., 2023; Esmat et al., 2021; Mazzola et al., 2019; Soto et al., 2021; Sousa et al., 2019; Tushar et al., 2020, 2021; Zhang et al., 2017). They have also investigated the so-called trilemma challenge – scalability, security, and decentralization – of blockchain technology, and how this challenge effect P2P energy trading (Wongthongtham et al., 2021). Additionally, studies have examined the relationship between distributed energy resources (DERs) and P2P trading, including the involvement of photovoltaic prosumers and electric vehicles (Al-Saif et al., 2021; Lopez & Zilouchian, 2023).

Despite the potential of the combination of both technological developments, several challenges arise in regards to the technological and socio-economic domain, which is often overlooked. Consequently, it is crucial to comprehensively understand this technological development from various perspectives. This includes examining its regulatory implementation, data management, privacy considerations, integration into the centralized energy system, market dynamics, as well as user and social dynamics. Hence, a multidimensional understanding of these aspects is essential for the successful integration of these technological developments into society.

1.3. Objectives, structure of the research and scope

[1] Smart meters are electronic systems that measure the electricity fed into the grid (pre-meter) and consumed from the grid (post-meter) (European Commission, 2023a).

[2] *if*, *else* statements that act as conditional mechanisms to make something in the blockchain happen (Sheridan et al., 2022).

Hence, the purpose of this thesis is to create a tool to assess the level of readiness of P2P-blockchain energy trading platform within the context of The Netherlands energy ecosystem and consequently understand how P2P-blockchain energy trading platforms can be implemented in The Netherlands.

Therefore, this thesis aims to answer the following research question: ***How can a comprehensive framework be developed to assess the readiness level of P2P-blockchain energy trading platforms in the Netherlands, considering key criteria?***

To address the research question, a literature review is preformed to gather information on the following. First describe how P2P energy trading and blockchain technological developments relate. Second, describe the current socio-technical environment[3] in which P2P-blockchain energy trading platforms are emerging. Third, understand and select what are the necessary requisites for successful implementation of P2P-blockchain energy trading systems in the socio-technical context of the Dutch energy market. This literature review culminates with the creation of a readiness framework on P2P-blockchain energy trading platforms. Moreover, Distro platform from Distro Energy company is chosen to be the case study to assess the created framework. Distro Energy company is a transactive energy start-up situated in the Port of Rotterdam, which facilitates seamless peer-to-peer energy trading, enabling direct energy transactions between companies in the port (Distro Energy, 2023). The use case of Distro platform aims to (i) put in practice the readiness framework assessing "how ready" is Distro ecosystem at the current time, and (ii) gather insights to re-evaluate the created framework and improve its functionality together with feedback from other stakeholders of the energy market. Finally, an assessed version of the framework is presented.

Even though, this thesis can't assume that the readiness level of Distro ecosystem[4] is representative of the overall situation of P2P-blockchain energy trading platforms in The Netherlands, a final discussion is going to be added on what is the current readiness level of P2P-blockchain energy trading platforms in The Netherlands.

Therefore, five separate sub-questions are developed to help answer the overall research question:

1. *How do peer-to-peer energy trading platforms work and what added value does blockchain provide for enhancing the implementation of P2P energy trading platforms?*
2. *How does the dynamics of the current Dutch energy ecosystem surrounding the emergence of P2P-blockchain energy trading platforms work?*
3. *What are the key domains and their corresponding indicators that need to be considered to create an analytical framework to assess the readiness level of a P2P-blockchain energy trading platform?*
4. *Utilizing the analytical framework created, what is the current level of readiness of Distro P2P-blockchain energy trading platform?*
5. *What key insights can be learned from Distro platform to assess the proposed the P2P-Blockchain Energy Trading Readiness Framework?*

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[3] Refers to the integrated interplay between social and technical factors within a given ecosystem, influencing the development, adoption, and use of a technological development (Geels, 2004; Kanger & Schot, 2019). For example, current dynamics of the Dutch energy ecosystem, actors involved and their responsibilities, the Dutch energy regulatory framework, etc.

[4] *1.4. Research terminology* defines this concept

Moreover, this thesis uses the following methodology to answer these questions. Literature review is gathered to answer questions 1 to 3. Moreover, semi-structured interviews to different stakeholders in the Dutch energy ecosystems, including employees of Distro company, are used to answer questions 4 and 5. Finally, a thematic analysis is used to collect and organize the information from the interviews to (i) evaluate the readiness level of the Distro platform and (ii) assess the created analytical framework.

1.4. Research terminology

Finally, it is important to clarify the terminology that is going to be used in this thesis.

First, as *P2P-blockchain energy trading platforms* is an emergent technology, the definition around this concept is not yet standardized. Therefore, in this thesis is going to understand P2P energy trading platforms as the business model, based on an interconnected platform, that serves as an online marketplace where consumers and producers “meet” to trade electricity directly (IRENA, 2020). Of course, for these platforms to work, they need to be integrated within a *P2P energy trading system* which considers a market with its overall stakeholders and a set of regulatory frameworks for the platforms to work. Finally when talking about *P2P energy trading* alone, the thesis will refer to the overall idea of this technological development.

When talking about *socio-technical systems*, this thesis refers to the holistic, interconnected contribution of technology and the human system that operate together to integrate a new technological development into the society (Kapoor et al., 2021).

Furthermore, this thesis uses *Distro* to refer to the Dutch company Distro Energy (Distro Energy, 2023). When talking about Distro platform this thesis will refer to the operative P2P-blockchain energy training platform of Distro. Finally, when talking about *Distro ecosystem*, this thesis refers to the socio-technical niche in which Distro is being implemented in the port of Rotterdam.

Additionally, when talking about *energy*, this thesis is going to refer to electricity.

1.5. Significance for the broader field

The thesis adopts a socio-technical approach to understand P2P-blockchain energy trading platforms. The socio technical approach is defined as a way to understand technological developments adoption and implementation by considering not only the technical aspects, and also how the production, diffusion, and use is influenced by social factors like user behaviour, organizational culture, and institutional frameworks, etc, which are elements that are necessary to fulfil the societal functions of the technology (Geels, 2004; Kanger & Schot, 2019).

Therefore, the thesis is organized as follows. In Chapter 2, the thesis provides an overview of what P2P energy trading and blockchain is seen from socio-technical approach. Chapter 3 presents the conceptual and analytical framework of this thesis, followed by Chapter 4, where the methodology is outlined. Moreover, Chapter 5 presents the case study of Distro Energy company. Afterwards, utilizing the analytical framework the Distro platform readiness level is analysed in Chapter 6. And the thesis ends with a discussion on the analytical framework and potential future research directions presented in Chapter 7. Finally, Chapter 8 presents the concluding remarks of the thesis.

Chapter 2. Literature review

2.1. P2P energy trading system

This section is described using the theoretical definitions of P2P energy trading systems.

2.1.1. Definition

Traditional energy systems are centralized systems that are focused on a top-down approach. In these systems, energy is generated, transformed to high voltage, distributed through the grid, and supplied to consumers. This centralized architecture limits consumer choice and only allows them to receive electricity from a few suppliers [1] (Figure 1.1) (Mazzola et al., 2019). In the case of having active prosumers on this centralized energy market, the energy generated by prosumers goes back to the Distribution System Operator (DSO)[5] [2] which sells it to the market giving a small monetary reward to the prosumer.

The continuous integration of DERs is transforming the way we consume and share electricity towards a more decentralized energy market (Wongthongtham et al., 2021). This new system relies on an alternative bottom-up approach where energy transmission can happen bilaterally between actors [3], without having the local supplier or distributor as an intermediary (Figure 1.2). DERs are creating prosumers, which are consumers that also produce electricity with their DER. The EU legislation covers the notion of "prosumer" in different ways, however, in this research, the term *prosumer* is defined as end-users who generate and/or consume their energy, encompassing households, and large customers like hospitals, schools, factories or public entities (de Almeida et al., 2021).

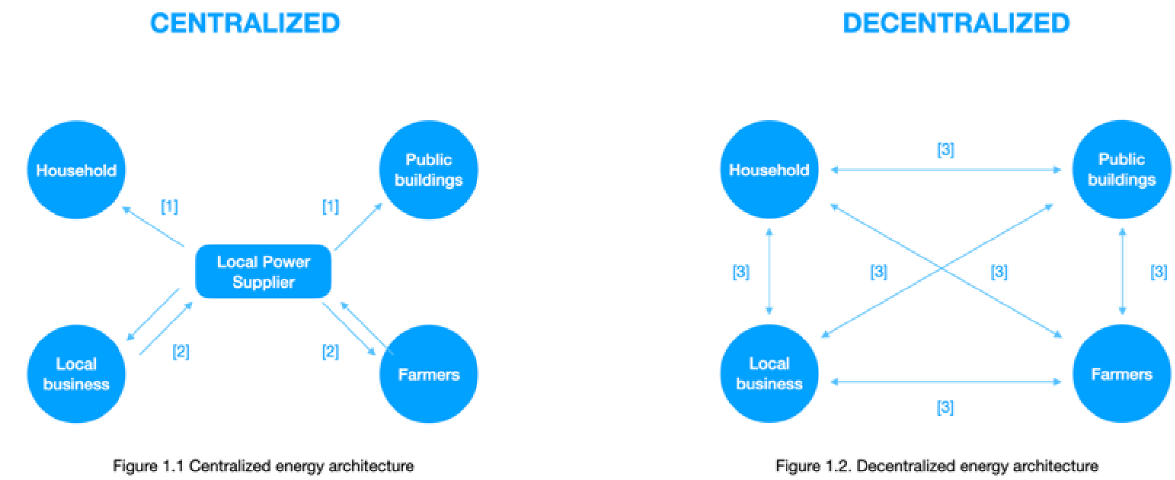

Figure 1. Difference between a centralized and decentralized energy ecosystem

The integration of these new users in the energy market is creating an ecosystem where there is space for more energy flexibility (i.e. variety in the energy mix), more consumer empowerment to participate in the energy system, and more generation and distribution of local energy. However, it also comes with an increase on voltage pressure on specific grid notes and increase on the importance of balancing the energy grid. This alternative market idea is generically named

[5] The actor in charge of distributing through the electric grid the electricity to end-users.

consumer-centric electricity markets, 20 years ago were just a visionary concept seen as an academic discussion. Nowadays, these type of markets which can be applied using different business models (i.e. peer-to-peer, community-based structures, etc) are a reality (Pinson et al., 2017; Sousa et al., 2019). Zhou et al., (2020) research highlights that Germany, The Netherlands, Denmark, and the UK are currently at the forefront of implementing consumer-centric electricity markets in Europe. Germany has 1750 projects, as well as The Netherlands with 568, a significant number compared to Austria with 282 or Italy with approximately 49 (Bertel et al., 2022).

This thesis is focused on peer-to-peer energy (P2P) trading systems or P2P-ET as they have received plenty of academic, research and industrial traction within the energy transition markets in the recent years (Zhou et al., 2020). P2P-ET is defined as a decentralized energy trading system where prosumers can trade their surplus electricity, usually generated by DERs, with other peers and without the need for intermediaries utilizing an electronic platform (Zhang et al., 2017). It is important to understand that P2P-ET does not just consist of micro energy trading (i.e. household), but also can include any other establishment such as local businesses, factories, farmers, or public buildings (Bax & Company, 2019). These business models have emerged to provide prosumers with secure, reliable, and cost-effective mechanisms to monetize their DERs (Wu et al., 2019).

P2P-ET is still in the emerging stages and therefore lacks a standardized definition of its different types. However, this thesis is going to use the definitions of Domènech Monfort et al., (2022) paper to provide the definition of the various P2P energy trading markets; *centralized*, *distributed,* and *direct trading markets*. Table 1 summarizes each market's characteristics.

In a centralized P2P energy trading market, all trading and communication occur through a central manager who coordinates the process, controls the DERs, and the smart meter data. Peers within the community have no direct interaction with each other, relying solely on the manager who is the one that runs and organized the platform software (Domènech Monfort et al., 2022). While this approach maximizes social welfare by having a central manager organizing the process, and simplifies contract and pricing concerns for peers, it also limits autonomy and raises privacy issues as the manager controls their devices (Tushar et al., 2020). In decentralized markets, prosumers can independently negotiate with one another to establish energy trading parameters without centralized supervision. Both the trading process and communication are decentralized, the platform is fully runed by the peers in a unanimous way, granting prosumers control over their DERs and ensuring privacy by allowing selective sharing of information. However, this decentralized structure place administrative responsibilities on prosumers, and limits revenue maximization without centralized coordination (Domènech Monfort et al., 2022). Finally, hybrid energy markets combine elements of both centralized and decentralized energy trading markets. Some aspects can be controlled by the manager and others by the prosumers. This market structure allows peers to have control over their energy devices, with responsibilities shared between the digital platform and prosumers. In this type of markets, the platform can be runed by a central manager or by the peers in a unanimous way. Coordinating internal trade agents, such as community managers, can present challenges (Domènech Monfort et al., 2022).

Aspect	Centralized market	Decentralized market	Hybrid market
Communication (between peers)	By the manager	By the peers	By the manager
Trading process	By the manager	By the peers	By the peers

Energy price	By the manager	By the peers	By the peers
Control of DERs and smart meters	By the manager	By the peers	By the peers
Platform management (software)	By the manager	By the peers	By the manager or the peers

Table 1. Summary of the dynamics of the different P2P energy trading typologies

The overall aim of P2P energy trading, as literature states, is reaching the decentralization of the market, thereby establishing a *direct* P2P energy *trading market* (Domènech Monfort et al., 2022). However, all technologies have nuances. In P2P energy trading the reader should understand the technology market dynamics within a spectrum from less decentralized to a more decentralized energy market. This differentiation will be crucial through the thesis as it will relate to the level of readiness of the technological development. However, until that point, the reader should understand P2P energy trading systems without taking into consideration its different typologies.

2.1.2. Benefits and challenges

The following section is going to highlight the main benefits and challenges of P2P energy trading which can be seen in the following figure.

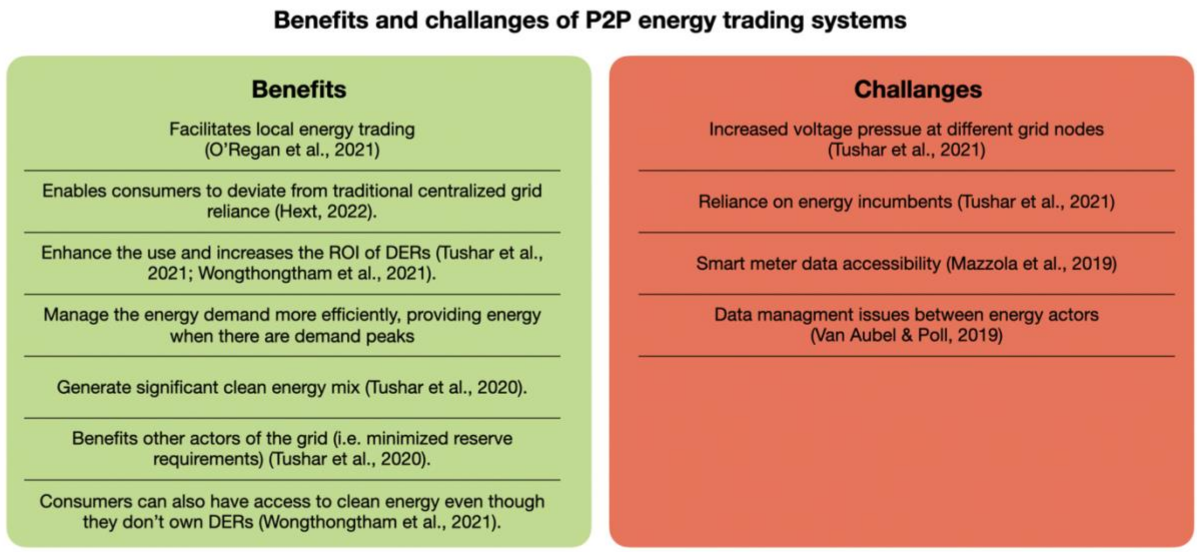

Figure 2. Benefits and challenges of P2P energy trading systems

P2P energy trading presents numerous advantages, as illustrated in Figure 2. However, like any new technology, it also faces challenges during implementation. Fortunately, there are already solutions available to address these issues. Figure 2 provides an overview of these challenges, and the subsequent section will delve into their respective solutions.

First, the increased number of prosumers participating in selling energy back to the grid, heightened the risk of voltage pressure at different nodes within the grid system. However, there are several solutions for this problem. Firstly, utilizing energy storage systems like batteries (at the household, community, or electric vehicle level) to store excess energy during high-generation periods and release it during high-demand periods (Tushar et al., 2021). Secondly, implementing demand response programs that allow participants to adjust their energy usage based on real-time market conditions. Additionally, developing predictive forecasting algorithms for accurate generation and consumption patterns. Finally, legislating regulations on the amount of energy each prosumer can export to the network at a given time slot, alongside market mechanisms and incentives that encourage participants to balance their energy production and consumption. These solutions contribute to stabilizing energy grid fluctuations with flexible devices, ensuring network safety and security (Tushar et al., 2021).

Another challenge is the need to consider the existing stakeholders within the current energy ecosystem when implementing P2P energy trading platforms. Conflicting situations can arise between actors in the energy ecosystem, when for instance, DSO sends signals to prosumers not to inject energy into the grid to prevent potential network voltage violations. Efficient techniques must be developed to address these issues (Tushar et al., 2021).

Smart meters have a critical role in collecting data for energy trading, they serve as the ground truth[6]. However, there are challenges related to their accessibility and data availability.

First, the current smart meters in Dutch households were designed for accurate billing purposes for DSOs, and not for P2P transactions (European Commission, 2023a; Mazzola et al., 2019). Even though this can be manipulated by users who have basic knowledge, for instance by connecting a reader to the P1 port the end-user will be able to read their energy usage, it's hard to adapt them to P2P requirements (Van Aubel & Poll, 2019). Second, the ownership of smart meter data provides a competitive advantage to actors within the energy ecosystem of those who possess it. Currently smart meter data is restricted to metering data companies, energy suppliers, DSOs, and smart meter end-users[7]. For other stakeholders in the Dutch energy market to obtain this data, they must request it from the suppliers, a process which introduces delays and causes bottlenecks in the energy trading data flow (Interview #5, personal communication, June 6, 2023). A lot of actors within the energy ecosystem are complaining about the low accessibility of this data, which is why communication protocols and data standards of these devices may require a redesign to facilitate P2P-ET (Mazzola et al., 2019).

However, broad data access among actors can reduce the security of energy trading. Academics and researchers state that cryptography and other technologies such as blockchain, can potentially help increase the security of the networks, especially in scenarios such as P2P energy trading which involves a vast array of stakeholders. Blockchain offers a tamper-evident record of all transactions, thereby ensuring the integrity and security of the trading process. Zhou et al., (2020) which reviews P2P energy trading projects around the world, states that most of the current operational projects on P2P energy trading involve utilizing blockchain technology to support and facilitate the P2P energy trading (Zhou et al., 2020).

While this section describes how does P2P-energy trading systems work the following section focuses on understanding why has blockchain emerged as a solution for P2P energy trading systems? How does its implementation add value to P2P energy trading systems? and finally what challenges also come with it?

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[6] Referring to the real smart meter readings at the time of the energy production and consumption, which is used to create the energy billing to the consumer.

[7] End users are the ones that consume the electricity and pay the corresponding energy bills.

2.2. Blockchain and P2P energy trading

This section will aim to understand what blockchain technology is. Bitcoin, cryptocurrency, metaverse, smart contracts, and blockchain are words that have lately very much resonated in innovation hubs, tech newsletters, academic research papers, and even technological companies (Roth et al., 2022). However, due to the buzz, it is hard to understand what the concept of blockchain is, this section will unscramble this.

2.2.1. Blockchain definition and characteristics

Blockchain is a type of distributed ledger technology (LDT) that facilitates the transfer of digital assets or transactions among peers without the need for intermediaries (Roth et al., 2022).

Simply speaking, blockchain is a decentralized, and publicly available shared database that groups data into a block structure. The blocks are linked together in an ordered chain – "blockchain"- that starts with a genesis block (AGL, 2017). Technically speaking, these "block" "chains" are replicated, shared, and distributed across multiple servers in a blockchain network – called nodes. The distributed term is the key characteristic of the blockchain. The integrity of the data is not just reliant on a centre actor, but simultaneously reliant on all actors (nodes) in the blockchain network (Teufel et al., 2019). To create another block in the chain, all nodes must agree on the validity of the data. *Consensus mechanisms are the processes that ensure the validation of this data,* they are complex concepts that go beyond the scope of this thesis (Teufel et al., 2019). Once the block is validated, they are concatenated (added one after the other) using a cryptographic hash function. The new block will have (i) the previous hash number and (ii) a new one, linking both blocks together (AGL, 2017). This particularity provides the blockchain a traceability characteristic as one can trace the data in every block up until the genesis block of the chain. In public blockchains, all actors in the blockchain network can view and track the blocks at any time, but cannot change them, a feature that provides the transparent and immutability characteristic of blockchain. Once the data is encrypted into the block and appended, it cannot be altered nor deleted. This provides the immutable property of blockchain. This simple description of blockchain technology shows that is possible to create a high degree of security against manipulation and facilitate trust between actors (users of the system) without the need for intermediaries (Teufel et al., 2019).

There are different types of blockchain networks; *public blockchain*, *private blockchain,* and *consortium blockchain*. The first is open to all users. Anyone can join and add to the blockchain as they like. Second, in a private blockchain, only a few users can verify and add to the blockchain. However, everyone on the network can view its status. The latter is the combination of both, just a single group of actors can be allowed to view, verify, and add to the blockchain, therefore being controlled by authorized nodes only. Even though there are different types of blockchain networks, the ultimate idea of blockchain is aimed to give the power back to users, in a decentralized blockchain. However, currently, the other two types of blockchain can prove to be very useful to help in the early stages of implementation of this technology.

Blockchain, like any emerging technology, presents its own set of challenges and risks. Firstly, due to its early nature, there is a lack of long-term experience and understanding of the technology. While there is broad knowledge about the financial industry, its implementation knowledge in the energy sector is limited (PwC, 2016). Second, the current state of blockchain systems, particularly public blockchain, currently has bad connotations, it is associated with relatively high transaction costs and a lot of use of computational time and energy. Moreover, there is a lack of standardization of the technology which could lead to inadequate functionating and security risks (PwC, 2016). Time will determine whether this or other technological developments are the appropriate ones to help implement P2P-ET (PwC, 2016).

2.2.2. Functional aspects

As explained in the previous section, blockchain is the underlying technology that can facilitate the transfer of digital assets (i.e. data, cryptocurrency, tokens) between peers in a network. However, for this technology to work in the energy sector, the following elements are key: smart contracts, digital wallets, and digital assets (cryptocurrency and tokens).

The contractual operations and transactions that are executed in the blockchain (i.e. whether is money, energy, or data exchange between peers in the network) are a concern of the smart contracts (Kirli et al., 2022). These are self-executable programs that can monitor and add to the ledger according to user-defined rules. They can be triggered when certain conditions are met and automatically executed. As the smart contracts are codified within the blockchain, they inherit its properties (automatization, decentralization, immutability, and security), when an event is triggered by a condition, this is recorded as a new block in the "block" "chain" (Kirli et al., 2022).

For transactions to occur in the distributed ledger the use of tokens (digital assets) is essential. Tokens represent any type of value. Being codified within blockchain brings them again all the inherent characteristics of this technology. Anyone can make a token by creating a smart contract and linking it to a specific use or utility (i.e. one token equals 1 kw/h) (Morris, 2018).

Finally, to be able to trade tokens and cryptocurrency, the users must have digital wallets, applications that are linked to a digital identity which can store and trade tokens with. The owner of the digital wallet owns and has full control of the digital assets stored within it (Sheridan et al., 2022). The host can choose which data wants to share, and under which specific circumstances (ID2020, 2022).

2.2.3. Contribution of blockchain to P2P energy trading

The common denominator between P2P energy trading and blockchain technological developments is the decentralized nature and the elimination of the middleman[8] (EU Blockchain Observatory, 2023). Literature shows that combining these two technological developments can help improve the implementation of P2P energy trading for the following reasons (Figure 3).

