Master's Thesis Internship – MSc Sustainable Business and Innovation

Blockchain technology as the digital enabler to scale up renewable energy communities and cooperatives in Spain.

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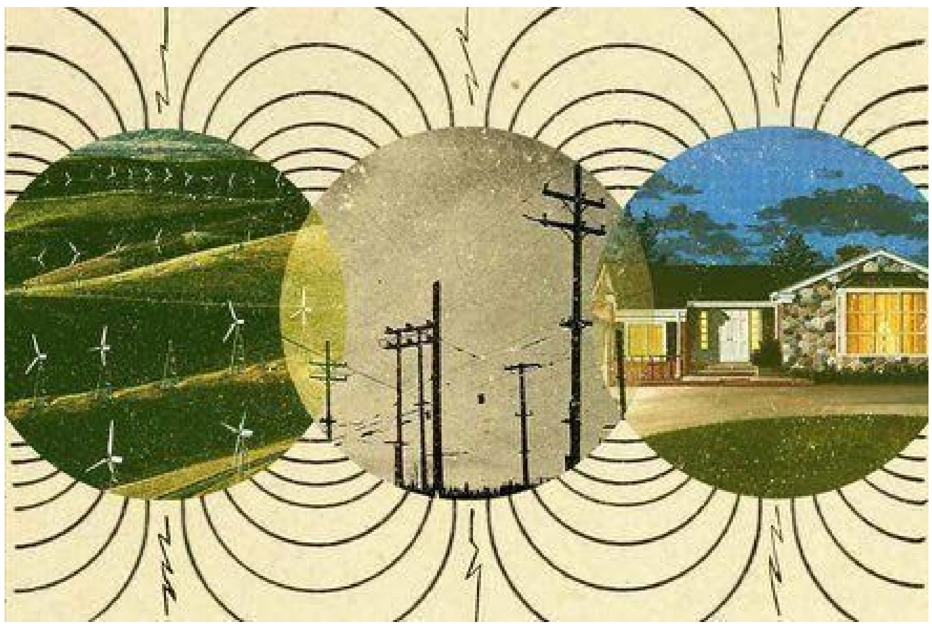

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Preface

The present research was conducted in combination with an internship with the Startup FlexiDAO. The selected startup FlexiDAO is a cleantech start-up company based in Barcelona (Spain) and headquartered in Amsterdam (Netherlands) created in November 2017 as a result of a 1-year research project by its co-founders, to accelerate the transition towards a decarbonized and decentralized energy industry, leveraging blockchain applications. They developed the first commercial blockchain application for the energy sector and they are interested in understanding the future developments of the market, the relationships between emerging and existing energy ecosystem actors and to develop blockchain applications to integrate different market entities into a collaborative and more sustainable future.

This internship allowed to develop this research from an insiders' point of view, granting access to relevant actors in the energy sector and in the blockchain ecosystem and especially access to the latest and most updated information. This enriched the research incomparably.

Abstract

The energy market is transforming at a fast pace and is leaning toward the direction of grid parity, when generation behind the meter of prosumers, energy communities and cooperatives (RECs) becomes cost-competitive with the actual generation system. The problem is that the current energy system is designed for one way flows of energy and does not account for the role of prosumers in creating bi-directional flows of energy. Regulators are therefore drafting new opportunities to integrate prosumers and communities in the market and create a new window of opportunity for their emergence as powerful energy actors. The transition toward a decarbonized and decentralized energy system, creates several challenges for all energy actors in terms of integration of new entities in the system. The main question is if digitalization can help to enhance system integration and how would that be possible. In particular, blockchain is analysed as a suitable technology to support this transition due to its decentralized nature.

This research, therefore, aims to investigate the pathway of development of the innovation of renewable energy communities and cooperatives in the perception of different actors of the system. In order to do this, a Multi-Level Perspective (MLP) is applied to understand what type of transition pathway is the most suitable to allow the scale-up of the innovation. Furthermore, drivers and barriers encountered throughout this development are analyzed and confronted with different blockchain

functionalities to understand to what extent blockchain technology can represent an enabler for the specific pathway development.

The present research was conducted following a qualitative inductive approach, implemented through a mixed method, consisting of both desk research, and semi-structured interviews involving several actors of the Spanish energy system. Results showed that perceptions of different actors at the regime and niche level diverge in the perception of the nature of interaction between niche and regime and this implies different pathways of development of the RECs. In these two different scenarios, the innovation faces different drivers and barriers and therefore two different designs of blockchain are confronted to address different functionalities. From the analysis of results it is possible to draw practical recommendations for energy ecosystem actors about which type of blockchain can be implemented and what benefits can bring to the development of renewable energy communities.

Executive Summary

After the new decree of the Spanish government about shared-self consumption, a window of opportunity opened for communities, but also for many other actors, like consultants, network operators, TSOs, DSOs, tech companies, etc... One of the most hyped technologies in the sector is blockchain technology, due to its decentralized nature. Blockchain has not to be intended as a fixed technology, but it can perform several functions and have different designs.

The present research was conducted in collaboration with FlexiDAO, a cleantech startup that developed the first commercially viable blockchain use case in the energy sector. They already collaborate with energy retailers and utilities to offer services of energy traceability, but they are continuously researching to expand the use cases of their software in the energy sector. Particularly, they are interested in prosumers and energy communities since their mission is to effectively coordinate millions of distributed energy resources into the grid. The ultimate aim of this research is to investigate if blockchain technology can fulfill a market need to integrate decentralized energy sources (DER) in the system and what designs and functionalities are the most suitable to do so. The analysis of drivers and barriers faced by energy communities in their scale-up reveals to be useful for the company in the design part of the blockchain algorithm, by selecting specific consensus mechanisms, rules and architecture designs suitable both to the community needs and to the needs of other market actors.

Furthermore, the most interesting part of the analysis is the collision between the vision of a collaborative relationship with RECs (formulated by regime actors) and the disruptive vision (formulated by niche actors) of their relationship of innovation with the regime. These different visions also influence the blockchain design since it can serve the purpose of coordinating independently several peer-to-peer (P2P) transactions, but also to integrate RECs and prosumers with utilities that can act as balancing actors and support their integration into the grid.

The clash between the two visions is not necessarily irreconcilable since their relationship might change in the future if energy providers change their business model and adapt to a future scenario in which RECs become integrated into the energy system. Therefore, the present research has also managerial implications for energy ecosystem actors that can take results into consideration when developing their innovation strategies.

List of Abbreviations

CO2: Carbon dioxide

CVNs: Collaboratively Validated Nodes

DER: Distributed Energy Resource

DLT: Distributed Ledger Technology

DPoS: Delegated proof of stake

DSI: Digital Social Innovation

DSO: Distribution System Operator

FBA: Federated Byzantine Agreement

GI: Grassroots innovations

GO: Guarantee of origin

gW: gigaWatt

IS: Innovation system

KwH: Kilowatt Hour

MLP: The Multi-Level Perspective

P2P: Peer-to-peer

PoA: Proof of authority.

PoS: Proof of stake

PoW: Proof of work.

PPA: Purchase Power Agreement

PV: Photovoltaics

RE: Renewable Energy

REC: Renewable Energy Community

SCADA: Supervisory control and data acquisition

SE: Secure Element

SI: Social Innovation

SI: System innovation

TEE: Trusted Execution Environment

TIC: Techno-institutional complex

TIS: Technological innovation systems

TPM: Trusted Platform Module

TSO: Transmission System Operator

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1. Introduction

1.1 The socio-technical innovation of renewable energy communities

Throughout the history of humanity, every industrial revolution has been connected to an energy revolution, that resulted in both industrial and social developments (Jifan, 2017). The next industrial revolution is the one toward a more sustainable production system and for this to happen a cleaner energy system is required to power it.

Historically, energy systems have been designed around a centralized system of production that leverages economies of scale, fossil fuel power plants and high voltage transmission across great distances, to distribute energy to a passive customer base (Howell et al., 2017). Traditionally, utilities had the monopoly over energy supply, since individuals could not afford to build a coal plant next to their factories and be self-sufficient and were forced to buy power from the centralized monopoly. Nowadays, two-thirds of CO2 emissions of greenhouse gases can be attributed to the energy sector (IEA, 2019) and fossil fuels are said to be responsible for over 0.3°C of the 1°C increase in global average annual surface temperatures compared to pre-industrial levels (Zhai & Lee, 2019).

As a reaction, a trend of decarbonization is reshaping the entire energy sector. The European Union has committed to 80-90% GHG reduction by 2050, implying an energy production system that will have to be almost carbon-free (European Commission, 2019). Renewable energy sources like solar and wind, instead, are by nature more democratic, in the sense that they are more accessible and affordable. Consequently, besides a trend of decarbonization, the energy market is also experiencing a decentralization trend since renewable energy sources are more distributed between different small producers. These two trends merged into the evolution of energy consumers from a passive to an active role of "prosumers" of energy, most often not yet self-sufficient, but simultaneously producers and consumers of energy (Szulecki, 2018). Connected with the emergence of small independent prosumers, a new concept has emerged: renewable energy communities and cooperatives (RECs) in which prosumers share and manage production and consumption of energy collectively. These different initiatives embrace the multiple ways in which energy consumers can now engage with a more decentralized production and consumption of energy by creating new collaborative relationships (Inês, 2019).

The emergence of these new energy actors poses several challenges to the integration of these new market entities in the system and raises the question of how will the transition to a more sustainable energy system will happen, who will be the actors involved, what relationship will they have with the present system and what will be the drivers and barriers they will face in their development. An appropriate framework to understand the dynamics of sociotechnical transition is the Multi-level perspective (Geels, 2002; Geels & Schot, 2007), which conceives transitions as the interplay between developments at three analytical levels: niches (the locus of radical innovations), socio-technical regimes (the locus of established practices and associated rules that enable and constrain incumbent actors in relation to existing systems), and an exogenous socio-technical landscape (Geels, 2014). The possible forms of transition from different levels are triggered by the opening of a "window of opportunities" and they result from changes at all three levels of the system that reinforce each other into systemic transformation (Schot and Geels, 2008).