[8] Idea which raises a lot of discussions among experts as whether blockchain eliminates the intermediary or it just change it into another form of middleman, for instance by using artificial intelligence (AI) or another type of algorithms. Additionally, the importance of the middleman differs depending on the type of P2P energy trading market used (centralized P2P energy trading markets v.s. decentralized energy trading markets).

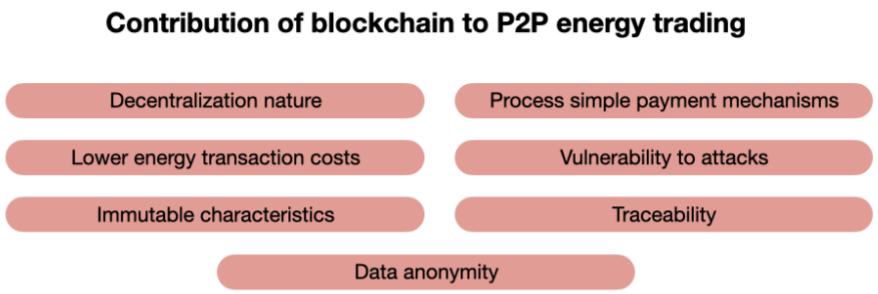

Figure 3. Contribution of Blockchain to P2P energy trading

First, it reduces the transaction costs of energy trading as when using blockchain technology the middleman is eliminated[9] (Tushar et al., 2021). Second, it ensures transparent energy transactions due to blockchain's immutable characteristics. This provides the integrity and non-change of the energy data among actors of the energy ecosystem (Dutch Blockchain Coalition, 2023; Interview #3, personal communication, June 2, 2023; Tushar et al., 2021). Third, it helps store and process simple payments with the use of smart contracts, digital wallets, and tokens (Roth et al., 2022). Moreover, thanks to the traceability characteristics of blockchain, is able to provide trading certificates called energy attribute certificates (EACs)[10] so the end user can know what type of energy they bought (i.e. renewable energy). Finally, users are identified by cryptographic public keys allowing user data to be anonymous (IEA, 2021).

Even though, blockchain is an attractive solution to help implement the so-called "energy transition" in our society. Experts also believe that is not the unique solution capable of ensuring the functioning of a decentralized energy system (Interview #4, personal communication, June 6, 2023). Blockchain technology is not required for instance in a pilot P2P energy trading project in Germany that works by storing transactions and data flows in a conventional database (PwC, 2016).

2.2.4. Value chain of P2P energy trading and blockchain

The following section describes the value chain of P2P energy trading when incorporating blockchain technology. Figure 4, shows in orange where blockchain intervenes.

In terms of technological infrastructure, is essential to distinguish between two layers; the physical layer and the virtual layer (Lopez & Zilouchian, 2023). The virtual layer considers *energy contracts*, *payment mechanisms*, *trading software, user interface platforms,* and *ICT to enhance the P2P* and *data collection mechanisms*. The physical layer is comprised of *smart meters*, *DER*, *physical electrical connection,* and *communication infrastructure*, it facilitates the transfer of electricity between seller and buyer once the financial settlement has been completed over the virtual layer platform.

Virtual layer

First, **energy forecasting and energy production will occur simultaneously.** **Energy** *forecasting* [1] is done through the virtual layer. There is a forecast for both the consumer and the producer. The forecasts are done using *historic data collection [I]* from previous energy usage of both peers and weather conditions to know how much energy is going to be produced. The *energy production* [II]

[9] Idem 8

[10] Proves that a given unit of energy is generated from clean energy sources and acts as a market-based instrument to incentive clean energy rollout (EU Blockchain Observatory, 2023).

is done by the physical layer. Within the local energy community, the energy producers generate power with the use of ***distributed energy resources*** (DERs). There is no minimum amount of DER needed to start a P2P energy trading, however, the ratio of renewable consumption/total consumption has to justify the creation of an energy trading (NRG2peers Consortium, 2021).

While the energy is being generated, ***(smart) meters*** records the energy flows. ***(Smart) Meters*** are electronic systems that measure the electricity fed into the grid (pre-meter) and consumed from the grid (post-meter) (European Commission, 2023a). Data produced ranges from simple consumption measures (i.e. energy import from the grid) up to advance information about the devise usage and status (i.e. type of energy source) (Mazzola et al., 2019). These devices are essential in the value chain of P2P-ET as they serve as the ground truth[11] for energy exchange (European Commission, 2023a).

Third, **the energy trading window starts in the local energy market platform [2].** A ***digital trading platform***, which can run upon blockchain, acts as a marketplace for the participants connecting producers and consumers, enabling them to trade energy directly with each other. Trading platforms are a fundamental piece for the implementation of P2P models as they store and manage all the transactions (energy records, data, contracts, etc…) (Soto et al., 2021). Normally, platforms make use ***of advanced analytics (AI) and algorithms*** to trade the energy, forecasting for instance the estimation of surplus of energy generated. The energy prices and quantity are established depending on the type of P2P energy trading market and the seller's preferences. Consumers submit their energy consumption requirements and their consumer preferences (i.e. maximum price they are willing to pay, type of energy they want to buy, etc). During the trading window trading offers and bids naturally fluctuate until finding the appropriate match. Therefore, **the energy trading match occurs [3].**

When the match occurs, the ***verification window starts [4]***. Here, blockchain plays a crucial role. When the trade is matched, the order is sent to the blockchain. The intermediaries or centralized managers of the energy trading platform are replaced with the distributed network of digital users or validator nodes, known as miners, they work in collaboration to verify transactions and safeguard the integrity of the ledger. This is where the market rules are examined and enforced through consensus mechanisms. The most popularly used in the energy sector are Proof of Work (PoW) (World Future Energy Summit, 2023). For example, it verifies whether the consumer has sufficient funds in their digital wallets and ensures that the energy being traded falls within the maximum volume that the grid can support. Additionally, this stage involves the verification of ***smart contracts*** to guarantee their integrity (Wongthongtham et al., 2021). Once the trade is verified the blockchain settles it appending the transaction in the chain.

Physical layer

Then when the real **smart meter reading occurs** [III], the role of the smart meter is key to verifying that the traded energy is injected or received. This is also the time to check whether the produced forecast of energy has been matched. This occurs within the physical layer. Furthermore, the **physical energy transaction** [IV] occurs through the existing ***power grid infrastructure***. Even though the producer for instance, may not use the energy grid, it still pays the local DSO for utilising their grid infrastructure. The final step involves the platform handling the **payment transaction [6]** for the energy exchange using digital assets (i.e. cryptocurrency or tokens). The transaction is done

[11] See footnote 6

instantaneously between the digital identity wallets and stored in the blockchain (Wongthongtham et al., 2021). As it has been seen blockchain intervenes in various parts of the energy trading value chain increasing the security, transparency, and efficiency of the energy trading.

Additionally, ***communication infrastructure*** such as wireless communication technology, cellular networks, or Wi-Fi is needed for the P2P energy trading. In The Netherlands, 98% of households have a broadband connection (compared to the EU average of 88%), and the implementation of smart meters is between 80-90% by the end of 2022 (Bertel et al., 2022). To end, the users of the platform can monitor and control their energy transactions through the ***user interface of the energy trading platform*** (Esmat et al., 2021; Lopez & Zilouchian, 2023; Tushar et al., 2020, 2021).

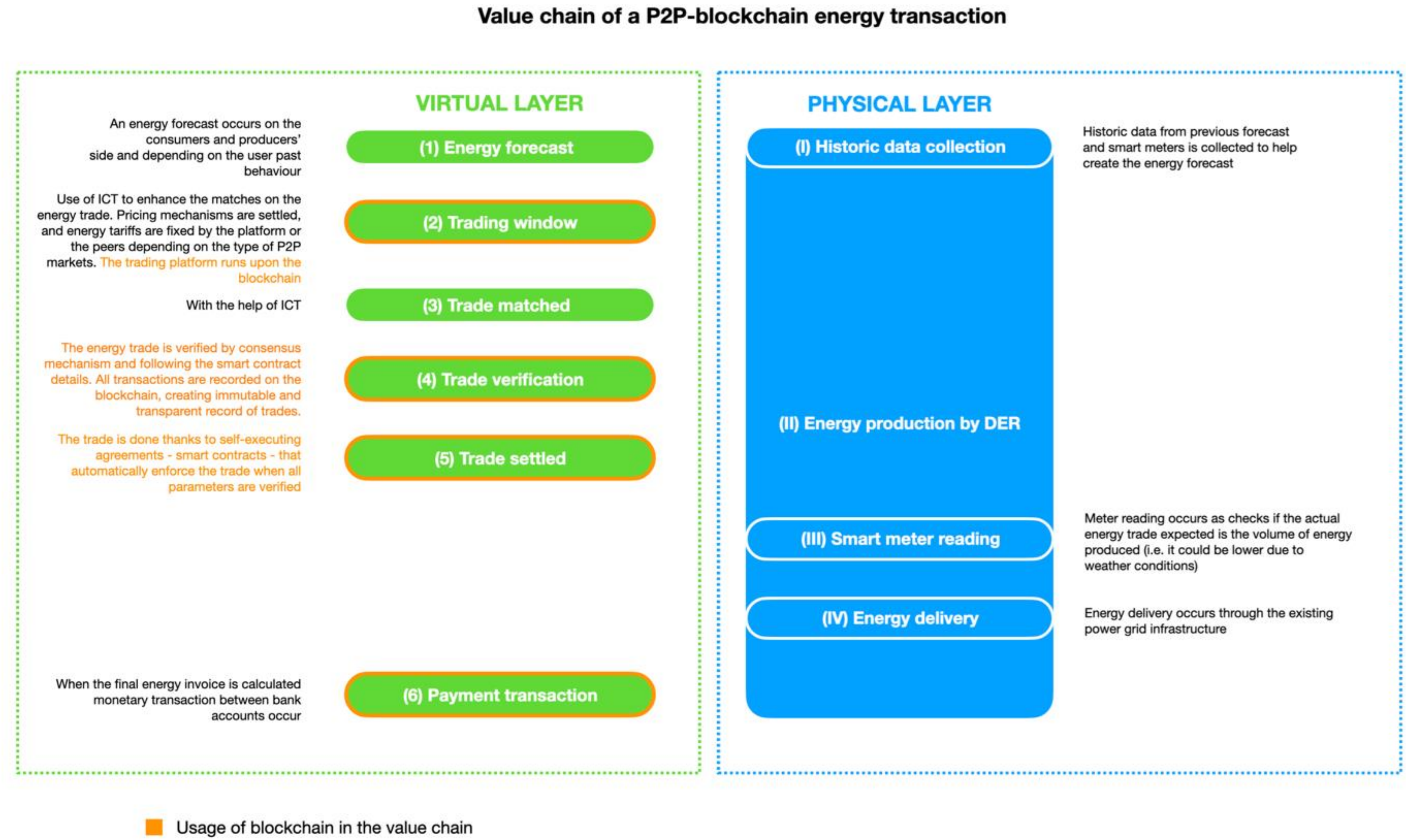

Figure 4. Value chain of a P2P-blockchain energy transaction

Up until now, the literature review has described what P2P energy trading systems are and how does blockchain works and adds value to these technological developments, as well as how does an ET transaction occur in a P2P-blockchain energy trading platform. The following section will focus on understanding P2P-energy trading systems from socio-technical lenses.

2.3. P2P-blockchain energy trading seen through socio-technical lenses in The Netherlands.

Thus far, literature has gathered information from a technical point of view, however as socio-technical system dynamics explain, all technologies in order to be property embedded in society they need to also be implemented considering the social factors such as user behaviour around the technology, organizational culture, market dynamics, economical dynamics, regulatory frameworks needed for the technology to be legally supported, etc (Geels, 2004; Kanger & Schot, 2019).

After going through a thorough literature review this thesis has selected four socio-economic domains to consider when implementing P2P-blockchian energy trading platforms in The Netherlands. The process of how this thesis ended up with these specific domains is explained on section 3.2. Analytical Framework of this thesis. Therefore, Figure 5 shows the definition of the four framework domains: *technological infrastructure, market dynamics, legislative and operations domain, and societal and user adoption domain.*

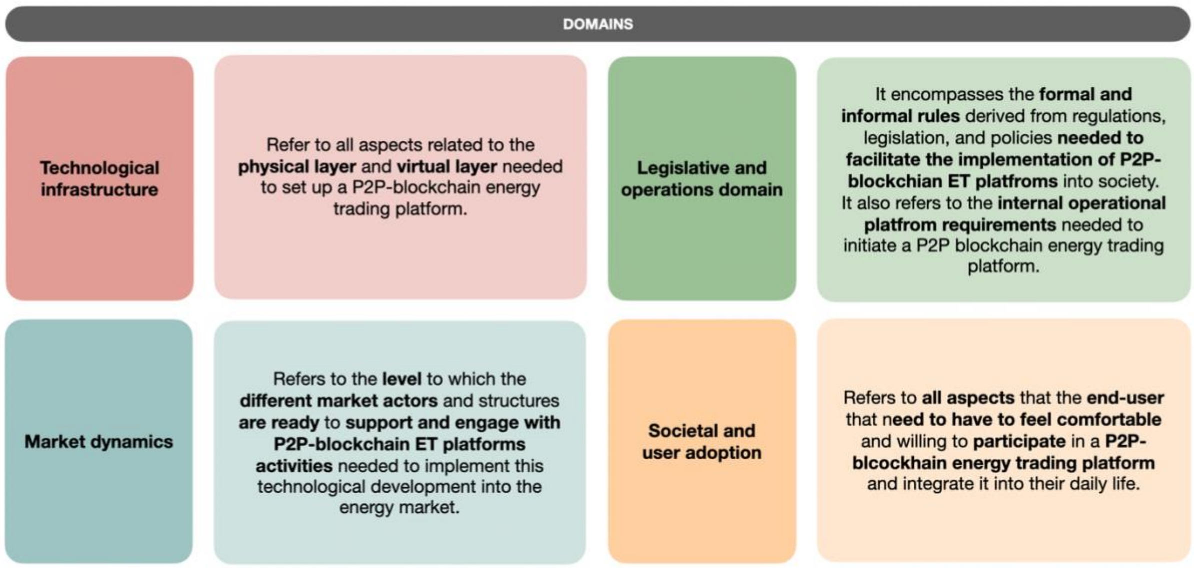

Figure 5. Domain's definition

2.3.1. Market dynamics

This analysis is tailored to the unique dynamics of the Dutch energy market.

The first necessary actor to consider in the energy system is the ***electricity producer***, the main responsible actor for the generation of electricity (Buth et al., 2019). At the time this thesis is written, the energy mix of The Netherlands is distributed as follows: natural gas (47%), wind (15%), coal (14%), solar (10%) and biomass (8%) (International Trade Administration, 2022). The electricity produced is sold directly to the grid using a marketplace which is operated by the ***market operator***. The energy can be sold to either large customers, traders, or suppliers, who will deliver it

to small and medium-sized consumers. The market operator is responsible for (i) the organization and administration of electricity trade, (ii) the settlement of payments among producers and customers, (iii) the creation of transparent price signals, and (iv) to ensure the delivery and payment of energy transactions (Buth et al., 2019).
Securely transporting energy over long distances is very important for the proper functioning of the grid, to maintain the balance between electricity supply and demand, and ensure the loss of the least amount of energy. The ***Transmission System Operator (TSO)*** is the actor in charge of this, it operates and maintains the high-voltage grid. In The Netherlands this function is carried out by TenneT. This monopoly has the final responsibility for maintaining the grid frequency of 50 Hertz at all times and overseeing the management of the transmission network (*Balancing Markets - TenneT*, 2023; Buth et al., 2019).

However, the TSO can't work on its own, while the TSO deals with high-voltage grids, the ***Distribution System Operator (DSO)*** is responsible for providing and operating low and medium-voltage grids for regional distribution and for managing the low-voltage grid infrastructure, they also install the smart meters (Buth et al., 2019). Sometimes additional data characteristics of the grid are needed to implement P2P energy trading, the DSOs are the actors in charge of providing this data. In The Netherlands, each region has its own DSO Figure 6 shows the main (IEA, 2020; Statista, 2022b).

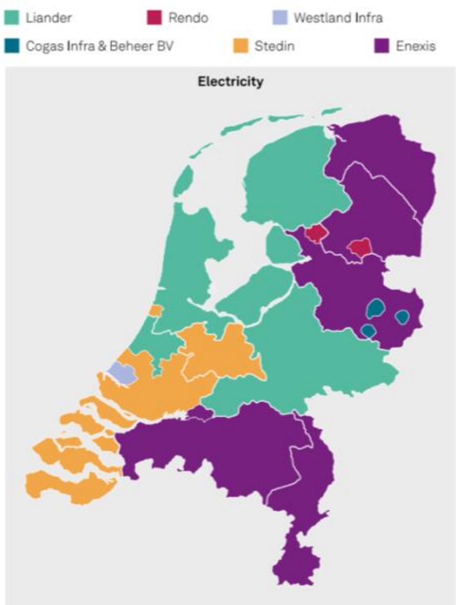

Figure 6. Main DSOs in The Netherlands divided by regional areas (Source: Companies's reports, S&P Global Ratings, 2023).

To ensure the overall transmission and distribution system are working, the inflow and outflow of electricity should be balanced. This requires accurate anticipation and adjustment of the electricity fed into and extracted from the grid by each party. The ***Balance Responsible Party/Trader* (BRP)** is responsible for balancing the acquisitions and sales volume of electricity and planning the daily usage (Buth et al., 2019). In The Netherlands, every electricity supply must have a BRP. TenneT is primarily responsible for this matter, although other parties can also serve as BRPs if they hold a certificate recognized by TenneT (business.gov.nl, 2023). Therefore, TenneT is responsible for both the transport of energy (TSO role) and the balancing of products in the high-voltage grid (BRP role) (Interview #3, personal communication, June 2, 2023).

Logic, however, essential actors in the energy system are ***consumers and prosumers***. Consumers are individuals who buy and use electricity and prosumers are actors that both produce and buy electricity (i.e. privately owned rooftop solar panels or windmills). The latter is essential for P2P energy trading (Buth et al., 2019).
Furthermore, once producers sell their energy to the marketplace, it is transmitted via TSO and DSO, and the **energy supplier** is responsible for delivering and managing the sale of energy to the end user. (Buth et al., 2019). Suppliers interact with the market operator for obtaining electricity, with the data facilitator to communicate consumption data, and with the end user to supply energy. These are some of the energy suppliers in The Netherlands, Engie, Greenchoice, Enco, Essent, Vattenfall, Oxxio, BudgetEnergie, and Energiedirect.nl (Gaslicht, 2023).

Finally, there are some additional actors who in recent years entered the market due to its shift towards a more decentralized and digitalized market.

Data facilitators oversee monitoring the growing amount of energy data and administrating the data exchange between system actors. There has been a growing number of companies developing this function in recent years, Energie Data Service Nederland (EDSN) being the most popular. They gather all smart meter readings and send it to various stakeholders, however, the data is not real-time data, which causes a vast of issues to other stakeholders of the market (Interview #2, personal communication, May 23, 2023).

API providers have emerged to solve this problem. They collect in a standardized way, historical data from smart meters from different suppliers as well as, daily reports of energy usage throughout the day (collecting data every 15-minute intervals). Having real-time data is crucial for P2P-blockchain energy trading. In terms of data privacy, a form is sent to the meter owner, who receives a request to share the data (Interview #5, personal communication, June 6, 2023).

Moreover, ***metering companies*** are another new actor, who has close relationships with suppliers, data facilitators, and API providers. These actors used to be part of the grid operators (TSO and DSO) but have now become separate entities. They supply, install and maintain electricity and gas meters, collect power and gas consumption data, and send it to the data facilitator and DSOs. Anexo B.V, Enavi B.V., Energie Consult Holland B.V, or Kenter B.V are some metering companies in The Netherlands (TenneT, 2023).

Finally, due to the increase of decentralized energy systems other actors such as, ***charge point operators*** for electric vehicles (EVs), ***energy aggregator*** that combine multiple small-scale DERs into single virtual power plant to generate electricity, ***mobility service providers*** for shared EVE services, or **home battery system providers** emerged (Buth et al., 2019).

Moreover, in terms of energy policy, the ***Dutch government and its regulatory institutions*** plays a crucial role. There are several ministries involved in the legislation of energy markets; The Ministry of Economic Affairs and Climate Policy has the primary responsibility over energy policy and the design and implementation of measures to achieve the EU and Dutch energy sector targets. The Ministry of Infrastructure and Water Management is responsible for policy considering transport, including EV. The Netherlands Authority for Consumers and Markets (ACM) is an independent regulatory authority for the electricity, gas and district heating markets (IEA, 2020).

Additionally, in terms of ***research and development institutions,*** apart from private companies, two main institutions in The Netherlands conduct research in policy in the energy sector. The Netherlands Enterprise Agency (RVO) within the Ministry of Economic Affairs and Climate Policy, which monitors public spending on energy programs and research and development demonstrations. The Netherlands Environmental Assessment Agency (PBL), which is an autonomous research institute that conducts strategic policy analysis in the fields of climate and energy objectives (IEA, 2020).

2.3.2. Legislative and operations domain

This section deploys what are the legislative and operational characteristics of the Dutch ecosystem that relate to P2P-blockchain energy trading platforms. Figure 7 shows how this is divided. First a description of the legislative domain is outlined, within the context of P2P energy trading and blockchain separately, as there is not yet combined legislation, and they refer to very different laws. Within both divisions relevant formal and informal laws are described in both the European landscape and the Dutch landscape. Finally, the section describes the operations domain of P2P-blockchain energy trading platforms.

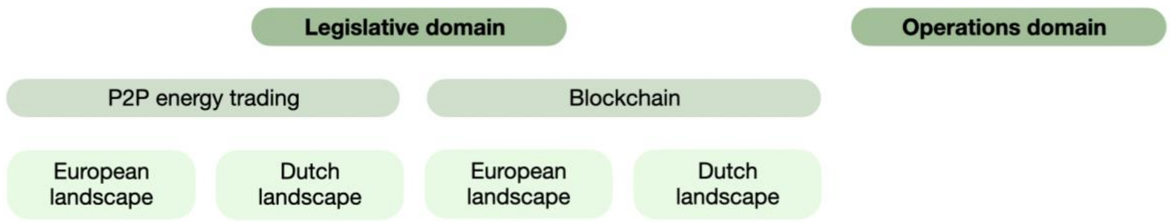

Figure 7. Shows the division of this chapter.

Legislative domain

Legislation within P2P energy trading

European landscape

The acceptance of the concept of "energy communities" by the European Commission came with the implementation of the **Clean Energy Package (CEP)** in 2019 marking a significant milestone for the European Union. The CEP directly supports P2P energy trading by promoting customer-centric energy markets and empowering the participation of prosumers (de Almeida et al., 2021). This package encompasses various directives, including Renewable Energy Directive (RED II) and Internal Market for Electricity Directive (IMED). RED II, indirectly supports P2P energy trading by promoting the development and use of renewable energy sources at a local level. And the IMED, promotes a competitive and integrated electricity market, removing entry barriers, enhancing market transparency, and ensuring non-discriminatory access to networks (RVO, 2023). Therefore, for the first time, a comprehensive set of rules are stablished around P2P energy trading, as these rules enable prosumers to access the grid and to unbundle and libertate the energy systems (Almeida et al., 2013).

However, the CEP directive does not cover all legal aspects needed to apply P2P energy trading platforms. There are some regulatory aspects that are left aside, de Almeida et al., (2021) propose in their paper laws that need to be considered when implementing P2P energy trading system in the European landscape.

Consumer law is a key concern when it comes to the status of prosumers participating in P2P platforms to sell surplus energy. As non-professionals, prosumers may lack the ability to ensure consumer protection or handle consumer complaints. Researchers state that the most suitable solution is to qualify P2P electricity platforms as providers (de Almeida et al., 2021).

In **contract law,** traditional bilateral contracts between buyers and sellers are transformed into multi-bilateral agreements in P2P energy trading. Blockchain and smart contracts are seen as promising technologies for implementing these transactions. However, the current proposal for the new *Data Act* of the European Union, while enthusiastic about adopting blockchain solutions, may not adequately address the technology's shortcomings (de Almeida et al., 2021).