The scope of the research will be defined by the fact that in Spain, the commonly known "sun tax" was abolished through the validation of Royal Legislative Decree 15/2018 (Barredo, 2018) and a new law regarding shared self-consumption was approved through the Royal Decree-Law 244/2019. Therefore Spain is considered a relevant case, due to the newest favorable regulations for shared self-consumption, which created a new "window of opportunity" for energy communities to flourish.

Geels & Schot (2007) identify different types of 'transition pathways' of development of innovation, influenced by specific factors. The first factor is "timing of interaction" and refers to the phase of development of the innovation when a window of opportunity is created at the landscape level. The second one is that the "nature of the interaction" can be "symbiotic" and can be adopted as complementary or as an add-on to the regime system or it can be "disruptive" and represent a competing alternative to the socio-technical regime. These two dimensions and the resulting pathways are summarized in Figure 1.

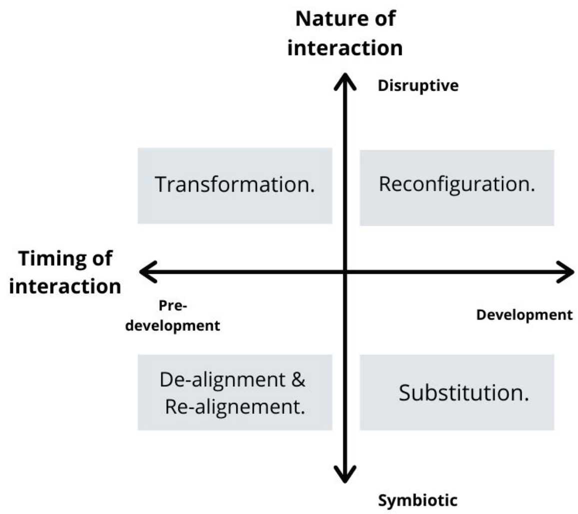

Figure 1:

Matrix representing the two dimensions and the consequent pathways of development of innovation

In the case of RECs, their innovation is quite well-developed at the niche level, but not sufficiently to take over the regime structure when the window of opportunity presents from the legislation. The most interesting point is the nature of the interaction with the regime; it is unclear if their innovation implies disruption for the previous model of energy sourcing offered by energy companies or if it can have a symbiotic nature and be integrated into their model and how this relationship is perceived by different actors in the energy system. These leaves open the question if the innovation will imply a dealignment and realignment in which the present system starts developing problems and flaws and RECs' innovation better satisfies the new needs of the market, or a transformation of the regime to integrate RECs in the present system.

At the top-down level, regulators are trying to remove sociopolitical barriers to scale up the community model and at the bottom-up level, communities are already keeping up with the trends of decarbonization and decentralization, but they still lack the digital tools to scale-up from the micro to the macro level, a process defined as a socio-technical transition of innovation.

A new trend of digitalization is also reshaping the energy industry, requiring the emergence of a new technological infrastructure to manage decentralized energy production with consumption (Di Silvestre, 2018). One of the most hyped digital innovations for the energy sector is blockchain technology (Roubini & Byrne, 2018). Blockchain is said to be a possible technological enabler for the renewable energy transition, due to its decentralized nature that reflects the changing landscape of the energy sector and the possibility to manage huge amounts of data, while maintaining traceability, transparency, and trust between all system users. This research, therefore, aims to explore the potential of blockchain to be the digital enabler for renewable energy communities and cooperatives (RECs) to transition from the niche to the regime level and what role might it have in different development scenarios.

1.2 Research question and relevance of the research

Several attempts have been made to analyze the reasons for users to join community energy initiatives (Kotilainen et al., 2016; Hoppe et al., 2015; Oteman et al., 2014; Ruggiero et al., 2014); considerably less attention has been dedicated to understanding the dynamics that allow or hamper the scale-up of RECs model. As highlighted by Kotilanen et al. (2016) the role of prosumers and RECs is critical for the ecosystem development, but the relationship between the prosumer market, the structure of the industry, and other actors remains unresearched. This research aims to fill this research gap by investigating the different perceptions of actors at different levels (niche and regime) of the pathway of development of innovation and the repercussion on the development of innovation in case perceptions are conflicting.

On the other side, current literature about blockchain is often very technical and does not consider also the social and organizational dynamics involved in its implementation (Nichol & Brandt, 2016). Hence, for this research blockchain will not be conceptualized as an innovation system per se, but as the technological infrastructure that has the potential to facilitate new types of governance and economic organization that is distributed, decentralized and more transparent (Davidson et al., 2016; MacDonald et al., 2016). Consequently, the scope of this research is not limited to analyze the possible pathways of development of RECs, but to research, if blockchain can represent an enabler for their scale-up and what functions and designs it can assume in different scenarios of development of the innovation. This is operationalized by answering the following research question:

What designs and functionalities can blockchain assume to be an enabler of different transition pathways of renewable energy communities and cooperatives (RECs) in Spain?

This can be broken down into more specific research questions:

1. *What are the perceptions of energy actors about the possible pathway of development of RECs innovation in Spain?*

2. *What are the perceived drivers and barriers by the Spanish energy actors each possible transition pathway?*
3. *What functionalities and designs configuration of blockchain are the most suitable to help to realize the pathways by leveraging on drivers and overcome barriers?*

The present research is combined with an internship project with a startup that developed the first commercial blockchain application for the energy sector. This allowed for direct access to relevant actors, conferences, and media both in the blockchain and energy ecosystem. The selected startup FlexiDAO is a cleantech start-up company created to accelerate the transition towards a decarbonized and decentralized energy industry, leveraging blockchain applications.

The structure of the following research starts with an in-depth literature review to define background concepts like prosumers and energy communities, then it explores technical concepts with a specific focus on blockchain technology and its applications for the energy sector. It follows a section in which the theoretical models used for analysis are introduced. The Multi-Level perspective is explained at the three levels of the landscape, regime, and niche. Then the different possible transition pathways of innovations to scale up are analyzed. This theoretical section is followed by a methodology section in which research design and methods are explained. The research takes an inductive qualitative approach. It aims to implement data triangulation through a mixed data collection method. This includes both desk research of academic and grey literature and interviews performed with several actors of the Spanish energy system in order to depict a more nuanced picture of the different pathways, based on different points of view. Concepts derived from interviews are coded and analyzed consequently in the result section. This section includes the possible transition pathways of niche innovation from the point of view of different actors at the regime and niche level. It also highlights drivers and barriers of community development and to which of them could blockchain provide a solution. In the discussion section results are analyzed based on the selected theoretical framework and conclusions are derived consequently.

2. Empirical Background

The aim of this section is to deepen the reader's knowledge of several concepts useful for understanding the background of this research. It starts by describing the trends of decarbonization, decentralization, and digitalization of the energy sectors that shaped the context of the rise of prosumers, in order to depict what factors are driving the development of the sector. This can help to contextualize the development of the innovation in the sector. The second subsection explains the rise of prosumers in light of these trends and briefly elaborates on the development of the concept of prosumption and completes it with a literature review of the concept. The last subsection is essential to explain the various forms of energy sharing and to draw the line between energy sharing and collective self-consumption. These sessions aim to clearly define concepts like prosumption, energy sharing and collective self-consumption, this is useful to analyse results and label them in light of the definitions.

2.1 A 3-Dimensional energy future: Decarbonized, Decentralized, Digitalized

Lately emissions have decreased due to a reduction in energy demand as a consequence to the lockdown measures implemented by several states as a consequence of COVID-19. This slow down of travel, tourism, and of the economy, in general, implied the highest ever annual emission reduction (Evans, 2020). CO2 emissions are predicted to decline by almost 8% in 2020 compared to the previous year, reaching the lowest level since 2010 (IEA, 2020).

The problem is that a reduction 0f 7.6% of emissions would be needed every year in order to avoid reaching 1.5 degrees Celsius above pre-industrial levels, following the "Emission gap report 2019" of the United Nations (United Nations Environmental Programme, 2019, p.13). Furthermore, a rebound effect is predicted to occur with an emission increase to foster economic recovery (IRENA, 2020).

The reconstruction that would be needed as a consequence of the health and economic crisis might also serve as an opportunity to rebuild the system over more sustainable foundations, but for a sustainable transition in all sectors, an overarching clean energy system is required to power it. The fuel to power this transition is expected to be produced mainly from renewable sources due to the lower costs of generation of new technologies like wind turbines which cost has fallen by 37-56% (IRENA, 2018) and solar panels which cost has fallen by approximately 80% (IEA, 2017).

This attempt of decarbonization of the energy sector through renewables implies also a trend of decentralization of energy generation since renewable sources are more distributed and democratic (Di Silvestre, 2018). This scenario gave rise to the proliferation of prosumers, that are both producing and consuming their own energy. Prosumers aggregated through several models of shared ownership of energy sources like renewable energy communities, cooperatives, shared self-consumption through which neighborhoods can share the renewable energy they produce, and so on. These initiatives create new forms of social relationships and value networks and therefore are seen by many as powerful catalysts toward a more sustainable energy system (Hewitt et. *al*, 2019; Bauwens & Devine-Wright, 2018; Walker, 2008). It was estimated that 83% of European households can potentially become energy citizens (Kampman et al., 2016).

The interconnectedness required for a coordinated decentralized system, implies a third trend of digitalization to manage the increased quantity of data generated by the new energy ecosystem actors. This change can give rise to the development of new business concepts and new types of energy services (Timmerman & Huitema, 2009). Digitalization is blurring the distinction between supply and demand and creates new opportunities for small producers to be integrated in the grid (IEA, 2017). Nevertheless a higher degree of transparency, interoperability and standardization are required in order to integrate real-time the decentralized energy sources into an integrated system, that allows for collaborative solutions for the common problem of the climate emergency.

2.2 Prosumers as citizens of an energy democracy

"Prosumer" is a neologism that refers to a consumer that is also producing for its consumption. The term was originally coined by Alvin Toffler (1980) to join both categories of production and consumption into a higher level of a socioeconomic network of collaboration (Araya, 2008.) Toffler theorized that prosumption was predominant in the pre-industrial era, that was followed by a "second wave" of marketization that drove 'a wedge into society, that separated these two functions, thereby giving birth to what we now call producers and consumers' (Toffler, 1980, p. 266). In the book "The third wave" Toffler explains how society is moving away from this separation of roles, toward the emergence of prosumers. Prosumers of energy represent the citizens of an energy democratic society (Szulecki, 2018) and as the first step toward energy democracy, prosumers have established renewable energy communities and cooperatives (Fairchild & Weinrub, 2017). A wide range of REC projects have been implemented around the world, but especially in Europe (Hewitt et. *al*, 2019) giving birth to new forms of active energy users and citizenship.

Collective self-consumption of energy could result in a diverse range of outcomes ranging from cooperative ownership of solar panels or wind turbines with a shared return scheme to investors, microgrids, rooftop solar panels for powering local homes and businesses through shared self-consumption, farmer's bioenergy collectives, community center renewable heat initiatives, locally-owned energy distribution networks ecovillages that aim at energy self-sufficiency and so on (Hewitt et. *al*, 2019). All these diverse initiatives have the common characteristic of involving citizen participation around the issue of clean energy sources and constitute a form of social innovation (SI).

Their diffusion highlights the growing importance of principles such as energy democracy and self-consumption, assists the fight against energy poverty, and contributes to reducing greenhouse gas emissions (Akasiadis et *al.*, 2017).

Walker (2008) researched copiously energy community initiatives and demonstrated that the concept of local communities increases the social acceptance of innovation and therefore can increase and positively contribute to the upscaling of innovations. Moreover the research of Bauwens and Devine-Wright (2018), based on a quantitative statistical analysis of community-based energy initiatives, showed that people who are in control of the way in which energy is supplied and regulated (like in the case of RECs) foster more positive attitudes toward renewable energy in general compared to non-members, consequently members can be considered more supportive of the implementation of renewable energy projects (Bauwens & Devine-Wright, 2018). RECs could therefore act as a catalyst for energy behavior change by offering a new model of relationship with energy and with people (Hewitt et. *al.,* 2019).

2.3 Energy as a shared resource: the various forms of community energy

Several researches concentrated on the factors driving these users communities to come to fruition and attributed it to a sense of independence, autonomy, and community rather than financial factors (Adil & Ko, 2016; Walker & Devine-Wright, 2008). This is echoed in the ideas of Richard Sennett and his analysis of communities in general, expressed in his books "Together: The Rituals, Pleasures, and Politics of Cooperation" (Sennett, 2012). This is also the case for energy communities, whose creation is often not only driven by the desire to provide alternative forms of renewable energy but arise from a desire of engagement and empowerment (Hoppe et al., 2015; Oteman et al., 2014; Ruggiero et al., 2014). RECs can be also seen as small energy democracies, based on the collective interests of certain groups (Chilvers & Pallett, 2018; Van Oost et al., 2009). These initiatives embrace the multiple ways the public can now engage with a more decentralized production and consumption of energy. In particular, research showed that community energy does not only refer to local generation, but it includes the social processes of producing local energy and managing it as a community (Walker & Devine-Wright's, 2008).

As mentioned before, renewable energy sources are more decentralized and therefore democratic, but they are also more intermittent because they are dependent on time and place of generation. This implies the energy demand and supply do not always match; so, in the absence of adequate storage technologies, the most feasible solution is sharing. This mismatch between local demand and renewable energy generation can limit the economic potential of photovoltaics (PV) systems not only for individuals but also for entities like schools, sports arenas, churches, but also companies that have renewable energy assets installed (3E, 2018). Therefore sharing makes economic sense. It also implies an environmental benefit of direct use of the energy produced and a social benefit of establishing a new type of collaborative relationship.

Self-consumption is the process through which prosumers self-generate electricity from their own power plant and use it instantly below the connection point of the grid (3E, 2018). The core concept of shared/collaborative consumption relates to obtaining value from untapped potential, or “idle capacity” of goods that are not entirely exploited by their owners (Sacks, 2011). This fits in the definition of sharing economy, as consumers granting each other temporary access to under-utilized physical assets (“idle capacity”), possibly for money, following Frenken et al. (2015). Frenken & Schor (2019) call “shareable goods”, the ones that by nature provide owners with excess capacity, implying an opportunity to lend out or rent out their goods to other consumers, and this is also the case of energy that is generated and not consumed immediately and cannot be stored. Some characteristics of the sharing economy are highlighted in table 1 and their applicability in the energy sector is shown.

Table 1.

Defining characteristics of the sharing economy and their applicability in the energy sector. Source: Plewnia, 2019, p.4.

Aspect	Application in the Energy Sector
Platform-based	Digital energy platform companies which do not own many assets themselves, but instead offer services of coordination and optimization.
Leverage on digital technologies	Digital coordination mechanisms as the backbone of the energy infrastructure, especially with increasingly fluctuating energy supply and need for demand or storage management.
Consumer-to-consumer/ peer-to-peer interaction	Distributed decentral renewable energies, energy storage, and smart management devices offer potential for increased C2C interaction. Local microgrids and digital platforms as spaces for increased C2C exchange of energy, money, information, and knowledge.
Access instead of ownership	Traditional core principle of energy system. Now increasing ownership of energy production, storage, and management devices in households and small businesses. Potential for optimization by sharing among decentral actors.
Under-utilized resources/Making better use of idle capacities	Not applicable for renewable energy generation facilities as these have little to no idle capacities. Batteries and electric vehicles can be used more efficiently if shared in districts or energy communities.
Shared values/ mission driven	Important factor for sharing business models in the energy sector to compensate for lack of cost advantages. Possibly even more pronounced in local sharing activities.

An important distinction needs to be made between energy sharing and collective self-consumption, since the first one happens through the intermediation of energy retailers through the grid, while the second one happens directly peer-to-peer. The concept of energy sharing, for now is implemented through the correction of the electricity bill from the energy retailer, based on the financial participation in a renewable project. The concept is similar to the one of Power Purchase Agreement (PPA), since it allows prosumers to participate in a renewable energy project, and have the financial returns be achieved through a deduction on their electricity bill (3E, 2018). This deduction can be a financial deduction or a deduction on the final invoiced energy consumption, but due to the number of intermediaries, the potential added value is limited (3E, 2018).

On the other side, the concept of shared/collective self-consumption refers to a group of individuals that act together as renewable self-consumers (or prosumers) and are joined for energy to be exchanged behind the meter or virtually through the grid. Examples of shared/collective self-consumption can range from a condominium with a shared PV system on the rooftop to an entire neighborhood with multiple prosumers connected to a single feeder (3E, 2018). The environmental benefit is clear since: “Every locally used kWh prevents the production, transport and associated losses of centrally produced and often still fossil-based electricity. Decentralized generation and decentralized consumption are achievable in many different constellations. These models ensure that the energy costs of all participants will decrease, thereby making an important contribution to reaching CO2 emission reduction targets” says in an interview Prof. Wilfried van Sark, Professor Photovoltaics Integration at the Copernicus Institute of Sustainable Development (Utrecht University, 2020). The main difference with energy sharing is that value creation happens through a reduction of overall systems costs since energy is not shared using intermediaries and therefore it increases the value of an investment in a PV system (3E, 2018). Collective self-consumption can be physical when a group of actors consumes electricity from a shared PV system (this is the case of energy communities), but it can also be virtual when the consumption and production of a group of households “can be aggregated to form a flexibility capacity equivalent to that of a power plant” (Koirala et al., 2016, p. 727) in the case of energy cooperatives.

While geographical proximity is one defining characteristic of energy communities (that consume energy behind the meter through a so-called microgrid), energy cooperatives are the oldest model of energy sharing and they imply a collective investment of consumer into a renewable generation asset, that is bought and managed collectively and provides energy (and revenues) to all actors even if they are not located in physical proximity, through the so-called exchange of “virtual green energy” through the grid (Capellán-Pérez et al., 2016; Hewitt et al., 2019).

3. Technical background

This section is aimed to provide the sufficient technical knowledge required to understand blockchain functionalities and its applicability in the energy sector. Starting from a short general paragraph on digital social innovation, a general definition of blockchain technology is provided and its main characteristics are highlighted. The following subsections are dedicated to deepen the knowledge of smart contracts and digital trust, the energy traceability application and the different design of consensu mechanisms.

The main aim of this section is to contrast the vision of blockchain as a fixed technology, often conceived as the solution to disruption and, instead, to shed light on the different facets, in terms of design and functionalities, that this technology can take. Specifically, blockchain can take different functions to fulfill totally different needs in different pathways of development. The transition problem is not simply about scaling up the technology of blockchain, but how blockchain can support and adapt to the new reconfiguration of actors, institutions, regulations etc..

3.1 Blockchain as a tool for digital social innovation

Social innovation theories refer to the reconfiguration of social practice in response to societal challenges (Polman et al., 2017). According to Mulgan (2006), Social Innovation (SI) refers to innovative activities that are motivated by a social need. Since 2014, a subdiscipline of social innovation has been defined in relation to the digitalization of several social aspects of our lives. This discipline is referred to as digital social innovation and refers to "a type of social and collaborative innovation in which innovators, users and communities collaborate using digital technologies to co-create knowledge and solutions for a wide range of social needs and at a scale and speed that was unimaginable before the rise of the Internet" (Maiolini et al., 2016). As argued by Vaccaro and Madsen (2009), internet-based technologies can assist the change of relationships between individuals and business practices, in relation to ethical issues and social challenges.

This is also the case for the blockchain system, that has been developed to use technology not to centralize information and detach users from their data, but to empower them with transparency, control and personalization (Casey & Vigna, 2018). The system acts as a chain that links together all the blocks of digital information from different sources, since every block is identified with a unique piece of code (header) that is linked to the header of the previous block (Casey & Vigna, 2018). This makes it a decentralized database that records transactions between different users.

Blockchain technology is said to be a suitable enabler for the scale up of RECs because it can collect all real-time decentralized information in one place: a shared ledger that is accessible by everyone in the system, acting as a trusted platform. Until now, reliability of databases would depend on the trusted centralized authority that would own them and control them, but everytime intermediaries are involved, inefficiencies can arise therefore increasing time of transaction and costs (Attili et al., 2016). Blockchain technology was developed to address the problem of trust from a different perspective: instead of externalizing trust in the hands of a central authority that acts as a trusted intermediary between transacting parties, the technology aims to distribute trust through different consensus mechanisms (Casey & Vigna, 2018). When information is distributed, the overall level of transparency increases, contributing to increased trust between different actors. A distributed model is sketched in Figure 2.