Liabilities law deals with responsibilities in cases of dysfunctions, accidents, or errors (Cornell Law School, 2023). In a complex system combining traditional energy infrastructure and advanced technologies like blockchain, the allocation of liability becomes crucial (de Almeida et al., 2021). Currently, P2P energy trading does not have any type of regulation related to this matter. New intermediaries bear the responsibility of electricity supply. What it is known is that in cases where accidents result from coding or design errors, traditional rules on product liability apply to P2P energy trading platforms (de Almeida et al., 2021).

Even though, **property law** remains unaddressed for P2P energy trading, it is essential to establish clear ownership rights of DERs in contractual agreements between users and trading platforms. Additionally, a question arises when talking about who rips the benefits of the DER where the landlord and tenant have different interests and incentives towards DER investments (de Almeida et al., 2021).

Moreover, **competition law** becomes relevant when P2P platforms, due to its digital platform characteristics can gain significant market power through network effects and economies of scale. While P2P energy trading models are still emerging, new competition law regulations are needed, particularly in areas like price setting (de Almeida et al., 2021).

Finally, about **data law**, CEP supports the transition to more smart meter data availability. But there is still work to do, observers noted that data gathered by smart meters is not sufficient to enable P2P energy trading, and should be complemented by other data (network data, electric vehicles data, home appliances data, etc) (de Almeida et al., 2021). Moreover, data privacy is crucial for P2P energy trading. The General Data Protection Regulation (GDPR) in the European Union establishes the foundation for data protection. P2P energy trading schemes must adhere to GDPR to ensure proper collection, storage, usage, and transfer of data (Belen-Saglam et al., 2023).

Additionally, to enhance citizen to use DERs, **Feed-in-Tariff (FiT) and net-energy metering (NEM)** have been proposed in various European countries. These electricity billing mechanism allow prosumers to sell their excess solar energy to the grid and buy energy in case of energy deficiency (Tushar et al., 2020). The application of FiT or NEM depends on the Member States (MSs). Even though these incentives are not focused on P2P energy trading they have influenced this technology as they have enhanced consumers to buy DERs.

Finally, the above presented laws that are currently billed out at the European level, need to be implemented and transposed to the national legal and regulatory framework of each MSs. Process that requires time.

Dutch landscape

The Dutch government is at the forefront of implementing the new CEP European energy directives, as they want to ensure their prompt and effective adoption (Uhde, 2022). However currently in The Netherlands it is "simply not allowed to have peer-to-peer exchange directly between people, because you need to be a certified energy supplier" (Interview #7, personal communication, June 12, 2023).

Currently, the Electricity Act of 2 July 1998 serves as the primary legislative support for energy in The Netherlands. The Act contains rules on the production, transport, and supply of electricity. The regulation requires all households to have an energy supply to be connected to the grid, protects consumers against extortionate prices, and checks network operators' (RVO, 2023; Zaken, 2021). The upcoming **Bill Energy Act (UHT)** is a comprehensive legislation that will merge the existing Electricity Act with the regulations of the Clean Energy Package (CEP). It aims to introduce innovative laws and regulations to address various aspects of energy trading, among others.

The emergence of P2P has been indirectly affected by other Dutch regulations such **net-metering scheme (NEM),** known in Dutch as "salderingsregeling" (Muhsen et al., 2022). Net metering is a pricing system that allows prosumers to sell their excess electricity back into the grid at retail rates. Energy suppliers are obligated to deduct all the power that a household feeds back into the grid, therefore, the user ends up paying the resulting balance (Uhde, 2022). In The Netherlands, this scheme has proved to be controversial. Although one of its purposes was to promote DERs at the household level and increase consumer accessibility to them, it has also resulted in increased energy risks on grid nodes as prosumer insert their surplus energy in moments of high energy generation (Bertel et al., 2022). Consequently, the Dutch government has decided to phase out net metering gradually, starting in January 2025 (Uhde, 2022). This change can be positive for P2P energy trading platforms, as while prosumers will not be able to generate monetary reward selling their energy back to the grid, they will be able to do it through the trading platform. Moreover, the abolition of this monetary incentive can encourage the adoption of self-storing devices, such as house batteries. This side effect is seen as positive as increasing the amount of self-storing devices in households will help decrease the volatility of the grid (Interview #9, personal communication, June 13, 2023). However, from another side, this abolition also undermines peer-level incentives for self-generation, making prosumers that are not capable of buying home batteries lose their energy. Finally, if there are no P2P level trading regulations set on motion soon, the elimination of this regulation could be seen as a step back from the decentralization goal of the Dutch energy ecosystem, as prosumers will still be reliant to P2P-ET platforms to monetize their DERs (Interview #7, personal communication, June 12, 2023; Interview #8, personal communication, June 13, 2023).

With regards to **smart meters**, in The Netherlands, the Dutch Data Protection Authority – the Dutch transposition of the GDPR – gives citizens the right to have access to their data, and to object to using a processing data (Lee & Hess, 2021). By law, in The Netherlands, smart meters are provided by DSO, and the data is managed by the energy supplier (Mazzola et al., 2019).

Legislation within blockchain

Second, another description is going to be presented around all the regulatory frameworks that need to be considered when using blockchain in P2P energy trading systems (Roth et al., 2022).

European landscape

Even though the **Council of European Energy Regulators (CEER)** defines the term "P2P energy transfer" already with the use of blockchain technology as a tool for certification within energy community projects, the regulatory developments regarding P2P-blockchain in Europe are still in their early stages (de Almeida et al., 2021). Therefore, the regulatory barriers are right now one of the main challenges in the blockchain (Sorge & Leicht, 2022).

Moreover, even though **The Fifth Anti-Money Laundering Directive (AMLD5)** introduces requirements for virtual currency exchanges and custodian wallet providers there is no regulation in Europe that relates it to blockchain technology. Additioanlly, *eIDAS regulation* implemented in Europe focused on regulating trust services, however, it assumes that these services are provided by individual trusted entities instead of multiple collaborating parties and not by blockchain (Roth et al., 2022).

Concerning data law, in February 2022, the European Commission unveiled a proposal for an EU regulation – the **Data Act** – stating rules on fair access and use of data. The aim is to remove barriers to consumers' and businesses' access to data in a context where enormous volumes of data are being generated (Madiega, 2022). The proposal for the Data Act specifies who can create value from data (including IoT data) and under which conditions. In the Proposal, the Commission gives smart contracts a key role to make data transfers easier, therefore accepting and defining them as an "electronic ledger system". However, the proposal has proved to be problematic as it states that there should be a possibility of safe termination and interruption of smart contracts - called the "*kill switch*" – which goes against the principles of the immutability of blockchain technology (Adams, 2023; Circiumaru et al., 2023). The overall Data Act is still in the phases of review and will need time to be set in motion at a European level (Madiega, 2022).

Finally, concerning **GDPR**, blockchain is unaligned and not compatible with it for the following reasons (de Almeida et al., 2021). First, the GDPR in Art. 17 and Art. 21, introduces the capacity to delete personal data and sensitive data from databases, therefore it is not aligned with the principles of immutability and non-alteration of blockchain. Second, the GDPR requires the presence of an administrator or manager who can manage sensitive information, the main principle of blockchain and smart contracts is the decentralization of the system and the elimination of the middleman that needs to verify transactions. Moreover, GDPR assumes that data can be processed to keep a minimum of copies, and blockchain goes against data minimization as it stores the data in each connected node using append methods. In summary, currently, GDPR is not aligned with the decentralization, self-validation, immutability, and non-alteration of the data saved in the chain (Kirli et al., 2022). The non-update of GDPR in terms of blockchain is making P2P electricity trading platform providers reliant on the provision of GDPR-compliant aggregated (Schneiders et al., 2022).

Dutch landscape

The Netherlands has been involved in blockchain regulatory experiments since 2017. The Dutch Central Bank (DNB) has been pioneering in discussing the technology risks and possibilities, however without much traction (Abrams, 2023). At this point the DNB is the main regulatory entity around crypto-fiat exchanges, it manages the custodian of wallets and participates in pilots and start-ups around blockchain from a supervisory angle (Faria, 2021). Currently, in The Netherlands there are not any regulations regarding blockchain however, there are regulations that have been recently set in motion around specific aspects of cryptocurrency.

Thanks to the implementation of the 5th Anti-Money Laundering Directive (AMLD5) at the European level in 2020, the Dutch government has created an amendment to their current **Money Laundering and Terrorist Financing prevision Act (Wwft).** The regulation now affects individuals or legal entities that provide professional or commercial services for the exchange between virtual currency and fiat currency and are custodial of digital wallets. That is why currently, cryptocurrency transactions are allowed in The Netherlands lowering the entry barriers for virtual assets service providers[12]. According to the Wwft, anyone who offers these services in or from The Netherlands must be registered with the DNB. The DNB does consider crypto platforms to be within their scope of regulation. However, still there is much to do, as crypto-to-crypto exchange services and other types of crypto companies are still unregulated (Abrams, 2023).

The transposition of the GDPR in the Dutch context is the ***Dutch Data Protection Authority.*** This authority has recently announced that it will closely monitor the area of cryptocurrency, however, it has not addressed the use of blockchain or the processing and deletion of personal data on the blockchain. Therefore, currently, there is no guidance in The Netherlands of the use of blockchain in relation to the GDPR, data that is considered "personal" within the GDPR frames should not be stored in the blockchain (GLI, 2023).

Figure 8 shows an overview of the key current available around legislations around P2P-blcockhain energy trading.

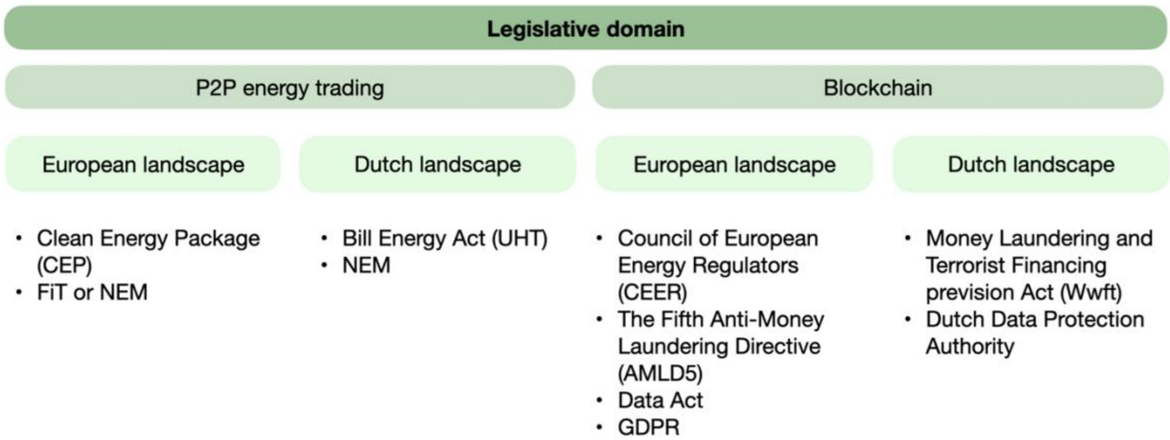

Figure 8. Current legislative scenario about P2P-blockchian energy trading

Operations domain

The operations domain, even though it might seem very secondary, it is crucial for a business model such as P2P-blockchain energy trading platform to work. Internally, the allocation of resources needs to be set on place for the coordination of the overall platform to work.

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[12] Under the Wwft directive, virtual asset service providers are considered the entities that do cryptocurrency exchanges and custody digital wallet.

First, the platform needs to have labour digital skills and competences to develop the trading platform and all the technologies within it (i.e. the market trading system, the energy pricing system, the blockchain, the energy trading dashboard to show the final users, etc). Second, the platform needs to have organizational and human resources labour to be able to deal with the overall employees as well as administrative tools to deal with the energy community (NRG2peers Consortium, 2021).

Third, in relation to the energy pricing the platform should be aligned to the whole market price to be able to provide competitive energy prices. In The Netherlands the energy prices are set by ACM, an independent regulatory authority responsible for overseeing the regulation of energy prices (CMS, 2023). According to the ACM, prosumers' surplus solar energy should be sold for a "reasonable price," which means at least 80% of the energy price that prosumers pay to buy power from the grid, minus taxes. These are perceived as best practice examples in Europe (Bertel et al., 2022).

Finally, in relation to the cost of the technology, it refers to the definition of the cost structure and revenue structure of the P2P energy trading platform. The platform needs to have the economic resources to be able to buy the physical assets needed for the platform to work. Considering the DERs, IoT devices, computer, data storage devices, shared batteries if needed, shared EV if needed, platform creation and maintenance, application costs, etc. As well as the applications and system setup revenues, investors, transaction fees, gamification revenues, financial support, and subsidies from the government, and SaaS[13] of the blockchain trade system (de Wilde, 2019).

2.3.3. Societal and user adoption

This section deploys what are the legislative and operational characteristics of the Dutch ecosystem that relate to P2P-blockchain energy trading platforms.

Knowledge and awareness

Final users should not need profound technical understanding to utilize any P2P-blockchain energy trading platforms (Interview #5, personal communication, June 6, 2023). User experience (UX), user interface (UI), and other technologies are designed to facilitate the interaction between users and a technological interface. These design elements aim to ensure that even users with limited technical expertise can effortlessly engage with the platform (IEA, 2021). However, users that do not wish to actively manage their energy trading, should be able to acquire automated software solutions. If this is not accomplished, P2P-blockchain energy trading will just be an option for an enthusiastic small group of consumers (PwC, 2016).

Moreover, when just talking about P2P energy trading systems users should be aware of both the advantages and challenges associated with utilizing this technology in their lives. These encompass a range of factors, including environmental, economic, financial, and social benefits, as well as potential negative impacts on their daily routines, fluctuating energy tariffs, limitations on household flexibility, and exposure to energy market volatilities (Interview #5, personal communication, June 6, 2023). In contrast, when talking about blockchain or even AI within P2P-

[13] Software as a service (SaaS) allows users to connect to and use cloud-based apps over the Internet (Microsoft Azure, 2023)

ET, users don't need to know how does these technology works, as it is they serve as a backend component of the platform without direct affecting user's day-to-day lives (Interview #10, personal communication, June 13, 2023). Additionally, given the significance of data privacy in P2P-blockchain energy trading, users should be knowledgeable about their rights as prosumers regarding data ownership. For instance, knowing that they are being monitored by energy trading platforms and other actors, or that they can have access to their own data whenever required (Lee & Hess, 2021).

Finally, critics argue that technology is advancing more rapidly than the public's comprehension of how and when to responsibly utilize it (PwC, 2016). Researchers such as Lamas et al., (2019, p. 91) state that the technological community and experts need to address the lack of understanding about P2P energy trading and DLT.

Values and goals

Research states that the level of engagement of users will determine how fast the adoption rate of the technology can be (NRG2peers Consortium, 2021). Therefore, even though is not essential, having the users' values and goals aligned with the values and goals of P2P energy trading is crucial for its fast implementation. Moreover, one of the main challenges mentioned in the scientific community related to the user adoption of blockchain in P2P-ET is the level of trust among actors. Whereas in centralized systems trust in handled by third parties, in blockchain applications trust is diffused among the individual participants, and this can be a difficult idea to understand. Explaining the concept of "trustless trust" to consumers is key for user adoption of the technology (NRG2peers Consortium, 2021).

Finally, due to cryptocurrency and Bitcoin, blockchain has been very debated in recent years. Sceptics argue blockchain's popularity is fuelled by the media's obsession with the 'next big thing' rather than the intrinsic potential of the technology, which creates a not reliable buzz (Chow-White et al., 2020). Blockchain technology has been subject to criticism, with concerns focused on various aspects. High energy consumption when storing data in the blockchain, fraudulent cases and scams associated with blockchain projects, resulting in significant financial losses, data privacy and security vulnerabilities, or regulatory challenges surrounding blockchain technology. These criticisms have contributed to a negative perception of blockchain. Addressing these concerns, erasing myths, and building trust within society are crucial for the adoption of this technology (Quarmby, 2023). However, even though it has its negative connotation, the study of Chow-White et al., (2020) states that the "general attitude about blockchain is predominantly positive".

Willingness and ability to participate

Finally, making use of a P2P energy trading platform requires a conscious consideration of what participation exactly means. Participation requires to have the necessary resources, such as economic means and time availability (NRG2peers Consortium, 2021). Furthermore regarding user participation, Lamas et al., (2019, p. 91) highlight that end-users have various motivations to engage in P2P-blockchain energy trading. Participants economic rewards for utilizing their DERs, having a sense of community as participants express their interest in trading energy with their neighbours. Developing individual intrinsic rewards from knowing they are positively contributing to reduce their environmental impact. And participants appreciation of the transparency, security, and fairness provided by the energy billing system in between others. However, even though there are some motivations, it is necessary to explore different strategies to enhance user engagement and improve the accessibility of these energy systems, using for instance economic incentives, social pressure, norm activation, and group contingency (Lamas et al., 2019, p. 91).

Chapter 3. Frameworks

This chapter presents the conceptual framework to understand the action arena of the research, and the analytical framework of this thesis which will assess the level of readiness of any P2P-blockchain energy trading platforms in The Netherlands.

3.1. Conceptual framework

This section presents the conceptual framework summarizing the foundation concepts and displaying the action arena of this thesis (see Figure 9). Specifically, this thesis research is focused on understanding how blockchain and P2P energy trading are combined as two technological developments within the up-to-date market and legislative energy ecosystem of The Netherlands.

This thesis came up with four main socio-technical domains using a thorough literature and media review. First, the Readiness Level Framework (RLF) for P2P-blockchain energy trading communities, established by NRG2peers Consortium, (2021) is used as inspiration. The paper presents a framework divided in different domains to assess P2P energy trading communities and it has been already assessed using outgoing P2P-ET projects. However, the framework shows some limitations, (i) even though the paper states that blockchain can contribute to better implement P2P-ET, blockchain technology is not used in the framework, (ii) the framework area of action is Europe, not taking into consideration the Dutch energy ecosystem, and (iii) the market dynamics is not well captured in the framework. This thesis also adds within this literature gaps. Second, the papers of Domènech Monfort et al., (2022) and Lopez & Zilouchian, 2023) are used as the first sets standardized terminology and structure of P2P-ET systems, and the second defines the technological layers needed for P2P-ET platforms to work. Tushar et al., (2020, 2021) are crucial to understanding which areas of action are important for P2P-blockchian ET to work, as well as (Green et al., 2020; Wongthongtham et al., 2021). And finally, (Allen & Flores, 2013; Hensen et al., 2015; Leitner, 2013; Noori et al., 2020; Nwaka, 2021; Toufaily et al., 2021).

Throughout these papers, several key topics emerged as highly important and consistently mentioned in relation to how P2P-blockchain energy trading systems work. These topics encompassed the technological infrastructure required for implementation, the functioning of the energy market, the legislative and operations aspects necessary to facilitate these technological developments, and the interaction of end-users with this business model. As a result, the main domains addressed in this thesis are *technological infrastructure*, *market dynamics*, *legislative and operations domain,* and *societal and user adoption*.

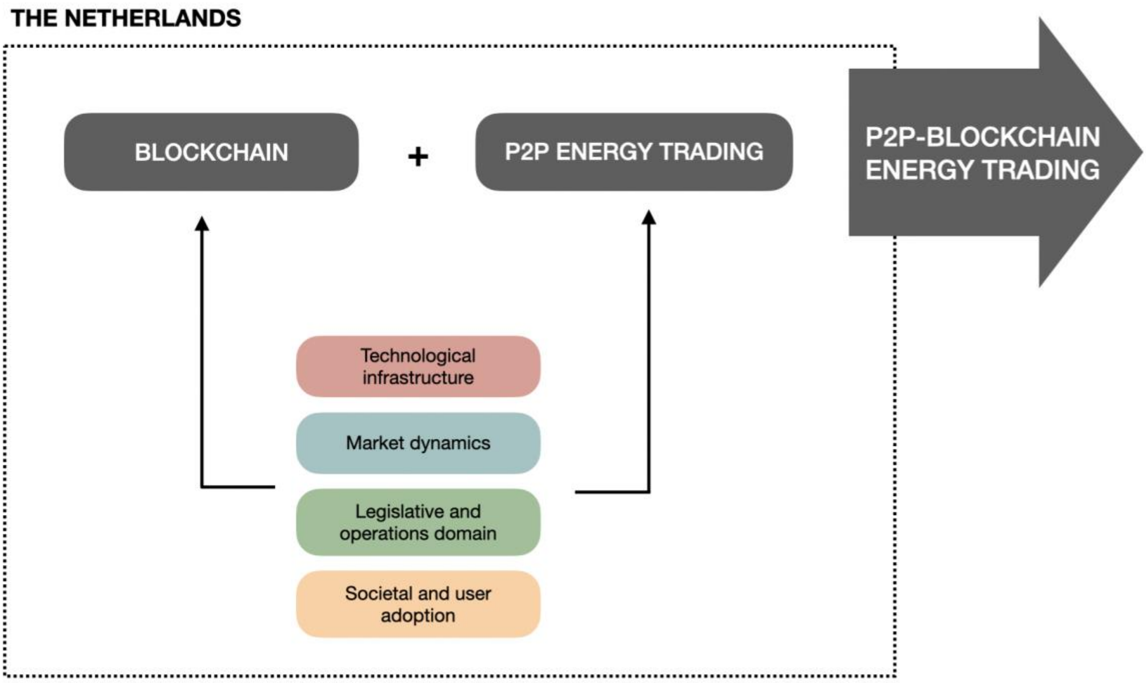

Figure 9. Conceptual framework

3.2. Analytical framework

3.2.1. Aim

With the literature and media review, and specifically the information extract from the papers outlined in Section 3.1. this thesis developed the "*P2P-blockchain Energy Trading Readiness Framework".* Figure 10 shows a summarized version of the framework and Table 2 presents the operational analytical framework. The framework aims to assess the level of readiness of any P2P-blockchain-based energy trading platforms in the context of The Netherlands. And it provides comprehensive insights into the essential elements necessary to operationalize P2P-blockchain energy trading platforms in the up-to-date energy market.

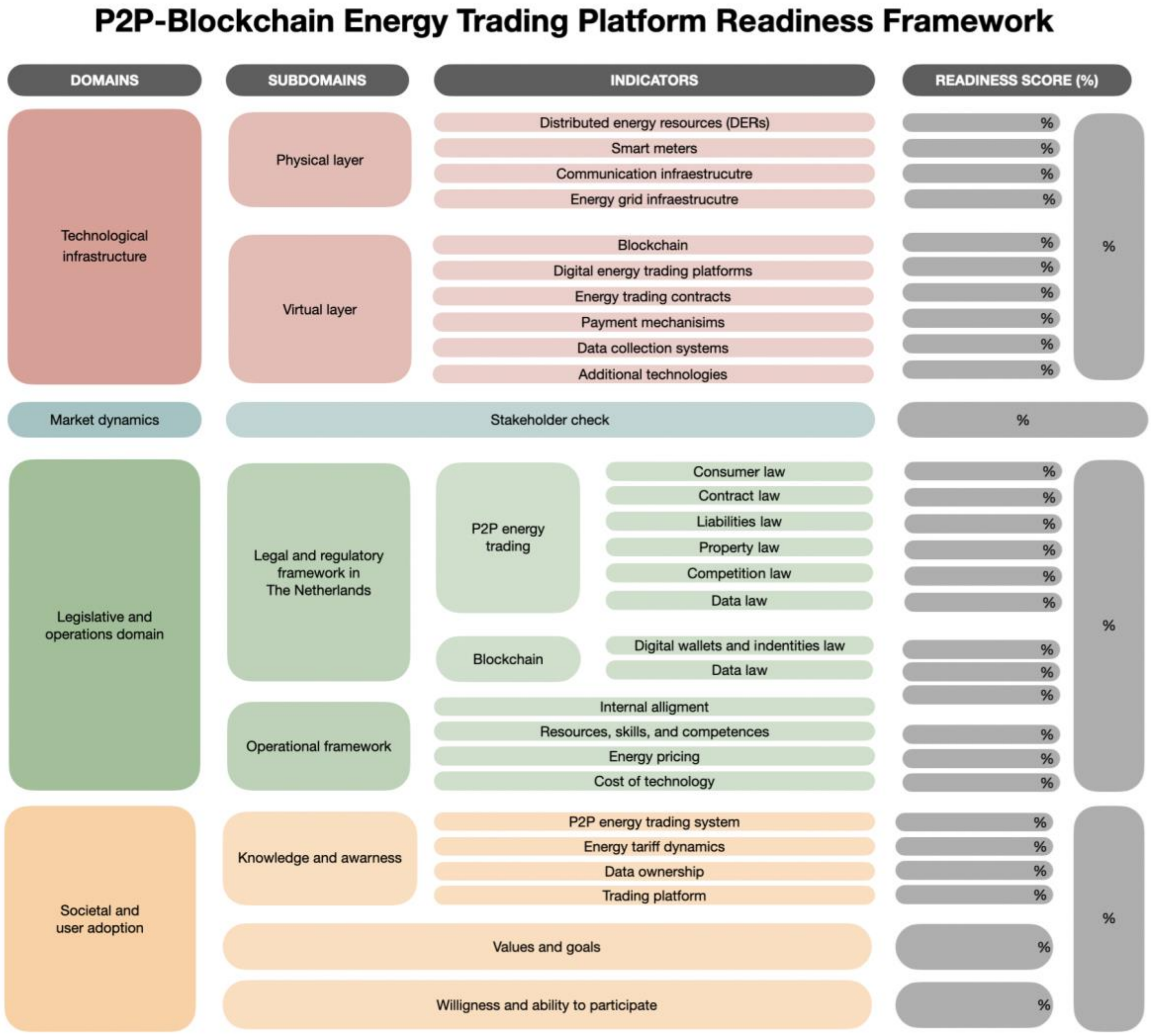

Figure 10. Overview of the P2P-Blockchain Energy Trading Readiness Framework

The framework is structured into the four above-mentioned domains. Within each of these domains, there are eight subdomains that further delve into specific aspects of the P2P-blockchain energy trading platform. These subdomains are accompanied by specific indicators, which serve as criteria for evaluating the platform's readiness and suitability for operation within the Dutch energy socio-technical ecosystem.