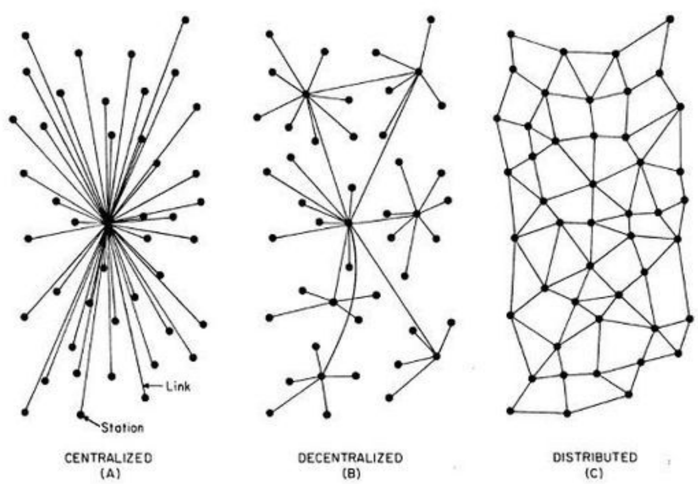

Figure 2.

A visual representation of the centralized, decentralized and distributed model. Source: Hoelscher, 2015, p. 2.

All information recorded is both time and location-dependent and it is stored in a ledger accessible to all actors in the system, this is why blockchain is also called Distributed Ledger Technology (DTL). In this way, the technology is able to effectively coordinate millions of distributed energy resources into the grid. The core characteristics of blockchain are summarized in De Filippi (2017):

- Distributed Database: each participant has access to the distributed ledger and its complete history. Data are not controlled or owned by anyone, on the contrary, everyone can verify transaction without the need on intermediaries (depending on the consensus mechanism selected)

- Peer-to-Peer Transmission: communication occurs directly between every node and not through the intermediation of a central authority this implies the elimination of the need of third party validators.
- Transparency with Pseudonymity: all transactions are recorded in the ledger and accessible to all participants. Users are associated with a unique 30-plus character alphanumeric code/address that identifies them. Transactions occur between blockchain addresses.
- Immutability of Records: transactions are immutably recorded in the ledger and everyone has access to their history. This implies that past transactions cannot be altered/tampered, because they are "chained" to the previous transactions in chronological order and users can be sure that transactions will be executed under the expected conditions.
- Computational Logic: all the transactions are programmed and tied to computational logic and therefore can be automated, through the use of the so-called "smart contracts" that will be explained in the next paragraph.

3.2 Smart Contracts

One of the challenges of the actual system is to find an efficient way to manage ownership of energy produced and exchanged into the grid and how to develop a new model of trust through contractual relationships (Gancheva et al., 2018). For example, after the Spanish legislative decree, residents of a building can now collectively own and use a PV on top of their condominium, but there will be houses that use more of it and ones that use less of it, or there will be rainy days in which the sun does not produce enough energy to satisfy the demand. Blockchain aims to provide a solution to this complexity through the use of smart contracts. These contracts are executable programs that can automatically execute transactions when a set of predefined conditions are met (Chahbaz, 2018). These conditions are established and agreed upon by both parties and when they are all fulfilled transactions automatically start, like payment is sent when a shipment arrives (Peters & Panayi, 2016). In this way, there is a guarantee that a planned event will happen since the execution is independent of the will of parties involved and once agreed upon is impossible to withdraw from them (Chapron, 2017). This can be done without the need of a third party external validator by providing cryptographic proof for trust instead.

In practice, the consumer will ask for energy through the smart contract, which will automatically check the availability of the requested amount of energy at the present moment between different production assets (Ioannis et al., 2017). If there is availability, a request will be sent to produce and an automatic price negotiation between consumer and producer takes place based on the conditions defined in the rule protocol of the smart contract (Ioannis et al., 2017). Once both parties agree on the price, both money and energy flows can be exchanged and the transaction can take place (Ioannis et al., 2017).

It is also possible to convert money into a digital currency, with energy vouchers produced on demand, or an automatic reward mechanism associated with energy exchanges (Ioannis et al., 2017).

3.3 Digital trust

By eliminating the need for intermediaries to create trust, blockchain can allow to decrease costs of transactions substantially. Transaction Cost Economic theory can give some hints in explaining the rationale behind this (Voets, 2017). Transaction costs arise from uncertainty and therefore costs of writing, enforcing, and legally validating contracts are ultimately a defense against opportunism. Williamson (1985, p. 47) defines opportunism as “the incomplete or distorted disclosure of information especially to calculate efforts to mislead, distort, disguise, obfuscate, or otherwise confuse”. Therefore transaction costs are costs to enforce trust between different opportunistic parties. ledgers, to increase transparency and trust between parties at no cost. The peculiarity of this technology is that it is said to be decentralized and trustless, meaning that different parties are not required to trust each other as long as they trust the system itself (Lemieux, 2016). Hence, blockchain technology can provide a tool to counteract opportunism by eliminating the need for trust, which will drive down transaction costs, making blockchain technology an institutional technology, potentially competing with organizations or markets (Davidson et al., 2016). Disintermediation allows for considerable time and money savings, in terms of validation of documents by legal authorities, inefficiencies of public bureaucracy, litigation costs, etc..

The researcher Tarek AlSkaif supervised his student Gijs Van Leeuwen from Utrecht University, that is working to develop a blockchain-based peer-to-peer (P2P) energy trading platform and his research tests a blockchain energy management platform that is adapted to the characteristics of physical microgrids. They tested it on the East Harbour Prosumers Community and results of the research show also the economic implication of using blockchain, implying cost reduction in different scenarios (grid only, trade only, grid and trade) for both summer and winter (Van Leeuwen et al., 2020).

Anyway blockchain cannot solve a fundamental problem referred to as “garbage-in-garbage-out”, this means that all the data inserted in the database of blockchain, even if incorrect, are considered trustable. A way to address this in the energy sectors is to rely on the use of smart meter measurement, trusted computing using Trusted Platform Module (TPM), Trusted Execution Environment (TEE), Secure Element (SE) or any similar component that can be insured in smart meters with remote attestation service; in this way it is possible to determine if data has been tampered or not. (Ioannis et al., 2017)

3.4 Energy tracking

One of the most used commercial applications of blockchain is tracking to increase traceability of products and money flows. Energy is different from all the other commodities and tracking the energy flow of green electrons is impossible for physical reasons, since when they are injected to the grid they mix with all other electrons generated from other sources and result in what is defined as grey energy (FlexiDAO, 2020). Anyway is possible to track the time and location of their production and match data of generation and consumption in real-time, ensuring customers that the same amount of energy being consumed is also being generated nearby within the same hour. This can then be ensured through the automatic assignment of an energy attribute certificate that comes bundled with the energy transferred and can also prove where and when the energy was produced (FlexiDAO, 2020). This allows to track ownership, verify claims, and ensure that certificates are only sold once and that there is no double counting (FlexiDAO, 2020).

This is possible through a digital process called “tokenization of electricity” for which units of electricity become digital goods/assets and allow automatic certificate generation (timestamping), transfers and ownership tracking based on cryptographic proof (Varnavskiy et al., 2018). This process allows to assemble unique information associated with the product (electricity in this case) related to a specific time period and to create a digitized token of electricity that can be exchanged among users. This does not imply that the data are always correct, but that they were inserted according to a protocol rule. The accuracy of data can anyway be increased through the automatic gathering of generation data from national data hubs, smart meters, or supervisory control and data acquisition (SCADA) and records the information in the blockchain (FlexiDAO, 2020). In this way, energy producers can share data while retaining control and in turn foster transparency, customer inclusion and more efficient data management (Braden, 2019).

3.5 Consensus mechanisms

A short paragraph needs to be dedicated to explaining why in the past, several claims were made about blockchain being a very energy-intensive technology, therefore very unsustainable. The energy intensity is connected to the validation/approval of transactions by participants, but this mechanism can rely on different consensus architectures.

In the iconic case of Bitcoin, the consensus mechanism is called Proof-of-work (PoW). In PoW Validators are the ones that solve the cryptographic code of a block and add it to the system, based on their computational power, since the code can be cracked only through try and fail (Wang et al., 2019). This process is called mining and is very energy intensive since validators compete against each other to solve the code.

The first alternative developed consensus mechanism is known as proof of stake (PoS), it replaces the computational power with an element of randomness in the selection of the validators, that is based on their "stake" in terms of wealth and is related to the resources that they invested in the system (Wang et al., 2019). This approach could lead to a substantial reduction in electricity use and speed of transactions since there is no need to continuously produce new blocks to validate previous transactions (FlexiDAO, 2020).

Voting based mechanisms instead rely on finding a minimum consensus number of validators. In Delegated Proof of Stake (DPoS) a distributed voting system is in place to select the validator nodes that will approve the new blocks, this is also referred as a shareholder voting consensus scheme because every member of the network can decide who can be trusted, not only based on who possesses the most resources (Wang et al., 2019).

An alternative method is the Federated Byzantine Agreement (FBA) with participants relying on a selected set of validators and members accepting only the transactions previously accepted by their trusted validators (Wang et al., 2019). Proof of Authority (PoA) in fact is a reputation-based consensus algorithm, based on the grant of special validation permission to one or more members in the system, not based on the "stake" of their wealth but on the "stake" of their reputation (Wang et al., 2019). Since the model relies on a limited number of validating authorities that act as moderators in the system, that is therefore fast and highly scalable. Even if it represents a more centralized approach, it can be appropriate under certain circumstances involving regulatory bodies and therefore is increasingly used by utilities in the energy sector (FlexiDAO, 2020).

Finally, a new consensus mechanism was developed specifically to embrace the collaborative nature of RECs. Proof of Cooperation (PoC) is born from the alliance between the blockchain startup Pylon Network and the cryptocurrency for sustainability Faircoin, which calls itself the "cooperative version of Bitcoin" (FairCoin, 2020) . The community decides which candidate will have the ability to find and sign blocks called 'Collaboratively Validated Nodes' (CVNs) that cooperate to validate transactions and secure the network, so each one has their turn to find a block and be the first to validate it (Pylon Network, 2018a).

With the advent of blockchain and its continuous development, early adopters of this technology could exploit its advantages also in the energy sector and jointly satisfy the threefold need of customers of a more decentralized, distributed, digital energy future. In particular, the energy sector is one of the most advanced in terms of blockchain adoption and the expectations around this technology is both of high impact but also high uncertainty (World Energy Council, 2018).

4. Theoretical background

The aim of this section is to deepen the reader's knowledge about the Multi-Level Perspective (MLP) and its three levels of the niche, regime, and landscape. Furthermore, a specific section is dedicated to explaining the different transition pathways that the niche can follow to scale-up to the regime level. The aim of the present research is to operationalize the MLP framework to understand from the relevant energy ecosystem actors which pathway(s) RECs are most likely to follow in their perception, in this way the MLP perspective is used as a guide to interpret and categorize results.

Finally, a new perspective of the MLP is explored, that is the one of different perceptions of transition pathways by actors at different levels of the MLP and what happens when these perceptions are in conflict.

4.1 The grassroots innovation of RECs and the Multi-Level Perspective

A growing body of literature defines RECs as grassroots innovations (GIs), since they represent a bottom-up sustainable solution that does not only involve only the technosphere but also the social sphere (Klein & Coffey, 2016). This is because RECs imply the creation of new value networks to establish new social infrastructure, institutions, values, and priorities that are different from the ones of the dominant regime of centralized energy (Everett et al., 2012).

GIs normally emerge when dominant innovations are locked-in and sustainable initiatives develop at a niche (Seyfang & Haxeltine, 2012). Christensen (1997) explains how innovations tend to emerge in niches, defined as small market segments where their unique attributes are valued by early adopters. In these specialized niches, innovations are ''nursed'' and can achieve improvements that allow them to overtake the dominant design (Unruh, 2002). In the case of the energy sector, the centralized structure that has characterized it for decades can be correlated to the so-called “Carbon lock-in” (Unruh, 2000). The concept refers to how industrial economies have become locked into fossil fuel-based energy and transportation systems, due to path dependency of energy actors and increasing returns to scale of fossil fuel power plants, culminating in a techno-institutional complex (TIC) (Unruh, 2002).

Incumbents are not only conceptualized as locked in and path-dependent but they are seen as actively resisting socio-technical changes that are not symbiotic with the regime, by trying to form alliances with policymakers based on mutual dependencies, based on the concept of regime stability theorized in Geels (2014). Incumbents are conceptualized as developed firms that participated in the previous generation of products and services (Chandy & Tellis, 2000).

The most suitable theories to analyze this innovation transition from the niche to the meso and macro level are part of the strand of the literature of transition studies, that take into account the multi-dimensional complexity of the factor influencing the transition. Transition studies can differ in the research approach if the subject is a system innovation (SI) or an innovation system (IS). Despite similar nomenclature, the main difference lies in the fact that SI focuses on the influence of societal and technical factors for the provision of human needs like water, food, mobility, energy, etc. (Buth, 2018). The focus of IS, instead, is less oriented toward the environmental factors of influence and more focused on the innovation system itself looking at the economic and institutional factors that influence the innovation system (Buth, 2018). For this purpose IS literature uses the framework of technological innovation systems (TIS) (Hekkert et al. 2007; Jacobsson & Johnson, 2000). TIS focuses on system dynamics to analyze system components, known as functions, that interact in different ways to determine strategies (Hekkert et al. 2007; Wieczorek & Hekkert, 2012). IS literature can deal effectively with firm strategies and agency (Buth, 2018) and it focuses mainly on the economic and institutional system surrounding an innovation, whereas SI focusses rather on the societal and technological factors involved in the transition from one socio-technical system to another (Wieczorek & Hekkert, 2012).

For the present research, a System Innovation approach is considered more suitable since the innovation is not a commercializable product, but relates more to social dynamics between different market actors. In line with this approach, a Multi-level Perspective (MLP) approach was selected, since it focuses on the interrelatedness of processes at three different levels (macro, meso, and micro) within the socio-technical system (Buth, 2018). The definition of socio-technical system relates to: “the linkages between elements necessary to fulfill societal functions” (Geels, 2004, p. 900), in the case of the present research societal functions are intended as the provision of energy services. The concept of socio-technical systems aims to link the social and technical aspects of technology in the so-called "technization of society" and the "socialization of technology" (Elzen & Wieczorek, 2005). The goal is to recognize both interaction and interrelatedness of the two aspects and their implications for society as a whole (Vos, 2002).

In their analysis of the diffusion of Dutch energy communities, Dóci et al. (2015) classify RECs as social niches, that are different from market niches and technological niches. Social niches refer to specific social groups, organizations, or communities that develop innovative methods to address their own societal problems (Witkamp et al., 2011). As a matter of fact, community energy projects do not only embed the environmental goals of sustainability but also involve the social sphere and can be contextualized into the field of social innovation. The Young foundation drafted a report to analyze all the definitions of Social Innovation and came up with its own: "new solutions (products, services, models, markets, processes, etc.) that simultaneously meet social needs and lead to new or improved capabilities and relationships and better use of assets and resources" (The Young Foundation, 2012, p. 18). Consequently, technological innovation is not the focus of the niche but rather a tool for satisfying a new social need (Dóci et al., 2015).

4.2 The three levels of the MLP

The core of the MLP is that transitions originate and depend on the interaction processes within and among three analytical levels: niches, regimes, and a socio-technical landscape (Geels, 2002). "Each 'level' refers to heterogeneous configurations of elements; higher 'levels' are more stable than lower 'levels' in terms of the number of actors and degrees of alignment between the elements" (Geels, 2011, p. 26). The three levels are sketched in Figure 3.

This perspective was developed by Arie Rip and René Kemp (1998), and further refined by Frank Geels (2002). When innovations overcome the micro and reach the meso level, they establish a new technological regime, defined by Rip and Kemp (1998, p. 338) as: "the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems, all of them embedded in institutions and infrastructures. Regimes are intermediaries between specific innovations as these are conceived, developed, and introduced, and overall socio-technical landscapes."

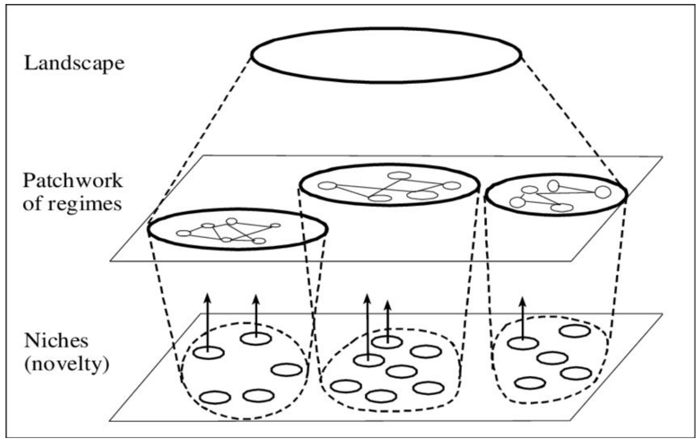

Figure 3.

Multi-Level framework for the analysis of socio-technical transitions. Source: Geels, 2002, p.1261.

The landscape level aggregates all the exogenous variables from the institutional environment that influence the present socio-technical system. This includes both political, social, and cultural norms and institutions. Geels (2011) brings the financial crisis, political ideologies or climate change as examples. Routines and institutions normally establish throughout long and gradual processes, but sometimes exogenous “shocks” can fasten the process. They are normally slow processes, but sometimes 'shocks' and faster processes occur Geels (2011). The basic theoretical understanding is that changes in the landscape put pressure on established regimes and force them to change. Geels (2011) also points out the importance of considering stabilizing as well as destabilizing landscape trends.

Below the landscape level, there is the socio-technical regime, conceived as a stable configuration of institutions, rules, practices, techniques, and networks that results in a set of norms for development and use of technologies (Rip & Kemp, 1998). These norms define the structure that accounts for the stability of the existing socio-technical system (Geels, 2004; Smith et al., 2010). This characteristic of stability makes the regime level central in the MLP perspective since change originates either from the landscape or niche level and needs to propagate to the regime level to create a new or different socio-technical system with other norms that define its stability (Geels, 2002).

In line with this, the regime has been described as a set of self-reinforcing regime selection environments (Geels, 2002; Geels & Schot, 2007; Smith & Raven, 2012) defined as ”a structure of interrelated factors that feedback upon one another, the combined influence of which gives rise to inertia and specific patterns in the direction of technological change” as Kemp et al. (1998, p. 181) write, and “not a set of factors that act separately as a containment force.” The aforementioned interrelated factors are; technologies and infrastructure, industry, science and knowledge, markets and users, policy and regulation, and culture (Geels, 2002; Geels & Schot, 2007; Smith & Raven, 2012).

The niche level is the lowest level of the socio-technical system. In this a protected, experimental space where the path-breaking disruptive innovations have room for development. This is why niches are called “incubators" for innovation rather than disruptive innovations per se (Geels, 2002; Geels & Schot, 2007; Kemp et al., 1998; Rip & Kemp, 1998). In fact, niches can still be conceived as socio-technical configurations, but smaller and less established compared to regimes. Anyway, niches differ from the regime because they represent “protective spaces” for the configuration and development of innovation (Schot et al., 1994). This initial protection is crucial for path-breaking innovations to develop and successfully compete with regimes (Smith & Raven, 2012).

For innovation to establish below the protected niche space, to the regime, a process of empowerment is needed. Smith & Raven (2012) described two main types of 'niche empowerment patterns', conceived as ways in which a niche innovation becomes competitive within the selection environment of an established regime.

- through a fit-and-conform empowerment: this is implemented by creating the innovation to fit the present regime and be competitive within an unchanged regime selection environment (RES). This implies that niches that follow this pattern are less revolutionary.
- through a stretch-and-transform empowerment: this is implemented by negotiating changes in the regime selection environment (RES) to favor niche innovation.