As for the users of this framework, there are two distinguished groups. The first group consists of people interested in starting or further developing a P2P-blockchain energy trading platform. These can be members of energy communities' initiatives or board members of existing energy cooperatives. The framework assists them in understanding the fundamental aspects across the four domains that are necessary to initiate or advance their platform's development. The second group consists of policy actors that are interested in better understanding P2P-blockchain energy trading platforms and learning how to improve their supportive programs. These actors utilize the framework to understand the overall context and relationships between the different domains, rather than specific project implementation (NRG2peers Consortium, 2021).

The definition of "readiness" is crucial for the proper implementation of the framework. At the beginning of each assessment, the assessor needs to set what it means to be "ready" for their specific case. Finally, when referring to the *full readiness level* this thesis understands it as the P2P-blockchain energy trading platform (i) operates within a decentralized P2p energy trading market, (ii) reaches a full decentralization and independence from market actors, (iii) the platform is operational within the energy market and (iv) the end-users have direct contract with the platform and have fully adopted it in their daily lives. Figure 11 proposes a definition for "*what does it mean to be ready*" for each domain.

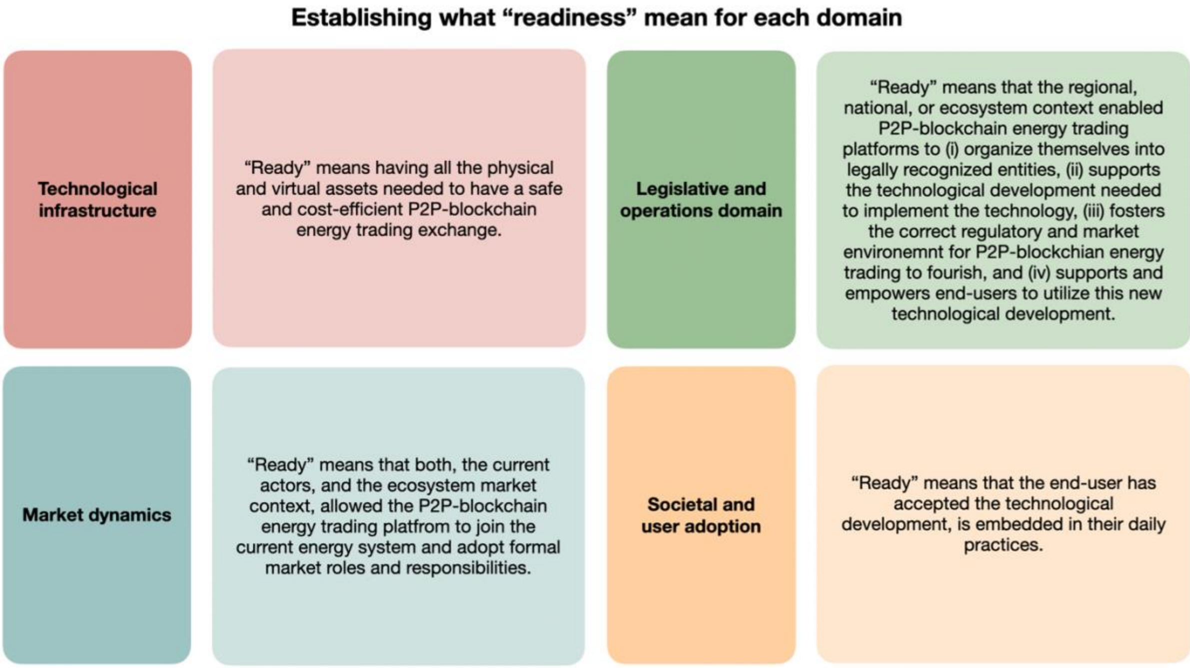

Figure 11. Definitions for "readiness" for each domain

3.2.2. Operational analytical framework

Table 2 shows the operational analytical framework used for the assessor to evaluate the P2P blockchain energy trading platform.

Operational P2P-Blockchain Energy Trading Readiness Framework

Technological infrastructure

	PHYSICAL LAYER INDICATORS	
A	**Distributed energy resources (DER)**	VALUE
1	The ratio of renewable consumption/total energy consumption justifies the creation of a P2P energy trading platform.	
2	There is physical space available for installing DER	
3	There is enough energy storage capacity installed to enable community P2P-blockchain exchange at the scale-level that is aimed at	
4	There are other storage solutions such as thermal storage, electric vehicles, etc to enable the P2P-blockchain energy exchange at the scale-level that is aimed at	
B	**Smart meters infrastructure**	VALUE
1	Smart meters are available in every household to monitor the DERs and enable real-time monitoring of energy flows.	

2	The smart meters are able to gain data not just from the consumption and production of power but also advance information about the devise usage and status (i.e. type of energy source, grid characteristics, etc)	
C	**Communication infrastructure**	VALUE
1	The peers of the platform (households, and other establishments such as local business, farmers, and public buildings) have the sufficient broadband connection (Wi-Fi) to enable bidirectional transmission of energy data between the platform and the peers.	
D	**Energy grid infrastructure**	VALUE
1	There is existing energy grid infrastructure to trade energy for P2P-blockchain ET	
2	The physical capacity of the energy distribution grids of the area allows the peers to exchange energy at the scale-level that is aimed at.	

	VIRTUAL LAYER INDICATORS	
E	**Blockchain**	VALUE
1	The platform runs upon blockchain (private or public)	
2	The platform utilizes specialized algorithms designed to optimize energy usage and storage, minimizing consumption to the greatest extent possible	
F	**Digital energy trading platforms**	VALUE
1	There is an existing digital platform that can remotely control, and steer assets based on the flexible energy needs to enable P2P exchange at the scale-level that is aimed at	
2	Digital infrastructure to ensure a proper functioning of energy management and monitoring systems for P2P-blockchain ET is in place	
3	The interfaces on the trading platform are informative and supportive for all users of the P2P energy trading system	
G	**Energy trading contracts**	VALUE
1	Existing energy contract generated between the peer and the energy company to sell the surplus of energy generated are on place	
2	Existing energy contract between the peers and the platform are on place	
H	**Payment mechanisms**	VALUE
1	The platform can host digital wallets	
I	**Data collection systems**	VALUE
1	Availability of real-time local weather data	
2	There is available access to API (Application Programming Interface) to read meter and sub-meter data.	
J	**Additional technologies**	VALUE
1	Forecasting algorithms are in place to predict load and, thus, to optimize energy sharing in the energy community	
2	Making the forecasting algorithmics the most cost-effective and sustainable as possible	

Market Dynamics

K	ACTORS	ESSENTIAL RELATIONSHIP	ADDITIONAL RELATIONSHIP
1	DER producing companies (i.e. producers of solar panels, wind mills, heat pumps…)		
2	Electricity producer		
3	Market operator		
4	Transmission System Operator (TSO)		
5	Distribution System Operator (DSO)		
6	Balance Responsible Party (BRP)		
7	Consumers and prosumers		
8	Suppliers		
9	Data facilitators		
10	APIs providers		
11	Energy aggregators		

12	Charge point operators or mobility service providers		
13	Regulatory institutions		
14	Research and development institutions		
15	Additional partners such as municipality, housing associations, project development companies, installers		

Legislative and operations domain

Legislative domain

	P2P ENERGY TRADING LEGISTAIVE INDICATORS	
L	**Consumer law**	VALUE
1	The trading platform is assuming that they are trading energy for commercial interests.	
2	Users of P2P energy trading platforms maintain their consumer status	
3	The customers are aware that the solar panels are currently rated with a 0% VAT	
M	**Contract law**	VALUE
1	The platform's hosting region ensures that peers within the trading platform have convenient access to the electricity grid.	
N	**Liabilities law**	VALUE
1	The platform is aware that is liable to the responsibilities in a case of dysfunctions (failures, accidents, or errors) for both the prosumer and the digital tools used in the platform	
O	**Competition law**	VALUE
1	The contractual platform tariff price is set at a competitive level within the market, ensuring it is not overpriced.	
P	**Property law**	VALUE
1	Ownership of Distributed Energy Resources (DERs) is explicitly outlined in the contractual agreements between the user and the platform, providing clear and transparent information regarding ownership rights.	
Q	**Data law**	VALUE
1	The customers are aware that they are allowed to have access their smart meter data	

	BLOCKCHAIN LEGISLATIVE INDICATORS	
R	**Crypto assets law**	VALUE
1	Do you comply with the Wwft (directive around cryptocurrency exchange and custodian wallets)	
2	The entity is registered as a cryptocurrency exchange agent and wallet custodian in the DNB	
S	**Digital wallets**	VALUE
1	The platform hosts a digital wallet which goes aligned with the GDPR	
T	**Data law**	VALUE
1	The information is stored in the blockchain complies with the current GDPR	

Operations domain

U	Internal alignment	VALUE
1	The platform clarifies how the distribution of economic benefits is divided and organized among members of the energy community (i.e. the platform providers)	
2	The platform clarifies how the use of collective assets (i.e. collective battery; shared mobility devices) are organized within the platform and energy community members.	
V	**Resources, skills, and competences**	VALUE
1	The platform has a clear short- and long-term organization on how and what available competences and skills (technical, financial, legal, social knowledge and skills) are needed to operate a P2P-blockchain ET platform. Also addressing the balance between paid and volunteer staff and differentiating between different types of expertise and skills needed.	
2	The platform has developed a business case(s) and has a financial plan prepared for the P2P-blockchain ET platform to work.	

3	There is clarity about the communication between platform daily management and peers of the community (i.e. channels (physical meeting, newsletters, etc.) messaging, frequency, etc).	
4	The platform has administrative tools (e.g. community member billing system) in place" (NRG2peers Consortium, 2021).	
X	**Energy pricing**	VALUE
1	The price of the energy is aligned with the wholesale energy market prices	
Y	**Cost of the technology**	VALUE
1	The platform has clarity on how all financial value flows are allocated and formally organized within the platform.	

Societal and User Adoption

	Knowledge and awareness	
Z	P2P energy trading system	VALUE
1	Users show an understand the interest in going beyond self-generated renewable energy towards self-consumption and flexibility.	
2	Users understand the various benefits (environmental, economic, financial, social) that P2P-blockchain ET platforms can provide them.	
3	Users acknowledge that participating in P2P energy trading systems may impact the timing of their daily activities and recognize the potential drawbacks associated with it (i.e. fluctuating tariffs, household flexibility limitations, and market volatilities).	
4	Users understand how P2P-blockchain ET works and what interactions occur when the trading is generated.	
5	Users have a basic understanding of energy-related climate change challenges	
AA	Energy tariff dynamics	VALUE
1	Users understand that there are energy tariffs within the energy community and how these tariffs are different from their current tariffs with their energy suppliers.	
AB	Data ownership	VALUE
1	Users are aware of agreements on data ownership and have explicitly agreed on it. They are aware that their energy data is being monitored by the platform, but that they can have access to their data.	
AC	Trading platform	VALUE
1	Users show a basic understanding of how the energy platform works.	
2	Users show an understanding of how the interfaces work, and they show a certain level of "experienced" control and empowerment.	

AD	**Values and goals**	VALUE
1	Users are interested to participate on this energy community within the P2P-blcockhain ET platform, and have a clear idea about the goals the platform (i.e. values, economic, environmental, social benefits).	
2	The users are aware of the level and type of engagement that is asked for them when being part of the P2P-blcockhain ET platform.	
3	The users show trust[14] in the organisational structure, the management of the platform and the "people" that represent it (i.e. the board members or intermediary platform).	

AE	**Willingness and ability to participate in P2P energy trading systems**	VALUE
1	Users show a certain willingness to invest (financially, time, knowledge, social relations) in the platform now and in the future.	

Table 2. Operational P2P-Blockchain Energy Trading Readiness Framework

[14] The level of trust can vary depending on the type of P2P-blockchain energy trading market which the platform is defined in.

3.2.3. Operationalization - Scoring system

To assess each domain, the framework developed several indicators, the assessor must evaluate them by adding a "1" or "0" in the "VALUE" column of the statements (See Table 2).
However, it is important to note that after the creation and assessment the analytical framework, it has become apparent that not all indicators carry equal importance in determining the readiness level of a platform. This nuanced perspective will be further elaborated in Section 7.1.6.

To decide on the value of each statement the assessor should gather information; by doing a *quick scan* (i.e. informed guess, based on workshops or other consultations as interviews), or by doing a more in-depth assessment (i.e. survey questions to multiple actors of the platform or energy community) (NRG2peers Consortium, 2021). The involvement of a bigger variety of stakeholders in the information-gathering process will lead to a more objective and well-defined results evaluation of the framework. The P2P-blockchain trading platform will be ready to implement in its socio-technical ecosystem when the readiness score of all the indicators reaches a 100%.

Additionally, in terms of market dynamics, the scoring system will differ. The positive score is assigned to platforms that maintain minimal dependencies (fewer essential relationships) with various market actors. This indicates that the project is more advanced in its implementation stages. Table 3 shows the definitions of essential relationships and non-essential relationships.

ESSENTIAL RELATIONSHIP	Are relationships with actors that are indispensable for enabling the energy trading process and needed for creating the minimum viable product (MVP) of the platform.
NON-ESSENTIAL RELATIONSHIP	Are relationships with actors that are not indispensable for the basic functioning of the platform, however that add value to the trading experience and performance.

Table 3. Definition of essential and additional relationships for the framework

Chapter 4. Methodology

This chapter outlines the methodology used to answer the thesis research question and develop the thesis. In overall, this research is based on a multi-method approach, and the methodology used goes as follows.

To cover how P2P energy trading systems work in The Netherlands, how blockchain can help implement P2P energy trading systems, and understand what the necessary requisites for successful implementation of P2P-blockchain energy trading systems in the socio-technical context of the Dutch energy market are, a literature review is done. The culmination of this data gathering process results in the development of the analytical framework to evaluate the readiness level of P2P-blockchain energy trading platforms in The Netherlands. This thesis choses Distro Energy company as a case study as is one of the currently operating P2P-blockchain-based energy trading platforms in The Netherlands. Distro Energy company is a transactive energy start-up situated in the Port of Rotterdam, which operates a blockchain-based platform that facilitates seamless P2P energy trading, enabling direct energy transactions between companies in the port (Distro Energy, 2023). The platform was chosen as is one of the currently operating P2P-blockchain-based energy trading platforms in The Netherlands. The case study is used to (i) put in practice the readiness framework assessing "how ready" is Distro ecosystem at the current time, and (ii) conduct a re-evaluation of the *P2P-Blockchain Energy Trading Readiness Framework*. Information to accomplish (i) and (ii) has been gathered by interviewing 11 employees of different stakeholder within Distro market actors. All the collected data was processed through a thematic analysis based on the search and generation of themes. Finally, this thesis re-evaluates the analytical framework using the insights and learning from the case study and the feedback provided by the interviewed Dutch energy market actors.

4.1. Data Collection

The **qualitative research** gathers data from various sources, including a literature and media review, a preliminary interview at a Distro employee, an initial literature research involving Distro and Distro platform, and 11 interviews done to the different Dutch energy market stakeholders.

First, an overall literature review is preformed to gather information on the following. Describe the interaction between P2P energy trading and blockchain technological developments, understand what added value does blockchain provide, as well as the advantages and disadvantages of the combined technologies. Second, describe the current socio-technical environment in which P2P-blockchain energy trading platforms are emerging. Third, understand and define what the necessary requisites for successful implementation of P2P-blockchain energy trading systems in the socio-technical context of the Dutch energy market are. Specifically, a literature and media research, peer-reviewed articles, news articles, project documents, webinars, legislative documents, and policy documents have been researched. Search engines like Google Scholar and Scopus have been utilized by using terms like "P2P energy trading," "P2P-blockchain energy trading," "energy systems," "implementation," and the four research perspectives "technology", "market dynamics", "legislative domain", "operations domain" and "user adoption dynamics".

Second, a preliminary interview with Distro employee, as well as a preliminary literature to provide a comprehensive understanding of Distro's background, activities, and contributions to the field, enhance the interviews quality and ensure a well-informed discussion is done.

Third, semi-structured interviews lasting 40-50 minutes are conducted to 11 participants from the following energy market stakeholders *TenneT, Stedin Group, Distro Energy, The Port of Rotterdam, University UNIPG, The Dutch Blockchain Coalition, Top Sector Energie, Energy Web,* and *TU/e.* The purpose of these interviews is to gather diverse and objective information for assessing the readiness level of Distro platform as well as feedback for re-evaluating the analytical framework of this thesis. Considering the different backgrounds of the participants, the questions differ between the actors. However, there is a final consistent 10-minute question aimed at soliciting feedback on the analytical framework. Finally, the actors within the Distro Energy platform who are interviewed are asked to assess the framework themselves. Examples of the interview questions are given in the Appendix A.

Furthermore, to secure the interviewee's privacy and obtain permission, verbal or written consent is asked from the study participants before the interview. In this case, information about the research, their rights as participants, and the potential risks and benefits of the thesis research are notified. Confidentiality and anonymity throughout the research process is maintained. Finally, during the interviews, the researcher must ensure trustworthiness and a relaxed environment to make interviewees feel comfortable to share their opinions as honestly as possible.

4.2. Data analysis

To analyse the collected data a thematic analysis is conducted. This analysis is focused on identifying and developing themes based on the data (Lai, 2017). In relation to the assessment of Distro platform. First, the interviews are transcribed using Microsoft Teams transcribing tool (See Appendix B). Second, the four themes are identified from the text. Moreover, relevant quotes are extracted to assess the value of each framework statement. And finally, Microsoft Excel is used to aggregate all the statements values and indicator percentages to determine the overall readiness level and to plot the results.

Second in relation to the assessment of the analytical framework, the same has been done. The data and quotes have been used to gather feedback on the utilization of the framework, identify areas that require improvement, as well as determine which indicators are adequate, and which one should be modified or eliminated. In overall this assures a more comprehensive and robust assessment of the framework's effectiveness.

In the following chapter a detailed explanation of Distro and Distro platform is presented.

Chapter 5. Case study: Distro platform

This chapter explains how Distro platform is conceptualized and understood by the company from its initiation stages to its future ideas of implementing Distro platform to the overall port of Rotterdam. It is important to note that the information presented in this chapter is what the company conceptualize as their product, not the current situation of its services.

5.1. Introduction to Distro

Distro Energy company is a transactive energy start-up situated in the Port of Rotterdam, operates a blockchain-based platform that facilitates seamless peer-to-peer energy trading, enabling direct energy transactions between companies in the port (Distro Energy, 2023). The company which is currently a subsidiary of the Port of Rotterdam Authority and part of Rotterdam DockLab originated during a hackathon (Port of Rotterdam, 2020).

"Distro makes everyone an energy trader", serves as a bridge between local energy consumers and producers as nowadays *"energy markets are incredibly complex and they are not accessible to the general public"* (Interview #2, personal communication, May 23, 2023). Distro platform adds value to the energy market in different ways. First, from a consumer perspective and by utilizing their Artificial Intelligence (AI) trading models and market engines, Distro platform aims to allow prosumers to have better energy prices and help them have a more cost-efficient use of their DERs (i.e. solar panels or batteries). Moreover, with the combination of these two technologies and storage devices, they aim to guarantee that the least energy goes to the imbalanced market (Interview #5, personal communication, June 6, 2023). Finally, it also provides more clarity of what type of energy consumers are using (i.e. renewable or non-renewable energy) making the consumer more aware of their energy consumption (Interview #5, personal communication, June 6, 2023).

Moreover, other energy actors – such as BRP, suppliers, or DSOs, also can benefit from Distro platform. The platform can manage the volatility of renewable supply, reduce peak shaving and solve intermittency of energy (i.e. with the use of self-executing storage devices) (S&P Global Platts, 2020).

Finally, compared to other business models on P2P energy trading, Janjoost Jullens, Director & Energy Lead of DockLab assures that Distro platform can fit new market energy paradigms into old market energy paradigms, serving as a bridge between the two markets and creating a good starting point for energy transitions. As it for instance, considers the wholesale energy market when trading energy within the local markets (Jullens, 2021).

5.2. How does the Distro trading platform work?

Taking all the dynamics of the energy market in consideration, four main components need to cooperate with one another to make the platform work (Jullens, 2021). It is important to note that this section provides a conceptual description of the Distro platform and does not reflect its current operational state. The detailed explanation of its current functionality is presented in Section 6.

Market Engine

This core software does what the energy market is supposed to do. Has a 48h forward market forecast (production and consumption prediction) and within every 15-minute intervals facilitates high-frequency energy trading working with several orders (Jullens, 2021).

AI training boot

In Distro platform the AI represents the energy market agent of any types of end-users[15], including consumers, producers, prosumers, and even storage devices (i.e. batteries). The idea behind the AI trading boot is to automatically sell energy with smart contracts whenever there is high demand or buy energy whenever there is low supply, making these devices cost-effective. The AI model works with three types of input.

First, the weather data and DERs information. The former is solar, and wind forecasts as it's the main renewable energy extracted within the port. The latter, is related to the DERs energy profile, which outlines the type of production DERs generate (solar energy production, wind energy production, hydropower energy production, energy ocean production, etc.) and the time of the energy production (Interview #2, personal communication, May 23, 2023, p. 2). Second, the price information from the wholesale market[16] and local market prices.And finally, the trading behaviours of users, using data from historic smart meter data and consumer preferences. The latter can be changed for the AI to work in the best interest of the end-user (Interview #1, personal communication, May 3, 2023, p. 1).

With all this input the AI predicts energy volume, generates price discovery, and creates trading strategies personalizing the overall energy trade of each end-user (Interview #5, personal communication, June 6, 2023; Jullens, 2021).

Additionally, and in relation to the consumer preferences. Distro platform categorizes its consumers based on their energy risk availability. Flexible users adjust their consumption based on market conditions, such as a factory increasing production during low-priced energy periods. They may also utilize smart devices to optimize energy usage. On the other hand, risk-averse users - like hospitals - prioritize reliable energy supply over obtaining the lowest prices. These consumer preferences are established during a customer onboarding processes (Interview #2, personal communication, May 23, 2023, p. 2).