4.3 The transition pathways of MLP

The empowerment pattern of the niche determines also the interactions with the regime. These can be either 'symbiotic', meaning enhancing value and competences to the regime or disruptive, meaning destroying what is not aligned with the new regime and represents an alternative socio-technical structure Geels and Schot (2007).

It can be easier to spot disruptive innovation when applied to commercial products or services compared to social innovations. When, instead, a disruptive model relates to the social side, is referred to as catalytic innovation (Christensen et al., 2006). These type of innovations share some characteristics: the scale and replicate to create a social change, they satisfy a need that is overserved (with too much complexity) or not served at all, they offer a cheaper and simpler alternative that is considered good enough, they generate resources in terms of donations, intellectual capital, volunteering works and for this reason they are unattractive to incumbents and they are often ignored or even encouraged by existing players that consider them as unprofitable innovations (Christensen et al., 2006).

Besides the nature of the interaction, there is also one crucial dimension that influences the pathway of development, and it relates to the timing of the interaction between innovation and regime. This refers to the stage of development of niche innovation when the landscape pressure is applied. This is crucial since the niche innovation can be already quite developed (or empowered) or still at a pre-development phase, therefore not capable of reshaping the regime. A dynamic perspective of transition is represented in Figure 4.

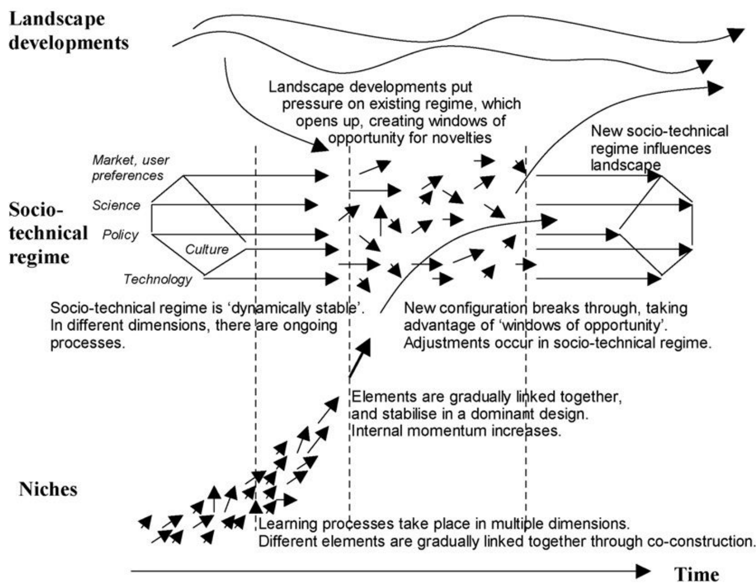

Figure 4:

A dynamic multi-level perspective on system innovation. Source: Geels., 2002, p. 1263.

The two dimensions of time and nature of the integration can be plotted in a matrix and result in four main pathways that are described in Geels (2011, p. 32), Geels and Schot (2007, p. 405-414) and Geels et al. (2016, p . 898-900) ans are represented in Figure 3:

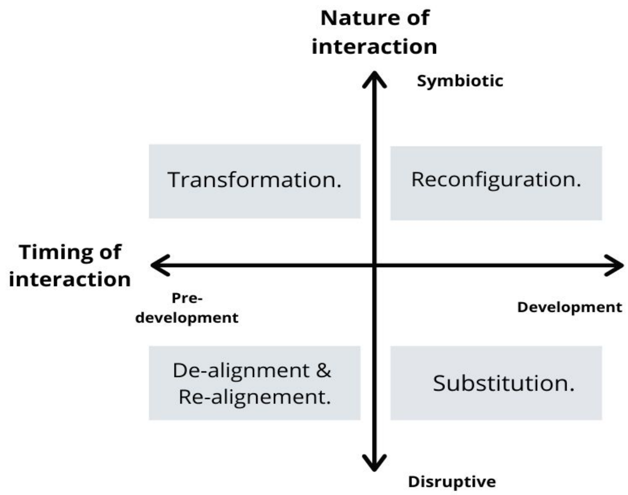

Figure 1:

Matrix representing the two dimensions and the consequent pathways of development of innovation

0. **Reproduction**: in case there is no destabilizing landscape pressure, dynamics are not altered and the regime will reproduce itself.[

1. **Transformation:** Socio-technical regimes change and adapt to one new dominant technology, as a reaction to landscape pressure. At the moment in which the window of opportunity is created, the innovation is not developed enough to completely change the present regime dynamics, but only to slightly modify them. This happens through a gradual re-orientation of incumbent actors toward the new regime.

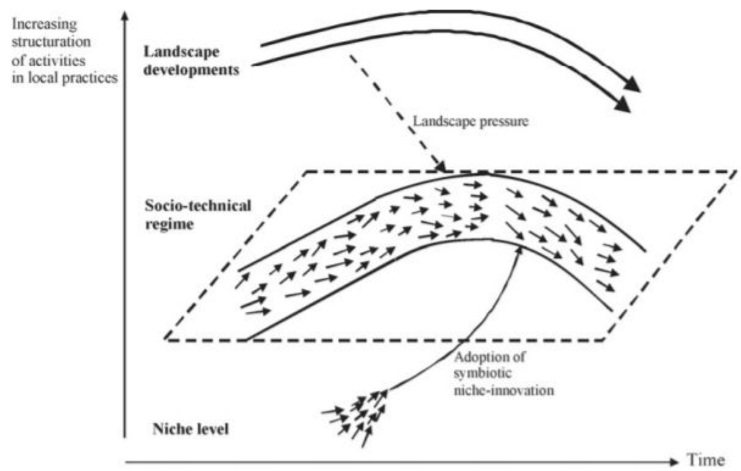

Figure 5:

Transformation pathway. Source: Geels and Schot 2007, p. 407

2. **Technological substitution:** The window of opportunity from landscape pressure, helps niche innovations that are already well developed to break through and replace the existing regime since they have a disruptive relationship with it. The innovative technology replaces the old one through a radical change in the regime

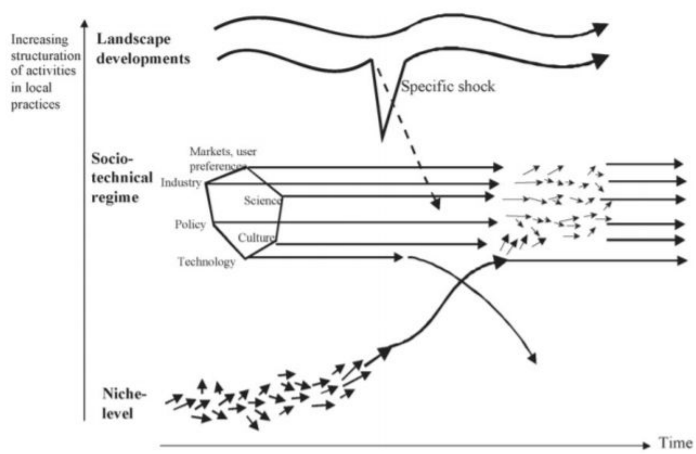

Figure 6:

substitution pathway. Source: Geels and Schot 2007, p. 410

3. **De-alignment and re-alignment:** The old regime starts developing problems and flaws and the new technology is more competitive in tackling these problems so it simply

overcomes the old one. In this case, landscape pressure shocks the regime from its foundations, causing it to disintegrate (de-alignment). The void created, leaves space for the emergence of niche innovations, but no one is developed enough to substitute the regime. Several niche innovations co-exist for a period of time and compete until one manages to establish as a new regime in a process of re-alignment.

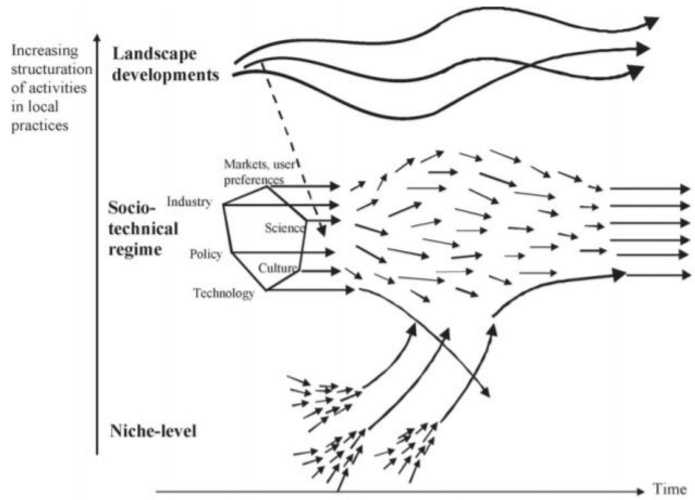

Figure 7:

De-alignment and re-alignment pathway. Source: Geels and Schot 2007, p. 409

4. **Reconfiguration:** Niche innovations develop a symbiotic relationship with regime and are initially adopted by the regime to solve local problems. The niche innovation is adapted to the broader regime context and the regime adapts to the niche innovation as well, therefore niche and regime combine to change the system framework. This can imply the formation of new relationships and alliances between incumbents and niche actors, with the consequence of fostering new knowledge, innovation, beliefs, goals that lead to new open-ended consequences.

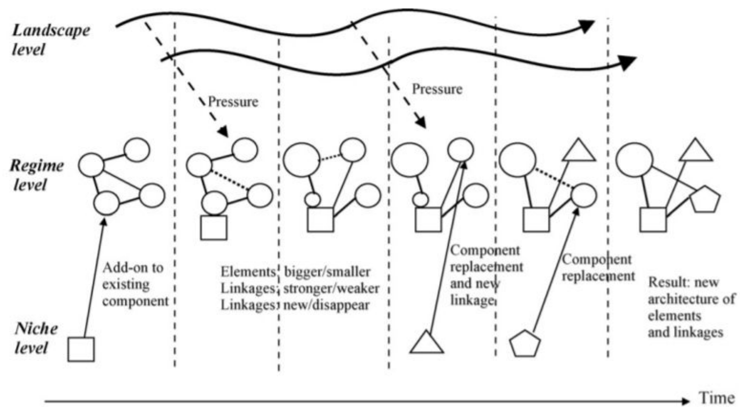

Figure 8:

Reconfiguration pathway. Source: Geels and Schot 2007, p. 412

Sequence: It needs to be taken into account that pathways are not mutually exclusive and can combine or happen in sequence (Geels & Schot, 2007), since actions and responses can exercise pressure and imply shifts between pathways. In case the landscape pressure puts pressure of a disruptive change on the regime, this pressure can take the sequence of transition pathways (transformation, reconfiguration, substitution, or dealignment and realignment).

4.4 Different pathways for different actors

Geels (2010) tries to answer to several criticisms moved to the MLP perspective like its lack of attention to the role of agency in transitions, the unsystematic work on case studies, the lack of time limits in the definition of transition (Smith et al., 2005; Genus & Coles, 2008) and the neglect of the social aspect compared to the technical ones (Geels, 2005). Shove and Walker (2007), instead, build their critique on the fact that the MLP perspective does not give insights on how actors can, might or should act to allow transitions to happen.

Nevertheless, none of the critiques addresses the fact that transition pathways in the MLP depend on the perception that relevant actors have of the innovation itself. These perceptions are inevitably shaped by the systems and social environments in which actors are embedded (Shove & Walker, 2007), consequently, they might differ between and across different levels of the MLP perspective.

The two parameters that determine transition pathways are the nature of the interaction between niche and regime and timing of the interaction when the window of opportunity is created. In case actors have different perceptions of the time of interaction, some of them might see the innovation as underdeveloped while some others might see ready to take over the regime and therefore adopt different strategies that might be conflicting. For example some actors might not see the risk of disruption in the short term and fail to act accordingly, or they might perceive the innovation as ready to take over the regime when it is not developed enough and lose faith in it.

The same is true if actors perceive the relationship between regime and innovation as disruptive while some others as symbiotic. This implies that strategies of different actors cannot be self-reinforcing and complementary, therefore making harder the transition itself. If actors perceive the relationship as symbiotic they would develop integration strategies and business model adaptations, if other actors perceive it as disruptive they will reject these models and develop strategies to be independent instead of integrated.

A key dimension of technological change is that it is path dependent, namely it depends sensitively on the past history that led to its current state (Foxon et al., 2013). Therefore, these misalignments can be due to factors like path dependency and all the dynamics of the carbon lock-in theorized by Unruh, for which learning effects and increasing returns of economy of scale lead to a process of "lock-in" that determines the exclusion of competing and possibly superior technologies

In conclusion, if actors have different perceptions, they will act accordingly to their vision of development and this might create a misalignment that translates into conflict instead of cooperation. Conflicts generally take time, effort and resources to be resolved, therefore constituting a barrier in the development of innovations.

Assuming homogeneity of perceptions is a limitation of the MLP perspective, when insead, different perceptions are very frequent, might explain why incumbents are disrupted: because they did not see it coming. They might not have seen the disruptive character of the innovation or they might have considered the innovation underdeveloped to take over the regime. This was theorized as the so-called "incumbent's course" for which large incumbent companies rarely introduce radical innovations to their business model, but rather tend to implement incremental innovation (Chandy & Tellis, 2000).

The other way around might also be true: a lot of the innovations see themselves as disruptive and already developed to take over the regime, while they might be developed on the technical side, but not on the institutional or market side.

Smith and Raven (2012) reviewed some case studies from Schot and Geels (2008) and concluded that expectations contribute to a successful development of the niche only when they are robust, in the sense that they are shared by many actors. In the present case, the other way around is true since expectations and perceptions are not robust, they are instead contrasting and therefore we can conclude they constitute a barrier for the development of the innovation. Unfortunately, the MLP model does not explain how to deal with different or conflicting perceptions of these dimensions by different actors.

In case of conflicting perceptions, it is not possible to draw conclusions about which pathway the innovation is more likely to follow, but it is possible to conclude that conflicting perceptions constitute a barrier in itself for the development of the innovation.

5. Methodology

This section aims to explain the different steps taken in performing the research, the different methods used, and how results were obtained. The section starts explaining the approach taken by the research to approach the subject matter and it is followed by a section that explains data collection methods and procedure. The section is concluded by explaining how data analysis was performed

5.1 Research intention and method

The intention of this research is evaluative, since it wants to investigate future possible scenarios of development (or pathways) of RECs and evaluate the role of blockchain in these different scenarios. In order to do this, the present research takes an inductive qualitative approach, for which theoretical conclusions are reached by analysing the data collected both through desk research and semi-qualitative interviews. It also takes a constructionist vision since reality is depicted building on the perceptions of different actors interviewed, trying to fulfill the aim of qualitative research to harness the analytical potential of exceptions, by describing a phenomena by different perspectives (Mays & Pope, 2000). It follows that apparent contradictions do not compromise the answer to the research question, but instead provide a broader scope for refining theories (Mays & Pope, 2000), like in the present case.

From an epistemological point of view, this research takes an interpretative function, in the elaboration of responses of different actors. In order to operationalize this, the empirical material collected through interviews and desk research is analyzed based on the theoretical framework of the Multi-level perspective. The steps taken during the research process are summarized in Table 2.

Concerns about validity are addressed in three main ways:

1. Data triangulation: data collection is based on mixed sources like databases, articles and academic papers and not only interviews (Somekh & Lewin, 2005, p. 50; Yin, 2013). In particular, knowledge about actors and institutions of the Spanish electricity system was mainly obtained by

the review of grey literature, while the knowledge about blockchain technology was mainly gained through interaction with experts during the internship period at FlexiDAO.

2. Theoretical saturation: saturation was reached as a total 19 interviews, when new interviewees could not contribute with any additional information in terms of drivers and barriers of development of RECs
3. Transcription verbatim: all interviews were transcribed before the coding process.

Table 2:

Steps of the research process.

Phase	Method	Outcome
1. Empirical exploration	Literature review (both white and grey literature)	Clear definition of concepts like prosumption, energy community and cooperative, etc..
2. Technical exploration	Literature review, conferences, workshops, interviews with experts	Clear definition of blockchain and it components, different use cases in the energy sector, different design architectures
3. Theoretical exploration	Literature review (white literature)	Clear definition of the three level of the MLP and all possible transition pathways
4. Data collection	Semi-structured interviews	Interviews both with niche and regime actors to map their vision about future development of innovation
5. Analysis of results	Coding with NVivo software	Three phases of coding guided by concepts derived from the exploration in previous phases
6. Reflection on the results	Literature review (grey)	Research of articles and official

		website to find real-life cases of the scenarios depicted by interviewees

5.2 Data Collection

Before the beginning of data collection, an entire process of preparation was implemented. This included both an in-depth literature review to define concepts like prosumption, energy sharing and collective self-consumption and have a clear picture of the context around the research. Also a technical review was necessary to define concepts like smart contract, consensus mechanism, energy tracking etc.. It was also necessary to define the theoretical structure through which results will be analysed, in this case the MLP, this helped to identify the relevant actors to be interviewed at the regime and niche level.

A more in-depth analysis of the Spanish energy system was carried out before approaching the interviewees in order to select a relevant theoretical sample. This took the form of extensive literature research to understand the structure of the landscape level of the Spanish energy sector, to map the regime actors and their role in the Spanish energy system and the types of configurations of innovation at the niche level. The theoretical sample of the study includes several representatives of different actors in the energy sector, that interact in the socio-technical regime and constitute its social network. Theoretical sampling was selected since it offers some degree of control compared to random sampling and it can be useful to also include "outliers" to draw conclusions also from deviant cases (Barbour, 2001). In the present case the theoretical sample aimed to incorporate representatives of both actors at the regime and at the niche level and also blockchain experts to complete the technical background.Theoretical sampling was driven by concepts derived from the research question and based on the concept of "making constant comparisons" (Strauss & Corbin, 1998, p. 201) more specifically niche and regime actors were interviewed to answer the first two research questions while blockchain experts to answer the last one. For each of the categories, subcategories were also created, more specifically:

At the level of blockchain experts, interviewees are part of:

- FlexiDAO: the world's first commercial blockchain application in the energy sector headquartered in Spain and the Netherlands

- Energy Web Foundation: a global nonprofit organization accelerating a low-carbon, customer-centric electricity system by unleashing the potential of blockchain and other decentralized technologies.
- Grid Singularity: as part of the Energy Web Foundation, thi organizations is building a blockchain software customized to enable P2P energy exchanges to enable a local energy marketplace
- PylonNetwork: a blockchain-based data facilitator for the energy industry, that developed a pilot project with one of the Spanish cooperatives

At the regime level, this includes:

- Spanish energy retailers, distributors and utilities
- The Spanish Transmission System Operator (TSO)
- The Spanish Distribution System Operators (DSOs)
- The Spanish Market operator

At the niche level this includes:

- Community participants of Union Renovables in Spain
- Cooperatives participants to ReScoop
- NGOs and activists for the advancement of energy democracy

An interview guide was also developed as a guidance for interview, to give structure to the question and make sure to obtain all relevant answers to the research question. Besides some introductory questions, the three main focus areas of the interview guide were: pathway of development of RECs in terms of timing and nature of the interaction with regime, drivers and barriers of this development, the role of blockchain in addressing these drivers and barriers. Sub-questions were also developed to trigger more detailed responses in some cases. Three different interview guides were developed for the three categories of actors in the market and they are attached in the Appendix.

Once interview guides were selected, interviewees were approached. They were all approached telematically due to the latest restrictions for COVID-19. In some cases interviewees were approached through the intermediation of the company FlexiDAO, in other cases, they were approached independently through Linkedin or through the official website of the organization. The interviewee list was enriched throughout the process by using snowball sampling, asking individuals to name other possible interviewees that might give valuable insights to the present research (Biernacki & Waldorf, 1981). In the present case for example one of the cooperatives interviewed collaborated with the organization Pylon Network for a blockchain pilot project and referred to one representative of Pylon Network in charge of the project, that was included in the list.

Responses were gathered through semi-structured interviews, this means that the interview guide provided some kind of structure to each interview, but still some degree of flexibility was preserved and each interview could deviate from the regular structure depending on the interviewee (Kvale, 2008). This flexibility given to the interviewees, increased also the variability of the length of interviews: while normally to complete an interview would take around 30 minutes, some of them lasted more than an hour. In general, the interview lasted from 19 to 85 minutes. Furthermore, previous interviews served to reorient some questions or create new ones to trigger more specific responses . This is why blockchain experts were interviewed first in order to get background knowledge about the specifics of the technologies, energy regime actors were interviewed as second to gain their responses and use them to trigger responses in the interviews with niche actors and catch the different point of view in terms of the nature of the relationship between the innovation and regime dynamics. The different role of interviewees in their organizations are reported in Figure 4.