Blockchain

Distro platform uses blockchain to provide a secure environment for both the market engine and the trading AI to operate in (Interview #5, personal communication, June 6, 2023). The idea is to utilize a series of self-executing smart contracts already signed and accepted by the Distro platform and the end-users to trade this energy. Smart contracts can potentially also enforce market rules, validate identities, and perform energy balances. When transactions are successfully verified, the blockchain can potentially safe them in the ledger and settle them using utility digital assets (i.e. tokens) as the payment mechanism (Jullens, 2021).

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[15] There are ongoing debates among blockchain experts regarding the role of artificial intelligence (AI) and its potential impact on decentralization in P2P systems. Some argue that AI could potentially act as a middleman, raising concerns about the full decentralization of P2P networks.

[16] Wholesale energy market refer to the trading and exchange of electricity, national gas and other energies on a large scale between producers, suppliers, and intermediaries facilitating the bulk purchase and sale of energy (European Commission, 2023b).

Tokens

Moreover, the idea is that Distro platform utilises tokens to facilitate payment transactions between peers, they are stored in the digital wallets. Distro platform has two different types of tokens: *management tokens and energy tokens.* One *management token* equal one euro, therefore users potentially purchase tokens to pay for their energy transaction. And one *energy token* is a physical representation of an energy unit consumed or generated (Interview #1, personal communication, May 3, 2023). These energy tokens are used during the energy transaction, as an accounting tracking (Interview #2, personal communication, May 23, 2023).

Contracts

Distro has different types of contracts or agreements within the platform. They operate on a subscription-based model, charging users for platform access and utilization (Interview #1, personal communication, May 3, 2023; Interview #2, personal communication, May 23, 2023). In addition, they facilitate flexible rate contracts between peers, which differ from the typical long-term agreements known as Power Purchase Agreements (PPAs) used by renewable energy generators to purchase energy at predetermined low prices (Iberdrola, 2023). Distro leverages its AI trading boot and batteries (which hypothetically will be owned by the prosumers, even though Distro also have storage capacity by its own) to provide flexible rate contracts between peers and optimize energy prices.

Energy prices

The energy prices are set by the Distro platform market engine, AI trading boot, and with the preferences of the companies (Interview #2, personal communication, May 23, 2023).

Overall platform premises

Finally, for the platform to work several premises are settled. First, the user is always sovereign of the Distro platform and energy trades. It has the ultimate control, authority, and power over the platform and its data[17]. Second, the smart meters collect the ground truth[18] data that will posteriorly be used to trade the AI boot with. Finally, even though the users don't trade with the external energy markets the platform is connected to them and complies with them to assure economic profit (Jullens, 2021).

5.3. Distro platform in the Port of Rotterdam

The Port of Rotterdam is considered the largest port in Europe covering around 40 km from Rotterdam city centre to the sea. This energy-intensive area generates 20% of The Netherlands' CO_2 emissions as the port hosts different industries and logistic companies including refineries and petroquemical companies. Therefore, the port of Rotterdam has the imminent position of reducing its CO_2 emissions to achieve the Paris Agreement and national climate targets. Their strategy to reduce their carbon footprint is based on developing infrastructure for energy transition, generating new energy systems (i.e. windmill plants, solar panels, etc), and developing new types of energy business models focused on circular economy. Here is when Distro comes into place. The port believes that having transparent markets will help to create competitive energy prices and improve the energy dynamics of the port (van Dooren, 2021).

[17] Idea which can be debatable, see Chapter 6.

[18] Referring to the real smart meter readings at the time of the energy production and consumption.

The Port of Rotterdam Authorities and Distro decided to start the pilot project of Distro platform in the Innovation Dock within the port. Due to the port's environmental challenges and current situation, the Dock proved to be the perfect location with a controlled environment to test the Distro platform. The building is a former submarine factory and currently serves as an innovation space for 40 cutting-edge technology companies. Out of the 40 companies, 32 decided to participate in the pilot (Interview #2, personal communication, May 23, 2023). The companies within the dock already had installed their solar panels and smart meters (owned by the Port of Rotterdam) to monitor the consumption and production of their local energy (Jullens, 2021; van Dooren, 2021). The pilot was initiated in August 2020 and lasted 6 months (Port of Rotterdam, 2020). The following Figure 12 depicts the map of the Port of Rotterdam and shows how little the Innovation Dock is compared to the overall port. Given the potential expansive dimensions that Distro platform could have to all the companies within the port, Distro and the port of Rotterdam highlight the potential positive impact that the platform can have in reducing their CO_2 emissions. However, this statement can be seen as oversimplification or exaggeration of Distro potential, as they cannot assume that Distro platform will single-handedly solve the emissions challenge within the port of Rotterdam created by the petrochemical-intensive industries that are in the port.

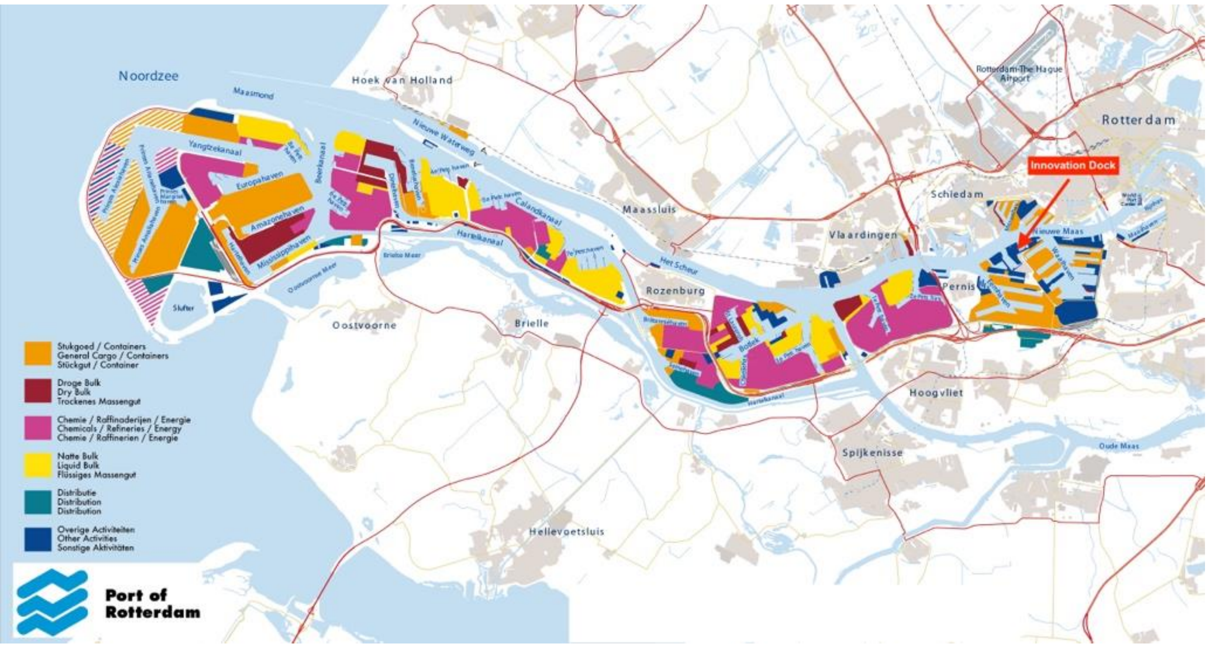

Figure 12. Map of the Port of Rotterdam and location of the Innovation Dock (Source: Port of Rotterdam)

5.3.1. Distro energy trading value chain

Using the same value chain as in the Section 2.2.4, Distro platform follows a similar energy value chain, Figure 13 shows the summarized Distro energy trading value chain.

The trading starts with a ***forecast from the producer and the consumer [1].*** The forecasts are done depending on the configuration of the users, their risk appetite, and their flexibility in energy usage. When the ***trading window [2] starts*** Distro platform uses its market engine and AI trading boot, to generate energy dynamics like the wholesale energy market, ***search for matches [3]*** in the local marketplace and create the energy tariffs and prices for the power that is being traded. At the beginning of the trading window, prices are still apart, *"producers always try to start at the highest price they get, and obviously, consumers start at the lowest price they can bit"* (Interview #2, personal communication, May 23, 2023). Every trading window is open every 15 minutes. The AI is controlling the bids and offers and suggests prices depending on the strategy and preferences of the users. Once the trade is matched, the information is sent to the blockchain where is stored and ***verified [4]*** by the market rules and smart contracts. Then the ***exchange of management tokens [5]*** occurs between the platform wallets of the peers and the ***trading is settled [6]***. Afterward, delivery happens. In this moment, is when the ***smart meter reads the energy generated [III]*** and sees if it matches the amount of energy forecasted to sell. It may be that the weather forecast was that the solar PV generated 5 MW/h but, in the end, it was just possible to produce 4 MW/h as some clouds came across. In this case, Distro platform makes the producer pay for the imbalance with energy from the grid and using the current energy market prices[19]. Finally, the ***physical energy transaction [IV]*** is done by the grid infrastructure. As changes in the producers' invoices may occur due to weather conditions, Distro platform has generated a final reconciliation process within the blockchain where the imbalance prices are settled. This happens after 24h from the delivery period. (Interview #2, personal communication, May 23, 2023).

[19] Distro is searching for solutions when dealing with energy trading liabilities such as this one.

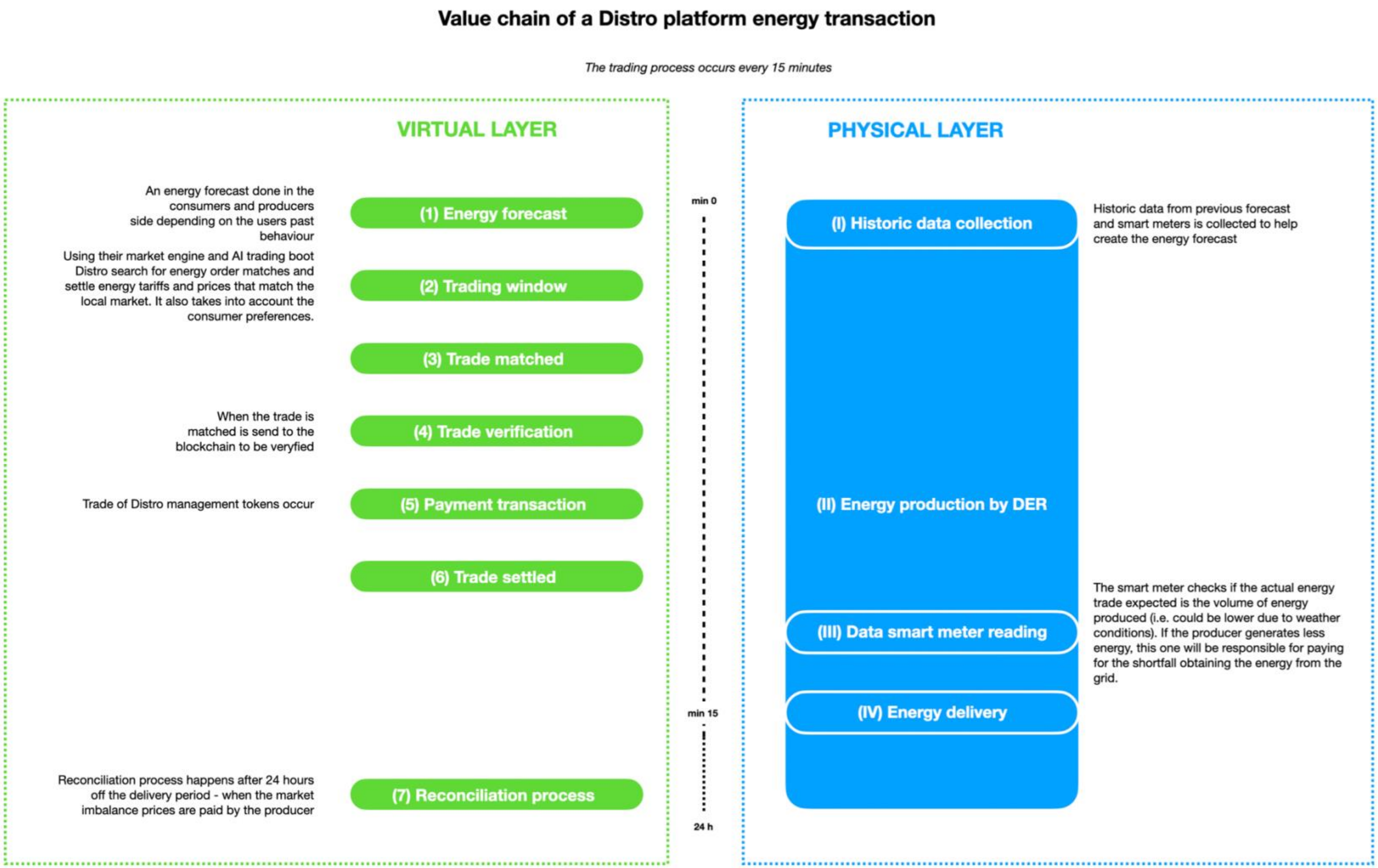

Figure 13. Distro energy trading value chain

5.3.2. Results of the pilot

The trial concluded after 6 months and proved to be more successful than expected. In terms of technical performance, the *market engine* scored high-frequency metrics, the *AI trading boot* had a 94% of accuracy[20], and the *blockchain* was able to do 2 million trades in 48h (maximum capacity of the current blockchain environment) (Jullens, 2021). Moreover, in terms of price discovery, the AI was able to perform iterative price formation to discover the right price on the local market. The system proved also to have self-arbitrage, the AI that represented the battery was able to buy and sell energy whenever there was a lot of demand or supply of energy, meaning that the battery was able to respond to economics. Finally, the blockchain private environment was able to do seamless integration with the banking environment. In terms of economic performance, the pilot created 92% of self-consumed energy via local matching, reached 22% better local prices thanks to its forward AI trading system, provided 20% better storage returns, via its arbitrage management of batteries, and reduced a 25% the Innovation Dock grid costs. It is important to highlight that non environmental results have been found in the literature.

5.3.3. Implementing Distro platform to the overall Port of Rotterdam

Distro's next objective is to apply the Distro platform not just only in the Innovation Dock, but make it available for the overall Port of Rotterdam (Interview #2, personal communication, May 23, 2023). Their aim is to achieve this at the end of 2030. As Interviewee #5, (personal communication, June 6, 2023) states up until now, Distro has created a "very simple minimal viable product" and they are now "slowly starting to add more suppliers, market operators, clients" […] and "make the product more complex". However, this comes with already some challenges. As Jullens, (2021), Director & Energy Lead of DockLab Rotterdam explain in a webinar, Distro platform is currently not working in an optimal market and is not big enough to work with different players. Therefore, the next steps are not only incrementing the size of the platform but also the variety within it. They want to be able to trade between multiple parties, within users with different consumption profiles, and demand responses, and using different DERs to generate energy.

Interview #2, (personal communication, May 23, 2023) assures that increasing the variety is relatively easy. It would be solved by fitting data and training the AI trading boot to pick out new patterns and produce new forecasts. The real challenge comes when Distro wants to increase the size and reach of the platform. First, data quickly can become massive, and costly, therefore having problems accessing it. And second, due to problems related to blockchain if they want to still make it cost-effective. Currently, Distro platform has 4-5 nodes in the blockchain and runs about 250 transactions a second, however, this might not be enough if the project is scaled up. They are currently in the process of reassessing different bottlenecks to increase the platform in scale. Therefore that is why it can be hard to increase the size while still making it cost-effective (Interview #2, personal communication, May 23, 2023).

In overall, Distro platform might need more blockchain capacity – or use another type of technological development to help implement P2P energy trading to increase in size. More storage capacity also to increase in size. And finally, more energy profiles of DERs and users to increase in a variety (Interview #2, personal communication, May 23, 2023, p. 2). The following chapter

[20] Good accuracy is subjective to every AI project, however anything greater than 70% is a great model performance (Barkved, 2022).

outlines the real situation of Distro platform and presents the in-depth analysis of the actual state of the Distro platform utilizing the P2P-Blockchian Energy Trading Framework.

Chapter 6. Results

6.1. Assessing Distro platform

This chapter critically evaluates the current readiness of Distro platform for implementation in the Dutch energy market, based on up-to-date insights and comprehensive interviews. It follows the *P2P-Blockchian Energy Trading Readiness Framework* (See Figure 10) which examines four key domains: *technological infrastructure, market dynamics, legislative and operations domain,* and *societal and user adoption domain.*

6.1.1. Current dynamics of Distro platform

Before digging into assessing its readiness level, is important to understand the current dynamics of Distro platform in the Innovation Dock depicted in Figure 14 as it differs from Distro's initial idea described in the previous Chapter 5.

Currently, Distro platform is characterized as a centralized P2P-blockchain energy trading system. The company relates with various stakeholders to make the platform work: The port of Rotterdam, the companies within the Innovation Dock, the port of Rotterdam energy suppliers, Distro's API provider (Meter Insights), the DSO of the region, and finally, the local energy market operator.

As explained in the literature review and in theory, understanding who owns and manages the devices helps identify what type of P2P energy trading the platform is.

In Distro case, the port of Rotterdam, as the overseer of the Innovation Dock building, owns the DERs (particularly solar panels) and controls the smart meters within the building (Interview #2, personal communication, May 23, 2023). Distro owns and controls the batteries as they decided to acquire them to optimize local energy consumption at the beginning of the pilot (Interview #2, personal communication, May 23, 2023). Distro owns and controls the energy trading platform. Finally, all three devices, are influenced by the consumption and production patterns of the different companies within the Innovation Dock (Interview #2, personal communication, May 23, 2023). Table 4 shows which actors own, control, and influence the technological infrastructure (components in a square shape) used for energy trading. Figure 14 shows in different colours what technical components are owned by which actors.

It is important to note that in this case, the companies are not the ones that own the DERs and smart meters, as a decentralized P2P energy trading market would define, but the Innovation Dock manager. By doing so, the dock manager can have one supplier for all the smart meters, also making it easier to gather the smart data information. This decision was taken to minimize dependency on numerous stakeholders during the initial phases, making the implementation of the platform easier from a technical, managerial, and regulatory point of view (Interview #5, personal communication, June 6, 2023, p. 5). Moreover, in line with the above, Distro platform opted also not to directly interact with the companies within the Innovation Dock. Instead, a representative from the port of Rotterdam was assigned to manage, apart from the DERs and smart meters, also the data flows, and billing processes. However, this does not mean that the port of Rotterdam is the final user. While the port of Rotterdam serves as the current client of Distro platform, the end users are the companies located within the Innovation Dock which are the once utilizing the energy.

Currently, Distro platform runs within a private blockchain. Within this scenario, where the level of trust between peers is high, it can be questionable whether the use of blockchain technology is needed for the platform to work. However, in the long run, already starting to deal with the benefits and challenges of blockchain can be useful for the platform if they ever want to change from private to a public blockchain. Moreover, to comply with GDPR standards and technical challenges, and still be able to use blockchain they have created an encrypted hashes system to still be able to store personal data. They link the encrypted hashes to a private data set where they store the personal information of the end-users of the platform (Interview #2, personal communication, May 23, 2023; Interview #5, personal communication, June 6, 2023).

Moreover, Figure 14 also illustrates the three types of flow within the ecosystem: data flow, energy flow, and energy bill flow.

First, **data flow** goes from the DERs to the smart meters, which collect how much energy has been produced, passing it to Distro's API provider (Meter Insights) where real-time data is processed and finally sent to Distro platform to be fed in their AI trading boot and market engine. Additionally, Meter Insights also provides the data to the regional DSO. Finally, the supplier when it comes to the data flow, it just gathers data from the smart meters to create the energy bill (Interview #10, personal communication, June 13, 2023, p. 1). Companies within the Innovation Dock do not communicate between them to trade energy (Interview #2, personal communication, May 23, 2023; Interview #5, personal communication, June 6, 2023).

Second, **energy flow,** goes bidirectional, from the grid infrastructure – which is managed by the regional DSO - to the companies within the Innovation Dock. When there is not enough energy generated by the DER, the energy grid provides energy to the companies, and when there is a surplus of energy generated by the DER, they treat the energy within the Innovation Dock but though the grid infrastructure. Finally, energy also flows from the DERs to the batteries, to be stored and optimized the energy price, and from the batteries to the companies whenever the energy is needed.

Finally, **energy bill flows** work as follows. The billing of energy is done by the port of Rotterdam. The manager of the dock gathers the energy invoices provided by the suppliers or Distro platform and issues them out to each specific company within the dock (Interview #2, personal communication, May 23, 2023). As well as Distro Platform also bills out Distro subscription bill to the companies though the port of Rotterdam manager.

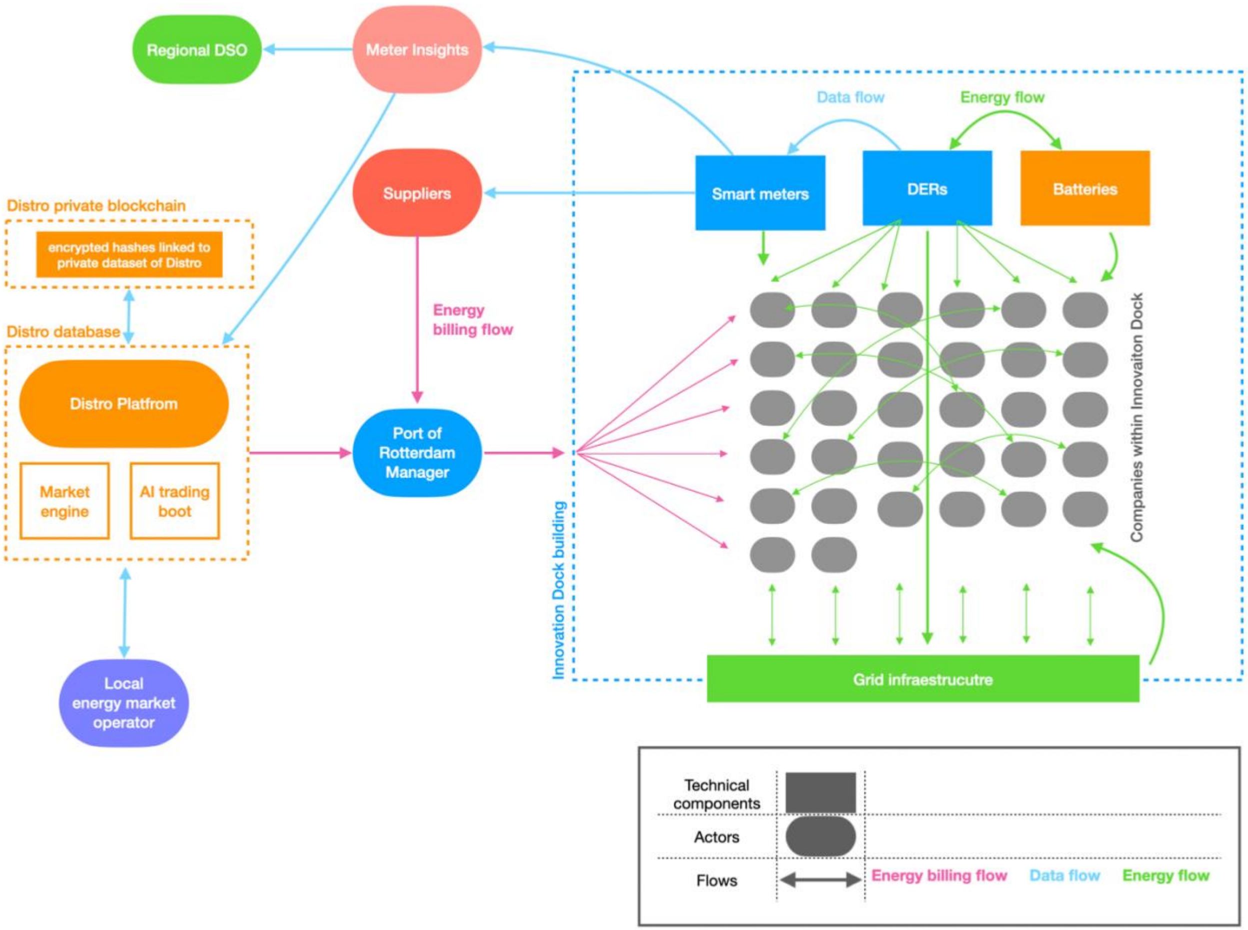

Figure 14. Ecosystem dynamics of Distro platform in the Port of Rotterdam.

Technological infrastructure	Owned by	Controlled by	Influenced by
Smart meters	Port of Rotterdam	Distro	Innovation Dock companies
DERs	Port of Rotterdam	Distro	Innovation Dock companies
Batteries	Distro	Distro	Innovation Dock companies

Table 4. Influence of actors among technological infrastructure in the Innovation Dock

6.1.2. Platform assessment

The assessment of the platform will consider its completion when (i) it is fully operational across the entire Innovation Dock, and (ii) all end-users have integrated the platform into their daily routines. This assessment is aligned with the definitions of "readiness" in all four domains outlined in Figure 11.

Technological infrastructure

As the framework shows the technological infrastructure is divided into two subdomains: the physical layer and the virtual layer.

Physical layer

Distro has the ratio *total renewable consumption/total energy consumption* justified and the available space to allocate DERs to start a P2P-blockchain energy trading system. There is enough physical space to install DERs. However, there are no other storage solutions implemented yet (Interview #2, personal communication, May 23, 2023; Interview #5, personal communication, June 6, 2023).

Additionally, smart meters are present in all companies within the Innovation Dock and the port. However, to facilitate energy trading, additional information is needed, for example grid characteristics (i.e. total capacity that the grid infrastructure at a certain point can support). This information might be difficult to obtain as it has to be requested to the suppliers (which need to ask to the regional DSO) making it hard for Distro platform to have access to it (Interview #2, personal communication, May 23, 2023).

Table 5. shows the values of each statement related to physical layer indicators with the current information available about Distro platform.

	PHYSICAL LAYER INDICATORS		
A	**Distributed energy resources (DER)**	VALUE	COMMENTS
1	The ratio of renewable consumption/total energy consumption justifies the creation of a P2P energy trading platform.	1	
2	There is physical space available for installing DER	1	
3	There is enough energy storage capacity installed to enable community P2P-blockchain exchange at the scale-level that is aimed at	1	
4	There are other storage solutions such as thermal storage, electric vehicles, etc to enable the P2P-blockchain energy exchange at the scale-level that is aimed at	0	No variety in their energy storage devices
B	**Smart meters infrastructure**	VALUE	COMMENTS
1	Smart meters are available in every household to monitor the DERs and enable real-time monitoring of energy flows.	1	
2	The smart meters are able to gain data not just from the consumption and production of power but also advance information about the devise usage and status (i.e. type of energy source, grid characteristics, etc)	0	Not all the data is available
C	**Communication infrastructure**	VALUE	COMMENTS
1	The peers of the platform (households, and other establishments such as local business, farmers, and public buildings) have the	1	

	sufficient broadband connection (Wi-Fi) to enable bidirectional transmission of energy data between the platform and the peers.		
D	**Energy grid infrastructure**	VALUE	COMMENTS
1	There is existing energy grid infrastructure to trade energy for P2P-blockchain ET.	1	
2	The physical capacity of the energy distribution grids of the area allows the peers to exchange energy at the scale-level that is aimed at.	1	

Table 5. Assessment for technological physical infrastructure indicators of Distro platform

Virtual layer

After gathering data from different actors within Distro to evaluate the status of Distro's blockchain, the following situation was encountered. As explained before, Distro platform currently operates on centralized private blockchain, specifically a "fork of the Ethereum blockchain" […] "with its own nodes and cloud infrastructure" (Interview #2, personal communication, May 23, 2023). The decision of running the platform in a centralized private blockchain was driven by the need of extensive data exchange between peers and the platform. High rate transactions in public blockchain are very costly and cost-energetic, rendering the whole objective of reducing costs and electricity of the local market and making DERs cost-efficient (Interview #5, personal communication, June 6, 2023; Jullens, 2021).

However, during the implementation process, Distro platform encountered several challenges. The high volume of data involved in storing, extracting, and interacting with the AI trading boot required fast transaction speeds beyond the capability of the current Distro blockchain. Interviewee #2, (personal communication, May 23, 2023, p. 2) noted that the platform was handling millions of trades every 15 minutes, and Distro "blockchain just couldn't keep up". Additionally, incorporating smart meter data into the blockchain proved time-consuming, resulting in significant trading delays (Interview #4, personal communication, June 6, 2023). Consequently, Distro platform had to reduce the amount of data stored in the blockchain, modifying their initial approach (Interviewee #5, personal communication, June 6, 2023).

Therefore, one could argue, what does Distro platform store in the blockchain and what do they use it for? Interviewee #2, (personal communication, May 23, 2023, p. 2) explained that currently they use it for "the wallets and the users ID", however, due to GDPR regulations, this information is encrypted and hashed, to later be linked to Distro's own datasets. Consequently, it becomes evident that Distro's blockchain is not yet fully equipped to handle large data volumes in its current state, and the company is seeking alternative approaches to leverage the technology while addressing data privacy concerns. This demonstrates how the existing technological challenges surrounding blockchain influence its implementation within the Distro platform.

Despite these challenges, Distro anticipates the maturation of the blockchain market already envisioning to shift from private to public blockchain to allow other peers to connect to the platform (Interview #2, personal communication, May 23, 2023). Consultations with industry experts suggest[21] that transitioning from a private permission blockchain to a public permission blockchain indicates a significant advancement in the platform's maturity level Interviewee #7, (personal communication, June 12, 2023) states "if they really value decentralization, they will

[21] The expert stated that "is not per se an indicatory of maturity, but in general you can see that the projects tend to move from more private to public permission blockchain" (Interview #7, personal communication, June 12, 2023)

move toward public permissions". Consequently, while it is not imperative for the platform's functionality to rely on a public blockchain, one could argue that the utilization of a private blockchain by Distro platform indicates its current low readiness level.
In relation to the trading platform, the platform currently works thanks to the AI trading boot and the market engine which combine the data to create personalized consumption and production forecasts. However, there is no assurance that the platform interface is well-designed.

Distro trading energy contracts are currently in place and add extra value by providing flexible contracts to the final users. Their prices are the real-market prices and they optimize them by utilizing their personalized AI trading boot and the batteries allocated in the buildings of the port (Interview #2, personal communication, May 23, 2023).

Furthermore, regarding payment mechanisms, Distro platform incorporates digital wallets for users to store their ID, and energy trading tokens (Interview #2, personal communication, May 23, 2023). However, the way they use wallets and tokens differs from the initial idea. Currently, they continue to conduct monetary energy transactions through traditional bank payment mechanisms, the tokens are just used internally. According to interviewee #1 (personal communication, May 3, 2023), this is due to legal considerations. If the company were to utilize the word "cryptocurrency", it would have to be liable to the financial standards of that term (i.e. how they deal with the money and how that is transacted). To avoid potential legal implications, the company decided to not use cryptocurrencies when doing energy transactions. Additionally, a comprehensive assessment with economic lawyers with expertise in cryptocurrency was done to ensure compliance with financial standards associated with terms like "cryptocurrency." The report's findings confirmed their adherence to legislation (Interview #2, personal communication, May 23, 2023).

In relation to data collection, Distro platform has managed to overcome the lack of data flow in the energy ecosystems by utilizing API providers. Meter Insights company is in charge of providing the data of the different supplier's smart meters and delivering it to Distro platform in a processed and standardized matter. By outsourcing data processing, Distro platform can focus on its objectives and gain competitive advantage increasing the company's efficiency (Interview #5, personal communication, June 6, 2023).

Table 6. shows the values of each statement related to virtual layer indicators with the current information available about Distro platform.

	VIRTUAL LAYER INDICATORS		
E	Blockchain	VALUE	COMMENTS
1	The platform runs upon blockchain (private or public)	1	However, Distro platform is utilizing a private blockchain, possible indicator of a low readiness level.
2	The platform utilizes specialized algorithms designed to optimize energy usage and storage, minimizing consumption to the greatest extent possible	0	
F	Digital energy trading platforms	VALUE	COMMENTS
1	There is an existing digital platform that can remotely control, and steer assets based on the flexible energy needs to enable P2P exchange at the scale-level that is aimed at	1	At Distro platform this is done thanks to the AI trading boot and the

			personalized consumer preferences
2	Digital infrastructure to ensure a proper functioning of energy management and monitoring systems for P2P-blockchain ET is in place	1	
3	The interfaces on the trading platform are informative and supportive for all users of the P2P energy trading system	0	No information
J	**Energy trading contracts**	VALUE	COMMENTS
1	Existing energy contract generated between the peer and the energy company to sell the surplus of energy generated are on place	1	
2	Existing energy contract between the peers and the platform are on place	1	
H	**Payment mechanisms**	VALUE	COMMENTS
1	The platform can host digital wallets	1	Even though they comply with the regulation, they are not utilizing cryptocurrency
I	**Data collection systems**	VALUE	COMMENTS
1	Availability of real-time local weather data	1	
2	There is available access to API (Application Programming Interface) to read meter and sub-meter data.	1	
J	**Additional technologies**	VALUE	COMMENTS
1	Forecasting algorithms are in place to predict load and, thus, to optimize energy sharing in the energy community	1	Using the AI trading boot and the market engine.
2	Making the forecasting algorithmics the most cost-effective and sustainable as possible	1	

Table 6. Assessment for technological virtual infrastructure indicators of Distro platform.

Market dynamics

This section is going to explain which are the essential and additional relationships that currently Distro platform must have with the Dutch energy ecosystem. Table 7 shows the summary of the current relationships between the Distro platform and the market actors.

First of all, **producers and consumers** as well as **DER company providers** are essential for P2P-blockchain ET platforms to work (Interview #2, personal communication, May 23, 2023). Second, **energy producers** are still essential for P2P-energy trading to work, as when there is no availability of energy due to the volatility of renewable energy resources, users still need to have access to electricity (Interview #2, personal communication, May 23, 2023, p. 2).

Likewise, relationships with **TSO**, **DSO,** and **energy suppliers** are still essential for Distro platform customers for several reasons. First, customers must have two types of contracts, one with Distro platform and one with its current energy supplier. Second, because energy still needs to be transmitted (1) from prosumers to consumers when they sell their excess of energy and (2) from energy producers to end-consumers when prosumers need additional energy (Interview #2, (personal communication, May 23, 2023). Finally, users participating in P2P energy trading still need to pay the DSO and TSO for grid usage (Interview #1, (personal communication, May 3, 2023, p. 1). In overall, these actors remain crucial for P2P energy exchange unless the energy community establishes its own grid infrastructure. These dependencies highlight the big reliance and work that Distro platform and other trading platforms have still to do to become more independent.

However, regarding TSOs specifically, there are differing opinions regarding the nature of their relationship with Distro. On one hand, Distro platform is not directly dependent on the TSO since they primarily manage high-voltage grid infrastructure and P2P energy trading involves locally generated energy. However, on the other hand, TSOs also play a role in managing grid imbalances, which is at the time still crucial for Distro platform functioning (Interview #7, personal communication, June 12, 2023; Interview #8, personal communication, June 13, 2023). In conclusion, it can be affirmed that Distro platform maintains a crucial relationship with the TSO.

Furthermore, while Distro goal is to reduce dependence on **Balance Responsible Parties (BRPs),** particularly by using their Distro batteries to prevent energy from being sent to the imbalance market, the company presently remains reliant on these actors (Interview #2, personal communication, May 23, 2023; Interview #5, personal communication, June 6, 2023).

Moreover, **data facilitators** are “probably the most important actors as that’s what’s used to make the assumption for the forecasting” (Interview #2, personal communication, May 23, 2023, p. 2). Similarly, API providers, *Meter Insight* company in the case of Distro, hold significant importance as they provide Distro platform with standardized and processed 15-minute interval data from the smart meters of the Innovation Dock DERs (Interview #5, personal communication, June 6, 2023). These **API providers** offer valuable access to smart meter data, which would be limited and of poor quality if it would come directly from data facilitators (Interview #2, personal communication, May 23, 2023, p. 2).

Moreover, according to Interviewee #2, (personal communication, May 23, 2023) **market operator** plays the role of facilitator. While having a relationship with a **market operator** is not essential for Distro platform to engage in energy trading in the wholesale market, currently they still choose to utilize their services to gain competitive advantage. This strategic decision helps Distro reduce the use of resources as the market operator provide them already with a forward curve cost to trade within the market that they produce. Therefore, the role of the market operator for Distro is still crucial as they can transfer the trading risks to them and focus on developing their core business objectives.

Furthermore, **mobility service providers, energy aggregators or mobility service providers** can bring value to the P2P energy trading platform by providing energy or contributing to grid balancing and flexibility. This is not the case for Distro platform at this moment. Both their involvement is not essential for the platform to work (Interview #2, personal communication, May 23, 2023, p. 2). Moreover, **regulatory institutions and research institutions** while they are important to have relationships to push the legislations around P2P-blockchain ET they are not crucial for the development of the platform. Finally, Distro platform collaborating with **additional partners such as the municipality** of Rotterdam can help the implementation of P2P energy trading systems by providing regulatory support, infrastructure development, and community engagement. However, they are not essential actors to relate with.

Finally, it is important to highlight that although Distro platform aims to decentralize from the energy market and reduce reliance on energy ecosystem actors, the relationships with key stakeholders are still crucial due to “the amalgamation of new technologies in relation to the old market” (Interview #2, personal communication, May 23, 2023, p. 2). As Distro platform operates within a transitioning energy ecosystem, they still need to adhere to the traditional system to achieve its objectives and use its services “until they get on board and start seeing the benefits of having something like Distro platform sitting in the middle" (Interview #2, personal communication, May 23, 2023, p. 2).

Table 7 shows if each actor is recognized as an essential or additional relationship with Distro platform.

K	ACTORS	ESSENTIAL RELATIONSHIP[22]	ADDITIONAL RELATIONSHIP[23]	COMMENTS
1	DER producing companies (i.e. producers of solar panels, wind mills, heat pumps…)	X		
2	Electricity producer	X		
3	Market operator	X		Not essential, however still needed to gain competitive advantage and be able to focus on their business model objectives.
4	Transmission System Operator (TSO)	X		However, there are existing discrepancies arguing whether TSO are essential for Distro platform as while they play a key role in managing grid imbalances, they are not directly related on Distro platform as they just manage high-voltage grid infrastructure and P2P-ET involves just locally generated distribution.
5	Distribution System Operator (DSO)	X		
6	Balance Responsible Party (BRP)	X		Distro aims to reduce their dependencies with BRPs.
7	Consumers and prosumers	X		
8	Suppliers	X		
9	Data facilitators	X		
10	APIs providers	X		Nowadays they are key partners as they provide real-time data access (Interview #2, personal communication, May 23, 2023)
11	Energy aggregators		X	
12	Charge point operators or mobility service providers		X	
13	Regulatory institutions		X	
14	Research and development institutions		X	

[22] When the actor involvement is indispensable for enabling the energy trading process and needed for creating the minimum viable product (MVP) of the platform.

[23] Refer to the relationships that are not indispensable for the basic functioning of the system and platform however that add value to the trading experience and the platform of the performance.

15	Additional partners such as municipality, housing associations, project development companies, installers		X	

Table 7. Assessment of the relationship between Distro platform and the actors within the Dutch energy ecosystem

Legislative and operations domain

Legislative domain

Energy trading

In relation to the **consumer** law, from the interviews with Distro, it can be said that they have implemented all the statements (Interview #1, personal communication, May 3, 2023; Interview #2, personal communication, May 23, 2023; Interview #5, personal communication, June 6, 2023).

In relation to **contract** law, the current approach is having 3 types of agreements: (i) an agreement between the Distro platform and the peers, (ii) multilateral contracts between peers, where Distro platform just provides the environment to make the trade trustworthy, and (3) contracts between peers and their energy suppliers, where it is stated that the peer can have certain amount of capacity bought from other sources. However, interview #10, (personal communication, June 13, 2023) states that they are still in the stages of development to figure out what type of contract or "terms and conditions" should be set within the different actors – suppliers-peers-Distro.

In relation to the **liabilities** law, liabilities within the platform and the trading system are covered and divided between different actors. The BRP manages the imbalance of the grid. Distro is responsible for the liabilities related to their AI trading boot and their market engine. In terms of consumers, the buyers or consumers of electricity "will be ultimately liable of the energy they buy" Interview #2, (personal communication, May 23, 2023). Finally, as the port of Rotterdam is accountable for the DER, if their solar panels underperform, generating less energy than the anticipated by the forecast, they are responsible for purchasing extra energy from the grid to meet the needs of the consumers they are selling the energy to (Interview #2, personal communication, May 23, 2023).

In relation to **competition law**, Distro platform charges a subscription fee to its users for utilizing their platform, however as there is no benchmarking, there is no information available to state whether the pricing is competitive compared to other offerings in the market.

Currently, the Port of Rotterdam is aware that they own and have control of the DER and it's smart meters within the Innovation Dock (Interview #5, personal communication, June 6, 2023). However, there is no information available that state that the end-users, meaning the companies within the Innovation Dock are aware that they can have access to their smart meter data.

Table 8 shows the values of each statement related to P2P energy trading legislative indicators with the current information available about Distro platform.

	P2P ENERGY TRADING LEGISLATIVE INDICATORS		
L	Consumer law	VALUE	COMMENTS
1	The trading platform is assuming that they are trading energy for commercial interests.	1	This may change with the incoming clean energy package being implemented in The Netherlands.

2	Users of P2P energy trading platforms maintain their consumer status	1	
3	The customers are aware that the solar panels are currently rated with a 0% VAT	1	
M	Contract law	VALUE	COMMENTS
1	The platform's hosting region ensures that peers within the trading platform have convenient access to the electricity grid.	0	Not clearly stablished yet
N	Liabilities law	VALUE	COMMENTS
1	The platform is aware that is liable to the responsibilities in a case of dysfunctions (failures, accidents, or errors) for both the prosumer and the digital tools used in the platform	1	
O	Competition law	VALUE	COMMENTS
1	The contractual platform tariff price is set at a competitive level within the market, ensuring it is not overpriced.	0	There is no benchmarking information available
P	Property law	VALUE	COMMENTS
1	Ownership of Distributed Energy Resources (DERs) is explicitly outlined in the contractual agreements between the user and the platform, providing clear and transparent information regarding ownership rights.	1	
Q	Data law	VALUE	COMMENTS
1	The customers are aware that they are allowed to have access their smart meter data.	0	No information available

Table 8. Assessment of legislative indicators for Distro platform

Blockchain

In relation to blockchain, there are different opinions on whether their challenges can be overcome on not, however there is a bigger tendency to state that its bottlenecks can be relatively easily solved (Interview #3, personal communication, June 2, 2023). For instance, TenneT experts assure that blockchain is not the main challenge to be overcome, but "the energy markets and regulation around it" which are now hindering to unlock flexible energy systems[24]" (Interview #3, personal communication, June 2, 2023).

The implementation bottlenecks of blockchain in Distro platform have been overcome in the following way. First, as explained before, they don't use tokens nor cryptocurrency to trade outside of the platform. therefore, they do not have to be registered at the DNB (Interview #10, personal communication, June 13, 2023). Second, in relation to the GDPR, they don't store personal information in their blockchain (Interview #2, personal communication, May 23, 2023, p. 2). To solve this problem Distro platform "use a series of hashes within a database and store the hashes within the blockchain. So the information is relatively meaningless" (Interview #2, personal communication, May 23, 2023, p. 2). Therefore, "if the user wants their particular meter data deleted, we can just remove it from the database" Interview #2, (personal communication, May 23, 2023, p. 2). While the resolution of this problem has been successful within Distro platform, the fact that they must implement a hashed system in their database it shows how there is still a misalignment between data regulations around blockchain and GDPR within the Dutch legislation.

Table 9 shows the values of each statement related to blockchain legislative indicators with the current information available about Distro platform.

	BLOCKCHAIN LEGISLATIVE INDICATORS

[24] TenneT refers to flex as the flexible energy market (Interview #3, personal communication, June 2, 2023)

R	Crypto assets law	VALUE	COMMENTS
1	Do you comply with the Wwft (directive around cryptocurrency exchange and custodian wallets)	1	
2	The entity is registered as a cryptocurrency exchange agent and wallet custodian in the DNB	1	Even though this doesn't comply with distro situation, to not lower the overall readiness level of the domain, it has been decided to still value the statement with 1.
S	Digital wallets	VALUE	COMMENTS
1	The platform hosts a digital wallet which goes aligned with the GDPR	1	
T	Data law	VALUE	COMMENTS
1	The information is stored in the blockchain complies with the current GDPR	1	Despite managing to comply with the current regulations, Distro Energy had to take an alternative approach to meet the requirements.

Table 9. Assessment for blockchain indicators of Distro platform

In overall, is important to highlight that Distro platform is not fully implementing P2P energy trading as literature and theory state, but they are implementing more the concept of "energy communities", as for instance the platform ensure that the liabilities are covered for the end users (statement which is aligned with the current Dutch regulatory framework).

Operations domain

In terms of operations domain, first, Distro has a business model aligned, the platform benefits are clearly clarified as well as the allocation of resources, skills, and competences (Interview #2, personal communication, May 23, 2023). Second, Distro platform has not yet established direct communication with the end-users of the platform, as they are currently under the control of the Port of Rotterdam. This indicates that the Distro platform is still in its early stages of adoption. Moreover, in relation to the **energy pricing**, as interviewee #1, (personal communication, May 3, 2023) stated "the energy price is set through the actual market dynamics", […] by using "high frequency trading to facilitate price discovery". Consequently, the energy prices will be competitive with the market.

Table 10 shows the values of each statement related to operational indicators with the current information available about Distro platform.

	OPERATIONAL INDICATORS		
U	Internal alignment	VALUE	COMMENTS
1	The platform clarifies how the distribution of economic benefits is divided and organized among members of the energy community (i.e. the platform providers)	1	
2	The platform clarifies how the use of collective assets (i.e. collective battery; shared mobility devices) are organized within the platform and energy community members.	1	
V	Resources, skills, and competences	VALUE	COMMENTS
1	The platform has a clear short- and long-term organization on how and what available competences and skills (technical, financial, legal, social knowledge and skills) are needed to operate a P2P-blockchain ET platform. Also addressing the	1	There is no volunteering staff

	balance between paid and volunteer staff and differentiating between different types of expertise and skills needed.		
2	The platform has developed a business case(s) and has a financial plan prepared for the P2P- blockchain ET platform to work.	1	
3	There is clarity about the communication between platform daily management and peers of the community (i.e. channels (physical meeting, newsletters, etc.) messaging, frequency, etc).	0	The platform is now starting to communicate with the end-users
4	The platform has administrative tools (e.g. community member billing system) in place" (NRG2peers Consortium, 2021).	1	
W	**Energy pricing**	VALUE	COMMENTS
1	The price of the energy is aligned with the wholesale energy market prices	1	
X	**Cost of the technology**	VALUE	COMMENTS
1	The platform has clarity on how all financial value flows are allocated and formally organized within the platform.	1	

Table 10. Assessment of operational indicators for Distro platform

Societal and user adoption

Up until now, Distro platform has just dealt with the port of Rotterdam as the main client, and the only interaction there has been between the companies and Distro platform is a first onboarding meeting where 32 companies decided to participate in the pilot project in 2020. Interviewee #5, (personal communication, June 6, 2023) states that "in the next couple of weeks, once we bring the system to life" the companies within the Innovation Dock will "get their own dashboard, system", [...] "and information where they can interact with the platform". Therefore, the societal and user adoption of the technology is at an early stage or even minimal stages of adoption.

However, something positive to highlight is that even though they will eventually start enrolling the companies into the platform, they have already outlined and put into practice an onboarding system. The onboarding system aims to provide prosumers with a clear understanding of energy trading within Distro platform by guiding them through a three-stage process: analysis, simulation, and marketplace implementation. In the analysis stage, a general overview is conducted to assess potential energy and cost savings for the user. Subsequently, real-time data is used to simulate different energy consumption scenarios, allowing the client to comprehend the potential energy savings. This second step is done by utilizing the pilot platform. Distro platform decided to keep the pilot platform operational to use it as a digital twin to simulate for instance, how many batteries a consumer might need. As it is a complex analysis the virtual twin simulation helps the user understand the benefits of using Distro platform (Interview #2, personal communication, May 23, 2023, p. 2). Finally, once the analysis is confirmed and the user recognizes the benefits of energy savings, Distro platform just has to connect their devices to the marketplace (Interview #5, personal communication, June 6, 2023).

Knowledge and awareness

Although almost all knowledge and awareness indicators have not been implemented in the Innovation Dock, as the end-users have not had direct contact with the platform, the users have already sensed the impacts of utilizing Distro platform in their daily energy usage (i.e their energy bills invoiced have been affected) (Interview #2, personal communication, May 23, 2023). Additionally, as interviewee #4, (personal communication, June 6, 2023, p. 4) states, explaining the key benefits of the system to the end-user is crucial for user adoption of the platform.

Moreover, as the innovative start-ups that are within the Innovation Dock must comply to the Port of Rotterdam sustainability actions it can be said that the end-users are aware of the energy-related climate change challenges. Finally, even though there is no information that states whether the user understands how P2P-blockchain-based energy exchange works, the platform should be aware that they do not need to explain this information. It will cause more problems as (i) energy trading can be seen as an overwhelming concept that requires major technical knowledge to be understood, and (ii) because, as stated in the literature, blockchain has negative connotations which could led to the end user not trusting and wanting to onboard on the platform.

Table 11 shows the values of each statement related to knowledge and awareness indicators with the current information available about Distro platform.

	Knowledge and awareness		
Y	P2P-blockchain energy trading system	VALUE	COMMENTS
1	Users show an understand the interest in going beyond self-generated renewable energy towards self-consumption and flexibility.	0	Still no direct interaction with end-users at Innovation Dock
2	Users understand the various benefits (environmental, economic, financial, social) that P2P-blockchain ET platforms can provide them.	0	Will be implemented once the end-users finalize the onboarding process
3	Users acknowledge that participating in P2P energy trading systems may impact the timing of their daily activities and recognize the potential drawbacks associated with it (i.e. fluctuating tariffs, household flexibility limitations, and market volatilities).	1	The end-users have been already a change on their energy bills due to their participation on Distro platform
4	Users understand how P2P-blockchain ET works and what interactions occur when the trading is generated.	0	There is no information about this
5	Users have a basic understanding of energy-related climate change challenges	1	
Z	Energy tariff dynamics	VALUE	COMMENTS
1	Users understand that there are energy tariffs within the energy community and how these tariffs are different from their current tariffs with their energy suppliers.	0	As they do not have direct access to the platform dashboard, they are not aware of the energy tariff dynamics
AA	Data ownership	VALUE	COMMENTS
1	Users are aware of agreements on data ownership and have explicitly agreed on it. They are aware that their energy data is being monitored by the platform, but that they can have access to their data.	0	Even though, the smart meter data is owned by the Port of Rotterdam, there is no available information that states that the end-users are aware of this.
AB	Trading platform	VALUE	COMMENTS
1	Users show a basic understanding of how the energy platform works.	0	End-users haven't yet had access to the platform dashboards
2	Users show an understanding of how the interfaces work, and they show a certain level of "experienced" control and empowerment.	0	End-users haven't yet had access to the platform dashboards

Table 11. Assessment of knowledge and awareness indicators for Distro platform

Values and goals

In terms of values and goals for user adoption, as said before, by being in the Innovation Dock the end-users must share common goals with the port of Rotterdam. Moreover, even though there is no available information to confirm that the end-users trust Distro platform, it can be said that the onboarding process presented by Distro platform is a good approach to achieve this statement completion.

Table 12 shows the values of each statement related to values and goals indicators with the current information available about Distro platform.

AC	Values and goals	VALUE	COMMENTS
1	Users are interested to participate on this energy community within the P2P-blcockhain ET platform, and have a clear idea about the goals the platform (i.e. values, economic, environmental, social benefits).	1	
2	The users are aware of the level and type of engagement that is asked for them when being part of the P2P-blcockhain ET platform.	1	
3	The users show trust[25] in the organisational structure, the management of the platform and the "people" that represent it (i.e. the board members or intermediary platform).	0	No information available, however the onboarding process is proposed to achieve this

Table 12. Assessment of values and goals indicators for Distro platform

Willingness and ability to participate

Finally, while users' initial willingness to participate in Distro platform is apparent, their ongoing commitment may change as the platform will start establishing more direct engagement with them in the incoming months. Monitoring end-user feedback and engagement will be essential for the success of the user adoption of the platform.

Table 13 shows the values of each statement related to willingness and ability to participate indicators with the current information available about Distro platform.

AD	Willingness and ability to participate in P2P energy trading systems	VALUE	COMMENTS
1	Users show a certain willingness to invest (financially, time, knowledge, social relations) in the platform now and in the future.	0	

Table 13. Assessment of willingness and ability to participate indicators for Distro platform

The following section shows the overall results of this evaluation.

6.2. Current Distro platform readiness level

[25] The level of trust can vary depending on the type of P2P-blockchain energy trading market which the platform is defined in.

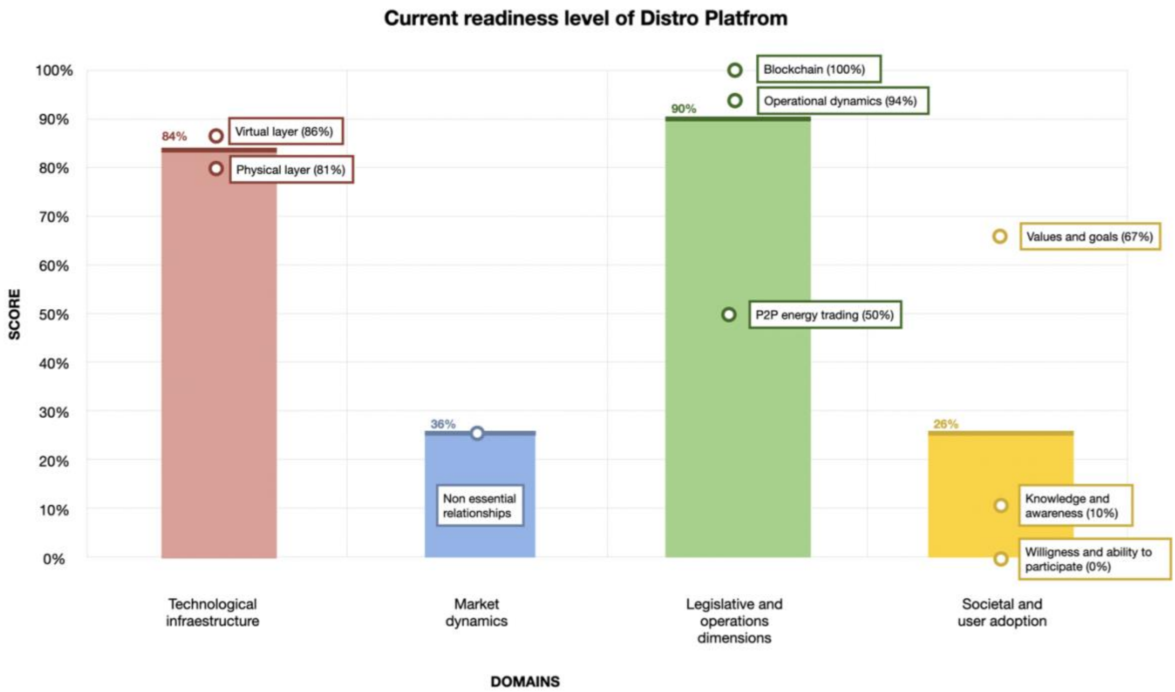

Figure 15. Results of Distro platform readiness assessment

By utilizing Microsoft Excel, this thesis collected and compiled the values of each indicator's statements. Then, as illustrated in Figure 15, the values were then summed and expressed as a percentage in relation to the total number of statements per indicator. Moreover, it is important to remember, that these results show the current state of Distro platform through the lenses of the created analytical framework. Reality can differ as the framework is still in stages of assessment. For instance, the gather of results followed in this assessment might not be the most optimum, Section 7.1.6. proposes an additional approach.

Based on Figure 15 it can be observed that Distro platform is still not ready for implementation in the overall Innovation Dock. Particularly, there are significant gaps in market dynamics, societal and user adoption, as well as incomplete implementation in other domains.

In terms of **technological infrastructure**, the level of implementation is very high, around 84%, that is why, even though the literature states that still there are some challenges in the implementation of the physical and virtual layer, Distro platform managed to find sideroads to make the platform operational within the current technological state-of-the-art. Additionally, results align with experts' opinion, as they stated that the technological layer is the least difficult to implement in The Netherlands as already a lot of technological infrastructure is in place to enable P2P-blockchain energy trading (Interview #3, personal communication, June 2, 2023; Interview #7, personal communication, June 12, 2023; Interview #10, personal communication, June 13, 2023).

In terms of **market dynamics**, it should be reminded that the aims are to have the least number of essential relationships, so the energy platform can be more decentralized and eliminate dependencies with actors of the Dutch energy grid. Therefore, results show that there is a long way still for Distro platform to get dependency from the energy actors as it is currently at a 36%. However, these results are reasonable as Distro platform operates within a transitioning energy ecosystem. The platform will need to wait until more actors of the traditional ecosystem onboard on the implementation of P2P energy trading to detach from them. However, these changes do not just depend on Distro but on the speed in which the overall dynamics of the market will be decentralized and unbundled, process that can take time.

Moreover, in terms of **legislative and operations domain**, Distro employees and the interviewed experts stated that legislative dynamics are the biggest challenge, and the actual barrier, that blocks the energy sector to implement P2P-blockchain energy trading systems in The Netherlands. At the time, there are no regulations that support this type of business model, as the country is waiting for the CEP to be implemented nationally. However, the results of Figure 15 show a completely different scenario. These results state that within this domain, the platform is at 90% of its completion. For this mismatch, two explanations have been found. First, the analytical framework fails to capture the internal dynamics of Distro ecosystem when dealing with the current national regulations. For instance, it does not illustrate how the blockchain platform uses a hash system to ensure compliance with GDPR when storing personal data. Or the way Distro platform is using digital assets internally in its platform but still the monetary transaction is done in a traditional way. This mismatch may arise from the framework statements, as they do not adequately demonstrate how Distro platform has navigated alternative routes to still operationalize its business model. And secondly, combining legislative and operations domains might have misrepresented the overall readiness score of the domain. This will be discussed in Section 7.1.6. Additionally, experts in the field assure, re-affirming this domain results, that past operative projects related to P2P energy trading had to back out for implementing P2P-ET as the regulations were not supporting them (Interview #7, personal communication, June 12, 2023).

Finally, in **terms of societal and user adoption**, Distro platform is at 26% in this domain as the platform has not yet been in direct contact with the end users. At the current time, the Innovation Dock manager deals with all the billing, and data flows of the energy trading. As interviewee #10, (personal communication, June 13, 2023) states during the summer, they will be contacting personally each company and helping them in the onboarding process. Once they start this process, societal and user adoption should be reassessed. Finally, in terms of blockchain, the platform should not be talking about blockchain to its end users due to the bad connotation this technology has.

6.3. Distro platform recommendations

This section presents a set of recommendations for Distro platform to reach the full implementation of the platform in the Innovation Dock.

First, the company needs to create direct contact between the platform and the end users, so they can really understand how the end-user sees, utilizes, and relates to the platform. Reassessment of the *societal and user adoption* domain is recommended after the end of the onboarding process with all end users. Second, while increasing the size and variety of the platform in terms of DER, variety of users, variety of suppliers, and types of storing devices, etc, this process should be done gradually. It must be approached with caution to ensure that the implementation does not disrupt the entire platform's functionality and performance. Furthermore, in relation to blockchain, as previously mentioned, the utilization of a private blockchain is currently unnecessary. However, as the number of end users engaging in platforms might increase after summer, it will become essential to re-evaluate the type of blockchain employed, as the level of trust between peers might have potentially diminished. Finally, while Distro platform strives to minimize dependencies on market stakeholders such as API providers and local market operators, it is crucial for them to maintain these relationships as they expand. As by outsourcing energy market services to external stakeholders, Distro platform can focus on its core objectives and effectively expand its core services. Once these core services have been successfully implemented, they can consider the possibility of insourcing those services in the future and decentralized from energy market actors. This strategic approach enables Distro platform to strike a balance between leveraging external expertise and developing in-house capabilities.

To **summarize**, the aim of Distro is to 100% implement their platform to the Innovation Dock, and in overall implement it in the port of Rotterdam. After conducting a successful pilot phase and nearly three years of operational experience, it has been demonstrated that the platform is highly manageable and delivers significant value to the energy market. However, its first stages of implementation have been done in a very controlled environment. The true test of the platform development will lie in expanding its services to a larger scale, a broader range of DERs, and end-users, while continue adding value and maintaining the subscribed companies. Such expansion will undoubtedly reveal areas that require adjustments and improvements for the platform to thrive successfully.

In the upcoming section, the thesis is going to come up, using an iterative approach, with the final analytical framework assessed thanks to the insights provided by the interviews.

Chapter 7. Discussion

7.1. Analytical framework assessment

Overall, the analytical framework presented in this study is robust, appropriate and it effectively fulfils its aims of evaluating the readiness level of a P2P-blockchain energy trading platform. The information included in the framework is aligned with the feedback provided by various stakeholders in the Dutch energy system. The framework covers essential aspects required for the operationalization of a P2P blockchain energy trading platform. Overall, the comprehensive assessment ensures that all necessary fundamentals are in place for successful implementation.

This being said, the following section will add to the current literature by explaining what aspects should be modified and creating an improved version of the readiness framework. All added statements will be highlighted in grey.

First, an initial section should be added to clearly define the assessment limits. The definition of these characteristics will help create a more comprehensive and objective assessment. Table 14 shows the proposed section.

	Limit	Assessment options
1	Define what is the purpose of doing this assessment	Platform assessment P2P ecosystem assessment
2	Define "what does it mean to be ready?" for the platform	Open answer
3	Define what type of P2P energy trading market the platform is built upon	Centralized market Direct trading market Distributed market
4	Define who is the end-user of the platform	Open answer

Table 14. Introductory limitations needed to assess before starting to evaluate a platform.

7.1.1. Technological infrastructure

Regarding the technological infrastructure, the presented indicators and statements are robust and aligned with what is needed from the technical side to operate a P2P-blockchain energy trading platform. However, some changes should be added.

First, a fundamental question should be added at the beginning of the technological virtual assessment: "Why would we use blockchain in our energy trading platform?" (Interview #7, personal communication, June 12, 2023, p. 7). This question is crucial since implementing blockchain in a platform requires substantial knowledge, effort, and resources. The true benefits of blockchain are most evident when operating at scale rather than in small-scale operations, as it is then when there are more untrusted peers within the platform and blockchain can provide trust and secure energy trading (Interview #7, personal communication, June 12, 2023, p. 7). Therefore, an additional statement addressing the use of blockchain should be incorporated into Indicator E (see Table 15).

	VIRTUAL LAYER INDICATORS
E	**Blockchain**
1	The use of resources and the trust level among the peers justify the need of utilizing blockchain in the platform
2	The platform runs upon blockchain (private or public)
3	The platform utilizes specialized algorithms designed to optimize energy usage and storage, minimizing consumption to the greatest extent possible

Table 15. Modifications of Indicator E

Second, it was observed that Indicator H (see Table 16) does not indicate whether these mechanisms operate within a blockchain framework. As seen in the case of Distro platform, there exists a major difference between using cryptocurrency to trade energy between peers or using traditional bank payment mechanisms. Therefore, an additional statement should be added to clarify what type of payment mechanism the platform is using to trade energy between peers.

	VIRTUAL LAYER INDICATORS
H	**Payment mechanisms**
1	The platform can host digital wallets
2	The platform performs its monetary trading between peers with cryptocurrency

Table 16. Modifications of Indicator H

Moreover, in relation to the energy trading contracts three types of contracts or agreements should be settled within the trading platform (i) contract or agreement between peer – regular energy supplier, (ii) contract or agreement between peer – trading platform, and (iii) contract or agreement between peer – peer. Therefore, the statements within Indicator J are changed as shown in Table 17 (Interview #10, personal communication, June 13, 2023).

	VIRTUAL LAYER INDICATORS
J	**Energy trading contracts**
1	Contracts or agreements between peers and the energy supplier are on place to be able to utilize the grid when selling their surplus of energy.
2	Contracts or agreements between peers and trading platform are on place.

3	Contracts or agreements between peer and peer are on place.

Table 17. Modifications of Indicator J

7.1.2. Market dynamics

Concerning market dynamics, experts in the field recognized that almost all stakeholders of the energy market are described in the framework. However, interviewee #3, (personal communication, June 2, 2023; and interviewee #8, (personal communication, June 13, 2023) proposed the addition of the Balancing Service Provider (BSP) and the Congestion service provider (CSP). The former is responsible on activating the balancing of the energy after TenneT noticed an imbalance in the energy grid using their pool of aggregated energy (*Balancing Markets - TenneT*, 2023). The latter is the actor involved in improving the network conditions for instance related to lowering the network load. Table 18 shows the additional actors.

Additionally, more research could be done on differentiating actors that have a direct relation to the energy systems and actors that have a relation to more implementation of the technology such as municipalities, or community managers.

K	ACTORS
	Balancing Service Party (BSP)
	Congestion service provider (CSP)

Table 18. Modifications in Indicator K

7.1.3. Legislative and operations domain

Legislative domain

After knowledge gathered from experts, it is important to highlight that the legislative domain is the hardest to understand, and therefore hardest to simplify in a framework. That is why is the domain that needs the most modifications.

In the current state, P2P energy trading is not legally permitted within The Netherlands. Therefore, the framework assumption of its feasibility needs to be re-evaluated. An additional indicator should be incorporated to allow assessors to indicate whether P2P energy trading is legally recognized or not within their regions. Table 19 propose overall indicators and statements for this matter. Moreover, with the eminent incoming implementation of the CEP in the Dutch regulations, it is important to highlight that the overall legislative indicators could change as the package comes with motion.

	P2P ENERGY TRADING LEGISLATIVE INDICATORS
L	**P2P energy trading law**
1	Existence of legal provisions explicitly permitting P2P energy trading within the country's energy regulations.
2	Recognition of P2P energy trading as a legitimate form of energy exchange by relevant regulatory authorities and market actors
3	Availability of easy licensing or registration procedures specifically tailored for P2P energy trading platforms or participants.
4	Prosumers are recognized as a type of actor within the energy sector
5	The exchange of energy between peers (prosumer to prosumer or prosumer to consumer) is legal and accessible

Table 19. Added indicator in the legislative domain on P2P energy trading

Moreover, is necessary to reformulate Indicator N (see Table 20) to account for the differentiation between the liabilities of the platform and the liabilities of the consumers, as these actors bear responsibility for different aspects. When considering the platform's liabilities, the statement should clarify the type of responsibility it holds for the technological devices and additional technologies used in trading, including potential failures or errors. The liabilities of the prosumers are directly tied to what they own. As interviewee #2, (personal communication, May 23, 2023) adds, prosumers are responsible for covering the energy costs that their DERs were unable to generate due to adverse weather conditions. Table 20 shows the modifications of these statements.

	LEGISLATIVE P2P ENERGY TRADING INDICATORS
N	**Liabilities law**
1	The platform is aware that is liable to the responsibilities in a case of dysfunctions (failures, accidents, or errors) for both the prosumer and the digital tools used in the platform.
2	The prosumer is aware that is liable to the responsibilities in a case of dysfunctions (failures, accidents, or errors) of technological devices they own (i.e. DERs)

Table 20. Modifications of Indicator N

Operations domain

In terms of the operations domain, feedback from experts and the implementation of Distro platform shows that the domain is successfully evaluated by the statements. However, interviewee #2, (personal communication, May 23, 2023) proposes to add a security indicator. The participant argues that "security is always a big concern, especially when you're dealing with a resource such as energy". The security indicator should focus on both physical and virtual security management. For instance, there are big concerns related to smart meters, as it is used as the ground truth for most of the energy trading. Attacks such as pinning or altering the smart meter readings can cause major problems to the system (Interview #2, personal communication, May 23, 2023, p. 2). Research should be done to treat both, virtual and physical security, as individual indicators. However, this thesis just proposes them as statements added inside the new indicator "security" (See Table 21).

	Security
1	Physical security of the technological infrastructure is assured (i.e. DER, smart meters, batteries)
2	Virtual security upon cyber-attacks is assured

Table 21. Additional security indicator

Finally, an additional change should be added in terms of the overall domain. It has been seen, that due to the Distro platform results, the legislative domain and operations domain cannot be added together as (i) they are in very different stages of adoption, and (ii) the legislative domain can vary significantly across years. To properly show its dynamics and changes it is better to represent them separately (see Figure 16).

7.1.4. Societal and user adoption

In the societal and user adoption domain, certain modifications need to be implemented. Firstly, in terms of terminology, the term "users" should be replaced with "end-users" to accurately represent the focus on the final consumers of energy rather than intermediary actors. This clarification is crucial as for instance at early stages of implementation platforms can always choose centralized managers to deal with the energy trading and make easier the coordination of the platform, as it was in the case of Distro platform. However, this is not the aim of P2P energy trading defined in this thesis.

Second, the section on *knowledge and awareness* requires changes in their indicators and statements seen in Table 22. Firstly, as interviewee #7, (personal communication, June 12, 2023) highlights, blockchain has become a central topic of discussion due to its association with cryptocurrency. However, this technology should be positioned in the background of our conversations as the backend technology that it is. Therefore, doesn't require users to understand its technical intricacies similarly that it doesn't require users to understand how energy trading works; they should be able to navigate the platform and understand what benefits it provides them without any understanding of the technology. These arguments support the addition of statement Y1 and removal of statement Z4.

Secondly, due to the previous changes, given the significant lack of knowledge and misconceptions among the public regarding P2P energy trading and blockchain technology, it is crucial for new consumers of any P2P energy trading platform to undergo through a comprehensive onboarding process. This process aims does not aim to teach them about these technological developments, but to instil trust and ensure that end-users are well-informed about the benefits and potential consequences associated with participating in P2P energy trading (Interview #5, personal communication, June 6, 2023). Additionally, if needed, this time can also serve as a moment for consumers to eliminate all myths and misinformation around energy trading and blockchain if needed. Finally, as interviewee #5, (personal communication, June 6, 2023) states, users that use renewable energy resources must "start with the acceptance that not all energy is available at all times". This fundamental knowledge should be understood by all users prior to engaging in P2P energy trading platforms so they are aware of the potential changes they have when utilizing flexible and volatile energy sources. These arguments endorse the addition of statement Z6. Table 22 show the changes of these statements.

	Knowledge and awareness
Y	**Onboarding process**
1	End-users has gone through a throw onboarding process, so they see how they can reap the benefits of participating in such platforms and that trust is generated between the platform and the end-user.
Z	**P2P-blockchain energy trading system**
1	Users show an understand the interest in going beyond self-generated renewable energy towards self-consumption and flexibility.
2	Users understand the various benefits (environmental, economic, financial, social) that P2P-blockchain ET platforms can provide them.
3	Users acknowledge that participating in P2P energy trading systems may impact the timing of their daily activities and recognize the potential drawbacks associated with it (i.e. fluctuating tariffs, household flexibility limitations, and market volatilities).
4	~~Users understand how P2P-blockchain ET works and what interactions occur when the trading is generated.~~
5	Users have a basic understanding of energy-related climate change challenges
6	The end user has learned is accepted that not all energy will be always available when using the platform.

Table 22. Changes in the statements of knowledge and awareness

7.1.5. Overall readiness framework assessment and future research

Finally, there are several changes affecting the overall framework that should be addressed.

Firstly, upon examining the assessment results of Distro platform, it becomes evident that certain domains within the framework fail to accurately reflect the platform's actual dynamics and reality. An example is observed in the blockchain legislation section of the legislation domain, where the assessment results diverge from the actual circumstances (see Table 23). In the statement T1, the framework shows that the platform should comply with GDPR regulations when utilizing blockchain, however is fails to capture the fact that for example, Distro platform uses a hashed system to comply with GDPR. These differentiations are important, as they indicate a lower level of readiness than expected when answering affirmative to this statement. Therefore, more research should be done to see how these dynamics can be captured by the framework.

	BLOCKCHAIN LEGISLATIVE INDICATORS
T	Data law
1	The information is stored in the blockchain complies with the current GDPR.

Table 23. Example of an statement not capturing the internal dynamics of a platform

Another notable example is Indicator E within the technological virtual layer (see Table 24). Despite the statement explicitly mentioning that the platform operates on blockchain, the framework fails to differentiate between private and public blockchains and does not consider the implications that using either type of blockchain has on the level of implementation. Improving and redesigning these particularities should be done in future work.

	VIRTUAL LAYER INDICATORS
E	Blockchain
2	The platform runs upon blockchain (private or public).

Table 24. Example of the framework not capturing the dynamics of the platform

Secondly, upon analysing the **various statements of the framework**, it becomes evident that not all statements should have the same relevance. Indicator L3 (see Table 25) shows an example of a statement that is not essential for the basic functioning of the platform.

	P2P ENERGY TRADING LEGISLATION INDICATORS
L	Consumer law
3	The customers are aware that the solar panels are currently rated with a 0% VAT

Table 25. Example of a non-essential statement

To solve this challenge, the framework should incorporate the differentiation between two types of statements: basic statements and advanced statements:

- Basic statements encompass the aspects of P2P energy trading that are crucial for its successful basic implementation. In other words, if these statements are not fulfilled, trades cannot occur.
- Advanced statements pertain to the additional aspects that contribute to the overall energy trading but are not essential for the platform's functionality.

To differentiate between the two, a weight system is suggested (see Table 26). This differentiation will enhance the accuracy and objectivity of the framework in assessing the readiness level of the platform. Additionally, interviewee #6, (personal communication, June 7, 2023) confirms the need of this differentiation as she explained that "the framework should be a balance between the accuracy and the simplicity to use the framework".

Category	Weight
Basic statement	*1
Advanced statement	*0,5[26]

Table 26. Weights of basic and advanced statements

Additionally, it is important to acknowledge that certain statements within the framework may not qualify as basic or additional statements, but as unnecessary. Take for example, indicator R2 (see Table 27) in the case of Distro platform, due to it's current circumstances Distro does not need to register in DNB, therefore this should not penalize their overall readiness level. Consequently, it is crucial for the framework to incorporate an option where unnecessary statements can be excluded, ensuring that they do not negatively impact the overall readiness score.

	BLOCKCHAIN LEGISLATIVE INDICATORS
R	Crypto assets law
2	The entity is registered as a cryptocurrency exchange agent and wallet custodian in the DNB.

Table 27. Example of an unnecessary statement

7.1.6. Final analytical framework

Here below the final *P2P-blockchain energy trading readiness framework* is presented. Figure 16 shows the final framework assessed with Distro platform case study and the overall feedback from stakeholders within the Dutch energy market. Moreover, Table 28 shows the final overall operational readiness framework.

[26] This is an option approach to state that advanced statements weight 0,5, however further trial and error research should be done to assure this is the correct weight for the advanced statements.

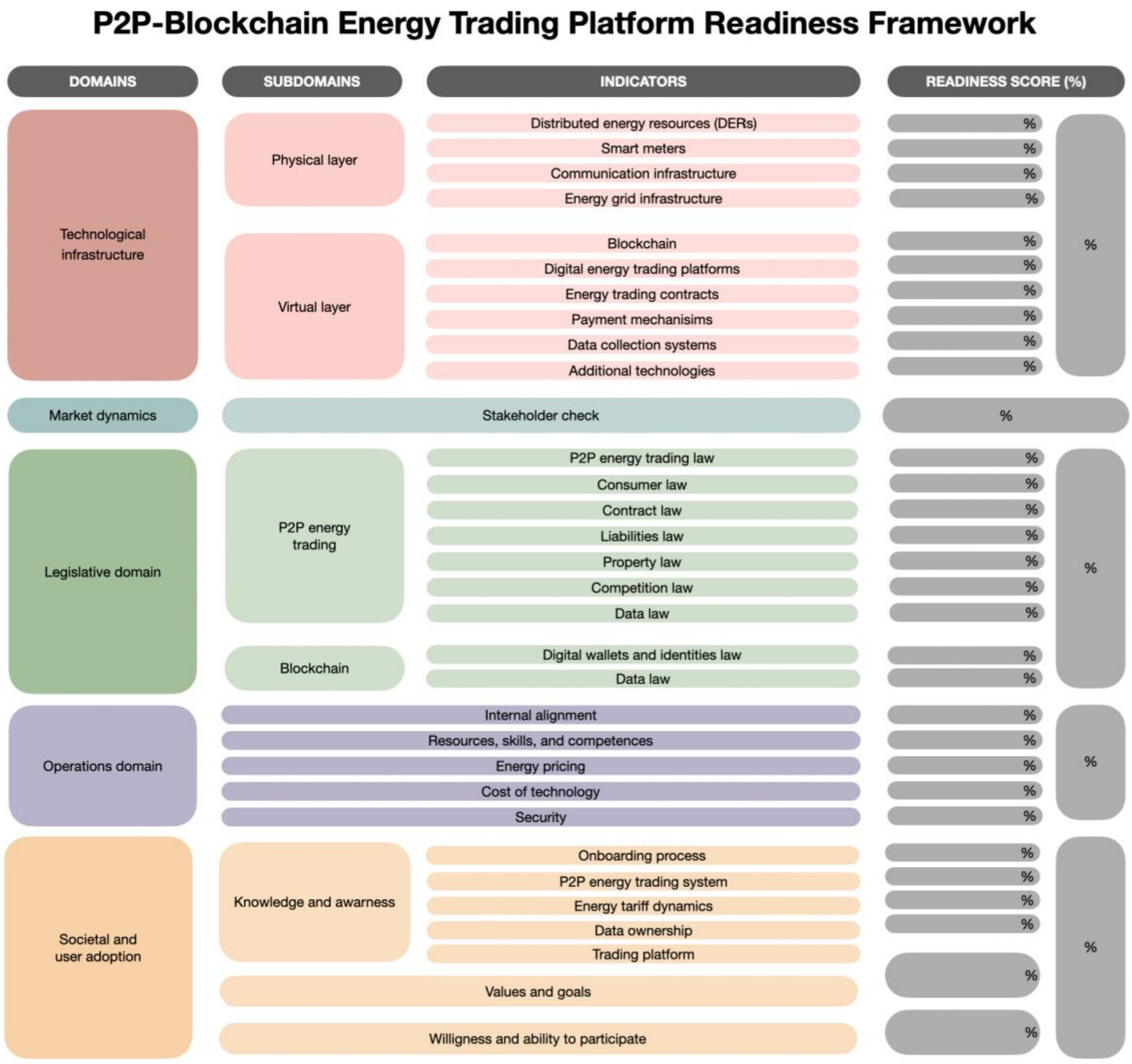

Figure 16. Final P2P blockchain energy trading readiness framework

Final P2P-Blockchain Energy Trading Readiness Framework

	Limit	Assessment options
1	Define what is the purpose of doing this assessment	Platform assessment P2P ecosystem assessment
2	Define "what does it mean to be ready?" for the platform	Open answer
3	Define what type of P2P energy trading market the platform is built upon	Centralized market Direct trading market Distributed market
4	Define who is the end-user of the platform	Open answer

Technological infrastructure

	PHYSICAL LAYER INDICATORS	
A	Distributed energy resources (DER)	VALUE
1	The ratio of renewable consumption/total energy consumption justifies the creation of a P2P energy trading platform.	

2	There is physical space available for installing DER	
3	There is enough energy storage capacity installed to enable community P2P-blockchain exchange at the scale-level that is aimed at	
4	There are other storage solutions such as thermal storage, electric vehicles, etc to enable the P2P-blockchain energy exchange at the scale-level that is aimed at	
B	**Smart meters infrastructure**	VALUE
1	Smart meters are available in every household to monitor the DERs and enable real-time monitoring of energy flows.	
2	The smart meters are able to gain data not just from the consumption and production of power but also advance information about the devise usage and status (i.e. type of energy source, grid characteristics, etc)	
C	**Communication infrastructure**	VALUE
1	The peers of the platform (households, and other establishments such as local business, farmers, and public buildings) have the sufficient broadband connection (Wi-Fi) to enable bidirectional transmission of energy data between the platform and the peers.	
D	**Energy grid infrastructure**	VALUE
1	There is existing energy grid infrastructure to trade energy for P2P-blockchain ET	
2	The physical capacity of the energy distribution grids of the area allows the peers to exchange energy at the scale-level that is aimed at.	

	VIRTUAL LAYER INDICATORS	
E	**Blockchain**	VALUE
1	The use of resources and the trust level among the peers justify the need of utilizing blockchain in the platform	
2	The platform runs upon blockchain (private or public)	
3	The platform utilizes specialized algorithms designed to optimize energy usage and storage, minimizing consumption to the greatest extent possible	
F	**Digital energy trading platforms**	VALUE
1	There is an existing digital platform that can remotely control, and steer assets based on the flexible energy needs to enable P2P exchange at the scale-level that is aimed at	
2	Digital infrastructure to ensure a proper functioning of energy management and monitoring systems for P2P-blockchain ET is in place	
3	The interfaces on the trading platform are informative and supportive for all users of the P2P energy trading system	
G	**Energy trading contracts**	VALUE
1	Contracts or agreements between peers and the energy supplier are on place to be able to utilize the grid when selling their surplus of energy.	
2	Contracts or agreements between peers and trading platform are on place.	
3	Contracts or agreements between peer and peer are on place.	
H	**Payment mechanisms**	VALUE
1	The platform can host digital wallets	
2	The platform performs its monetary trading between peers with cryptocurrency.	
I	**Data collection systems**	VALUE
1	Availability of real-time local weather data	
2	There is available access to API (Application Programming Interface) to read meter and sub-meter data.	
J	**Additional technologies**	VALUE
1	Forecasting algorithms are in place to predict load and, thus, to optimize energy sharing in the energy community	
2	Making the forecasting algorithmics the most cost-effective and sustainable as possible	

Market Dynamics

K	ACTORS	ESSENTIAL RELATIONSHIP	ADDITIONAL RELATIONSHIP

1	DER producing companies (i.e. producers of solar panels, wind mills, heat pumps…)		
2	Electricity producer		
3	Market operator		
4	Transmission System Operator (TSO)		
5	Distribution System Operator (DSO)		
6	Balance Responsible Party (BRP)		
7	Consumers and prosumers		
8	Suppliers		
9	Data facilitators		
10	APIs providers		
11	Energy aggregators		
12	Charge point operators or mobility service providers		
13	Regulatory institutions		
14	Research and development institutions		
15	Additional partners such as municipality, housing associations, project development companies, installers		
16	Balancing Service Party (BSP)		
17	Congestion service provider (CSP)		

Legislative and operations domain

Legislative domain

	P2P ENERGY TRADING LEGISTAIVE INDICATORS	
L	**P2P energy trading law**	
1	Existence of legal provisions explicitly permitting P2P energy trading within the country's energy regulations.	
2	Recognition of P2P energy trading as a legitimate form of energy exchange by relevant regulatory authorities and market actors	
3	Availability of easy licensing or registration procedures specifically tailored for P2P energy trading platforms or participants.	
4	Prosumers are recognized as a type of actor within the energy sector	
5	The exchange of energy between peers (prosumer to prosumer or prosumer to consumer) is legal and accessible	
M	**Consumer law**	VALUE
1	The trading platform is assuming that they are trading energy for commercial interests.	
2	Users of P2P energy trading platforms maintain their consumer status	
3	The customers are aware that the solar panels are currently rated with a 0% VAT	
N	**Contract law**	VALUE
1	The platform's hosting region ensures that peers within the trading platform have convenient access to the electricity grid.	
O	**Liabilities law**	VALUE
1	The platform is aware that is liable to the responsibilities in a case of dysfunctions (failures, accidents, or errors) for both the prosumer and the digital tools used in the platform.	
2	The prosumer is aware that is liable to the responsibilities in a case of dysfunctions (failures, accidents, or errors) of technological devices they own (i.e. DERs)	
P	**Competition law**	VALUE
1	The contractual platform tariff price is set at a competitive level within the market, ensuring it is not overpriced.	
Q	**Property law**	VALUE

1	Ownership of Distributed Energy Resources (DERs) is explicitly outlined in the contractual agreements between the user and the platform, providing clear and transparent information regarding ownership rights.	
R	Data law	VALUE
1	The customers are aware that they are allowed to have access their smart meter data	

	BLOCKCHAIN LEGISLATIVE INDICATORS	
S	Crypto assets law	VALUE
1	Do you comply with the Wwft (directive around cryptocurrency exchange and custodian wallets)	
2	The entity is registered as a cryptocurrency exchange agent and wallet custodian in the DNB	
T	Digital wallets	VALUE
1	The platform hosts a digital wallet which goes aligned with the GDPR	
U	Data law	VALUE
1	The information is stored in the blockchain complies with the current GDPR	

Operations domain

V	Internal alignment	VALUE
1	The platform clarifies how the distribution of economic benefits is divided and organized among members of the energy community (i.e. the platform providers)	
2	The platform clarifies how the use of collective assets (i.e. collective battery; shared mobility devices) are organized within the platform and energy community members.	
W	Resources, skills, and competences	VALUE
1	The platform has a clear short- and long-term organization on how and what available competences and skills (technical, financial, legal, social knowledge and skills) are needed to operate a P2P-blockchain ET platform. Also addressing the balance between paid and volunteer staff and differentiating between different types of expertise and skills needed.	
2	The platform has developed a business case(s) and has a financial plan prepared for the P2P-blockchain ET platform to work.	
3	There is clarity about the communication between platform daily management and peers of the community (i.e. channels (physical meeting, newsletters, etc.) messaging, frequency, etc).	
4	The platform has administrative tools (e.g. community member billing system) in place" (NRG2peers Consortium, 2021).	
X	Energy pricing	VALUE
1	The price of the energy is aligned with the wholesale energy market prices	
Y	Cost of the technology	VALUE
1	The platform has clarity on how all financial value flows are allocated and formally organized within the platform.	
Z	Security	VALUE
1	Physical security of the technological infrastructure is assured (i.e. DER, smart meters, batteries)	
2	Virtual security upon cyber-attacks is assured	

Societal and user adoption

	Knowledge and awareness	
AA	Onboarding process	VALUE
1	End-users has gone through a throw onboarding process, so they see how they can reap the benefits of participating in such platforms and that trust is generated between the platform and the end-user.	
AB	P2P energy trading system	VALUE
1	End-users show an understand the interest in going beyond self-generated renewable energy towards self-consumption and flexibility.	
2	End-users understand the various benefits (environmental, economic, financial, social) that P2P-blockchain ET platforms can provide them.	

3	End-users acknowledge that participating in P2P energy trading systems may impact the timing of their daily activities and recognize the potential drawbacks associated with it (i.e. fluctuating tariffs, household flexibility limitations, and market volatilities).	
4	End-users have a basic understanding of energy-related climate change challenges	
5	The end user has learned is accepted that not all energy will be always available when using the platform.	
AC	Energy tariff dynamics	VALUE
1	End-users understand that there are energy tariffs within the energy community and how these tariffs are different from their current tariffs with their energy suppliers.	
AD	Data ownership	VALUE
1	End-users are aware of agreements on data ownership and have explicitly agreed on it. They are aware that their energy data is being monitored by the platform, but that they can have access to their data.	
AC	Trading platform	VALUE
1	End-users show a basic understanding of how the energy platform works.	
2	End-users show an understanding of how the interfaces work, and they show a certain level of "experienced" control and empowerment.	

AD	Values and goals	VALUE
1	End-users are interested to participate on this energy community within the P2P-blcockhain ET platform, and have a clear idea about the goals the platform (i.e. values, economic, environmental, social benefits).	
2	The end-users are aware of the level and type of engagement that is asked for them when being part of the P2P-blcockhain ET platform.	
3	The end-users show trust[27] in the organisational structure, the management of the platform and the "people" that represent it (i.e. the board members or intermediary platform).	

AE	Willingness and ability to participate in P2P energy trading systems	VALUE
1	End-users show a certain willingness to invest (financially, time, knowledge, social relations) in the platform now and in the future.	

Table 28. Final P2P-Blockchain Energy Trading Readiness Framework

7.2. Implications limitations and further research

This section is going to critically present the limitations and further research of the overall thesis.

The primary limitation of this thesis is that the research is just focused on four implementation domains. Therefore, additional research should be done to create an even more objective and comprehensive tool. Economic domain or sustainability domain are some examples. In the latter interviewee #5, (personal communication, June 6, 2023) suggested the addition of the statements that could explain how P2P-blockchain energy trading can relate to the incoming Corporate Social Responsibility Directive (CSRD). This directive which is part of the Green Deal it aims to create truly sustainable economy in the European Union, business in 2024 business will be enforced to implement it (Deloitte Netherlands, 2023).

Second, the findings were based on a combination of literature research and interviews conducted within a single case study, Distro platform. While the pilot project and initial stages of Distro

[27] The level of trust can vary depending on the type of P2P-blockchain energy trading market which the platform is defined in.

platform provided valuable insights and contributed to an in-depth study, conducting additional assessments could have enhance the robustness, precision of the analytical framework. For example, reassessing the framework with operative P2P-blockchian energy trading platform within the Netherlands that had different sizes, locations, and financial and human resources.

Moreover, most of the interviewees that provided insights about Distro platform were from Distro, which means that they might be biased in their opinions on how ready their platform is. However, it is worth mentioning that the limited diversity of interviewed participants was not intentional, but rather a reflection of the relatively low recognition of Distro and Distro platform within the broader energy ecosystem. Additionally, these highlight the early-stage development of the company and the need for greater awareness and visibility within the industry to ensure a more representative sample of participants' opinions in future assessments.

Furthermore, more research should be done on finding different ways to gather a platform dynamic in its stages of implementation, on developing a weight mechanism to differentiate between essential and non-essential statements. And finally, on exploring potential collaborations with the researchers of (NRG2peers Consortium, 2021) paper, which addresses similar aspects. By joining forces, it would be possible to further validate the framework and build upon the initial findings in diverse contexts. Continued research in this direction will contribute to the ongoing advancement of P2P energy trading platforms.

These limitations do not negate the significance of the study's findings and the validated framework, as they have been endorsed by various stakeholders from different perspectives within the energy sector. This shows that the study successfully achieved its aim of incorporating multiple viewpoints to P2P-blockchain energy trading systems.

Chapter 8. Conclusions

P2P-blockchain energy trading is a promising business model that addresses the need for incentivizing local energy generation and improving the flexibility, decentralization, and unbundling of energy systems. By enabling trading mechanisms among peers, it tackles the volatility of renewable energy devices while fostering a trustworthy and transparent ecosystem without intermediaries. Moreover, it bridges the gap between energy production and consumption for end-users, creating a sustainable business model that enhances the profitability of distributed energy resources in the long term.

This research aims to create a tool to assess the level of readiness of P2P-blockchain energy trading platform within the context of The Netherlands energy ecosystem and consequently understand how P2P-blockchain energy trading platforms can be implemented in The Netherlands. Therefore, the thesis first develops a detailed literature review to gain insights into how blockchain could enhance the implementation of P2P energy trading technologies in The Netherlands. Second, establishes an analytical framework to assess the readiness level of P2P-blockchain energy trading platform in The Netherlands. Moreover, applies the framework to the currently operated P2P-blockchain platform of Distro company located in the port of Rotterdam. And finally, uses the feedback from experts in the field and the insights learned from Distro platform to assess the functionality of the analytical framework and conclude with a final *P2P-Blockchain Energy Trading Readiness Framework*.

The key findings of this research are presented in the following paragraphs.

In **terms of the Distro platform,** the following conclusions can be made. Firstly, despite having ambitious plans to implement a P2P-blockchain energy trading system in the port of Rotterdam and having had a successful pilot project, they still have a significant journey ahead. Second, their initial business model explanation is not implemented as planned. Due to having to comply with energy market dependencies or regulations, they have been forced to take sideroads in the implementation process of both P2P energy trading and blockchain. Looking specifically at the four domains of implementation within the Innovation Dock, the most advanced is the technological infrastructure. While the necessity of blockchain technology for the platform's operation may be questionable, given the high level of trust among peers, the remaining components of the technology are nearly in place. In terms of market dynamics, they are currently highly dependent on other energy market actors to operate their platform. These dependencies will be reduced when Distro platform has reached its core objective, and when the energy ecosystem gradually moves towards a more decentralized structure, a transition that could span several years. Moreover, in terms of legislation even though they comply with the regulations they are taking sideroads to apply P2P-blockchain energy trading as currently is not legal in The Netherlands. However, they can do P2P energy trading as they are doing it in the context of “energy communities” where the platform makes sure that the liabilities are covered for the end users. Finally, societal and user adoption is the domain that is lagging the most as their final users still don’t have direct access to the platform. Currently, the energy trading is controlled by the manager in the Innovation Dock. In the incoming weeks onboarding process with the end users will start.

In terms of the ***P2P-Blockchain Energy Trading Readiness Framework*** experts’ feedback and its successful application to Distro platform shows that the framework is very aligned with the basic requirements needed for a P2P-blockchain ET platform to be operationalized. However, during the re-evaluation process, certain limitations were identified. First, the framework would benefit from creating a clearer definition of what are the initial limitations and objectives when assessing a platform. This will enhance the overall assessment of the framework creating more specific outcomes. Second, some statements of the framework don't capture some internal implementation dynamics of the platform in some domains, specifically in the legislative domain. Moreover, not all statements should have the same relevance within the framework, a weighting system should be added to differentiate between statements that are essential for the platform functioning, statements that are additional and statements that can be not necessary for certain projects. Lastly, there is a need to incorporate additions, changes, and reformulations of certain statements to ensure its comprehensive coverage.

Finally, even though this thesis cannot assume that Distro ecosystem is the representation of the current **socio-technical ecosystem of the Dutch energy market** in which P2P-blockchain ET is being implemented. After understanding the market, and regulatory dynamics this thesis will present a small conclusion on the overall situation of the Dutch energy ecosystem. This thesis shows that there are no major difficulties in terms of the technological infrastructure to implement blockchain P2P energy trading in The Netherlands. In terms of market dynamics, the market is still very centralized and there are a lot of dependencies between market actors. Even though some energy incumbents have started implementing projects related to energy communities (i.e. Equigy by TenneT) the majority of the system actors are still very sceptical to invest on P2P-blockchain energy trading at a household level. One of the main reasons behind this is the low readiness level of the legislative domain. Even though a new European regulation related to energy trading is on the radar, the Dutch regulatory frameworks, and experts in the field show that currently there are no regulations that support the implementation of this type of energy business model. Finally, in terms of user adoption, little on-site information on how the end-user will deal with this new energy business plan has been found, as all the projects are in very early stages of adoption.

In conclusion, the creation, application, and assessment of this P2P energy trading readiness framework have proven to be successful as it has evaluated an existing operational energy trading platform. This study contributes to the existing literature on Innovation Sciences by adopting a comprehensive approach that recognizes the significance of multiple perspectives in the successful implementation of P2P blockchain energy trading platforms. Finally, as this thesis has proved that the regulatory framework is the least advanced in The Netherlands, further research is needed to determine the optimal regulatory framework and change the actor responsibilities within the energy market. Market and regulatory stakeholders in the energy ecosystem need to collaborate and acknowledge the collective benefits offered by this technological development, thereby fostering the transition towards a decentralized energy landscape with the adoption of P2P energy trading systems.

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Chapter 11. Appendix

Appendix A.

1. Introductory question on what does the interviewee does and how does it relate to P2P-blockchain energy trading systems?
2. What is the role of "*company name*" in facilitating the integration of P2P-blockchain energy trading platforms in the energy market?
3. Do you think blockchain can help implement P2P energy trading? What does it add?
4. What other areas should be considered besides technology when introducing P2P-blockchain energy trading into the market?
5. How are currently the blockchain regulations in the Netherlands? And P2P energy trading?
6. What is your opinion on net-metering regulations in the Netherlands?
7. What do you think will be the role of P2P-blockchain energy trading platforms within the energy market?
8. To what extent is important that users understand how P2P energy exchange works? And blockchain?
9. What key aspects are essential for an active participation of peers to involve in P2P-blockchain energy trading platforms?
10. After presenting the overall framework, the interview is asked to provide detailed feedback.

Appendix B.

Appendix B includes the transcripts of interviews conducted for this research, information which is confidential.