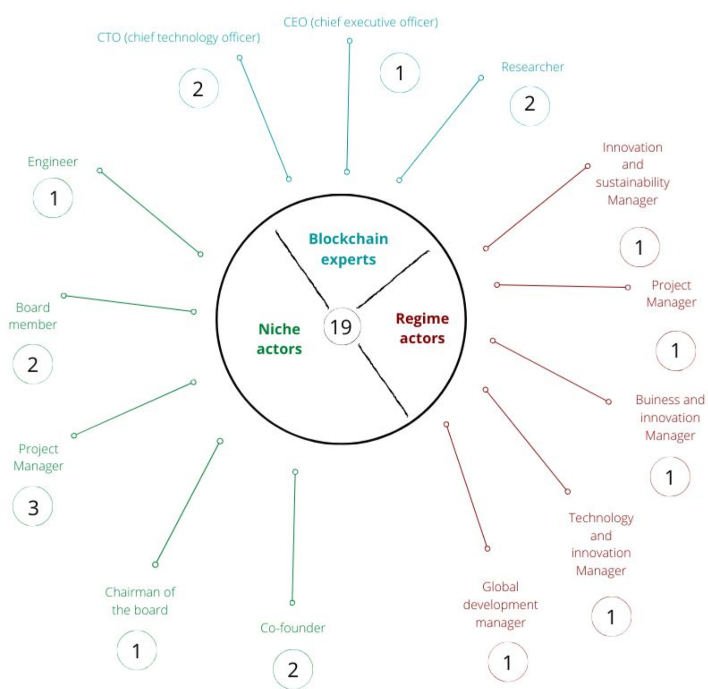

Figure 9:

Different roles of interviewees per category

In total, 19 interviews were performed: 5 with blockchain experts, 5 with regime actors and 9 with niche actors. The names of the interviewees are not reported to preserve anonymity and the names of the organizations are not listed either, as requested by interviewees that claimed that their responses cannot represent the company vision on such a "visionary" subject matter. Participants made clear several times that they were offering their personal opinion rather than expressing the view of the entire institution for which they work since on these questions there might be misalignments. Interviews were all held online due to the COVID-19 security measures and were all recorded using a phone in order to increase the accuracy of the transcription. Some of the interviews were performed in Spanish so they were translated directly in the transcription phase. The Otter software, based on Artificial Intelligence technology, was used to speed up transcription; it is a software used to generate notes for meetings but it reveals to be a useful tool to automatically transcribe recordings of interviews held in English. The outcome needs to be reviewed and corrections need to be implemented in the transcription, but it helped save quite some time in this phase of the process. Through these processes it was already possible to gain a deeper understanding of data collected.

5.3 Data Analysis

Once the first interview was transcribed, the coding process also started through the use of the NVivo software. The coding process involves breaking data collected into components that are labelled differently with codes (Strauss & Corbin 1998). "Coding means that we attach labels [concepts] to segments of data that depict what each segment is about." (Charmaz, 2006, p. 3). These codes are emerging and can progressively increase or change during the process, since they derive from the constant comparison between data and concepts. For example, responses related to pathways were initially coded into "transformation pathway" or "dealignment and realignment pathway", but during the process this changed and responses were coded into the different dimension of pathways "nature of the interaction" and "timing of the interaction", in order to spot more clearly were the differences in perception came from To do this, it was essential to enter the research situation with some degree of background knowledge, like in the present case about pathways of development; this is defined by Strauss and Corbin (1990) as "technical literature" that in this case included concepts from both the empirical, technical and theoretical knowledge explained in the previous chapters. As a matter of fact, the analytical and theoretical framework guided the coding and interpretation of interviews' responses to fit into the MLP conceptual framework.

The coding phase started as soon as the data collection began in an iterative and progressive process with evolving coding categories. The first round of coding allowed to understand concepts at a higher level. This allowed to code some of the highlighted drivers and barriers into concepts like "increased willingness of independency and to be sustainable" or "managing more people in an horizontal organization" for example. The second phase included axial coding, that relates different concepts into categories, their characteristics and their relationship between themselves. For example "environmentalism" or "independency" were both concepts pertaining to the category "reasons of development of RECs". This process was aimed to find patterns in responses and link them together into categories to a more abstract level. This was an essential step to understand to what extent can blockchain be an enabler of the transition, by leveraging the highlighted drivers and helping to overcome the highlighted barriers. All concepts and categories are summarized in the Appendix.

The last step of selecting coding allowed to isolate the core of data that constitute the contribution to theory, namely the opposition of view regarding the nature of interaction between the innovation and the regime. This helped to create a formal theory that is applicable at a higher level of abstraction, in every case perception of actors differ between different levels of the MLP perspective.

6. Results

This section is subdivided into five main subsections: the first three aim to describe the three levels of the MLP: landscape, regime, and niche. Descriptions are based on desk research and complemented with insights derived from interviews.

In the landscape section, the implications of the new regulations are explained and described as a "window of opportunity". In the regime section, different roles of different actors are explained and their responses in interviews are summarized and sometimes transcribed in the form of quotes. In the niche section, a brief history of the development of RECs in Spain is followed by the responses of the interviewee.The last subsection regards the possible pathways of development of RECs, confronting the vision of incumbents from the regime level to one of the innovators from the niche level, that differ in the perception of the nature of the interaction between the innovation and the regime. This implies two possible pathways of development of the innovation that is explained in detail, both in a theoretical way with concepts derived from literature and in a practical way with examples and opinions derived from interviews. Finally, a section is dedicated to the role that blockchain can play in these different scenarios.

6.1 The landscape level and the window of opportunity in Spain

At the moment direct peer-to-peer trading between consumers and independent prosumers or communities owning a renewable generation asset, is not fully legal in Europe. Nevertheless, the European Union has recognized the importance of RECs and is working to remove barriers for their diffusion; 2018 has represented a turning point in the field of self-consumption with the removal of several political, economic, and administrative barriers (UNEF, 2018).

From the higher level of the landscape, in Spain, a window of opportunity was created on April 5, 2019, when the Spanish Government approved the Royal Decree 244/2019 that regulates the conditions of self-consumption, driven by Royal Decree-Law 15/2018 that repealed the so-called sun tax, that implied extra cost to self-consume energy produced with the owned PV panel. The concept of the sun tax would measure costs based on the energy consumed, the higher the ratio of self-consumption the higher cost, implying a clear disincentive for the development of prosumption. “That would be like paying a charge if you grow tomatoes on your windowsill and then eat them yourself” comments Sebastian Mang, climate and energy policy adviser with Greenpeace EU, in an interview (Simon, 2017).

The work of Romero-Rubio and Díaz (2015) compared the diffusion of sustainable energy communities in Germany and Spain and attributes the low diffusion of this model in Spain to the drastic cut of incentives and that RECs have not been favored by the previous Electric Sector Law (Law 54/1997). Therefore, the approval of this decree signifies an important step toward energy democracy and Spain is the first European state to support it through public policy. This support translated into a substantial development of renewable power plants in the country, positioned as the pioneer of the solar boom in Europe with 4,7 gW of newly photovoltaic installations, overcoming both Germany (4 gW) and The Netherlands (2.5 gW) (Burger, 2019). This therefore makes Spain a very relevant case of analysis.

When interviewees were asked if they consider the new decree as a window of opportunity, the majority responded positively. At the regime level it is seen as a big opportunity, but more for commercial than residential entities:

That's clear now because there has been a movement in the sector. There are many consumers that are interested in the establishment of a shared self-consumption system. Mainly the interest is from the commercial side, from the industry, more than residential customers. There are some forecasts that say that in Spain there will be a 3 gigawatt increase of self-consumption for 2025 (Regime actor).

At the niche level it is also recognized as a good opportunity, but with many unknowns still:

Enabling collective self-consumption is a good achievement, but the legal figure is still unclear and very few neighbors' communities have made the attempt. [...] However, there are some barriers to this: bureaucratic processes are more complex, one supply point can only be supplied by one supplier, which effectively prevents a large prosumer to serve its neighboring consumers and there is no specific regulation for power storage (Niche actor).

Respondents from the niche level highlighted several practical barriers in their experience. "They don't know what to do with us at the administrative level" (Niche actor) and "Is still too much paperwork" (Niche actor). Furthermore they are still waiting for regulations that go beyond allowing self-consumption legally and directly incentivizes RECs at an economic level.

In conclusion, the new regulation is considered as a window of opportunity for the innovation to develop, but is not considered as a sufficient incentive to drive their development. The regulation is changing the landscape because it finally allows RECs to exist and to enjoy the economic benefits of energy self consumption (without the sun tax) but it does not give a real financial support to their development.

6.2 The regime level

The supply chain of energy is very different from the one of every other commodity, especially due to the lack of well-developed storage structures at the moment. This implies that the energy market is the only one in which we can see the instantaneous clearance of supply and demand.

For Spain, the electricity market is the Iberian Electricity Market (MIBEL), born as a result of the Protocol for the Cooperation signed by the Spanish and Portuguese Government in November 2001 (Crampes & Fabra, 2005). The Spanish energy sector was liberalized in 1997 (Crampes & Fabra, 2005). This also implied a clear separation of the roles of different actors involved in the supply chain of energy (generation, distribution, and consumption) and this implied a division of powers, but also a high degree of cooperation required between regime actors. This resulted also into a coordination in lobbying activities and a high degree of path dependency.

The phase of the supply chain of energy from production to consumption, involves several actors with different roles (Pylon Network, 2018b):

- Production/ generation of electricity either for their own consumption or for third parties. **Producers** can generate it from thermal sources (coal, fuel, nuclear, combined cycle) or renewable sources (solar, wind, biomass, ...)
- Control of production and the establishment of price. **Regulators and Market Operators** manage the auction system for the purchase and sale of energy in the daily market. Their responsibility is to match supply and demand and re-adjust the final price considering technical constraints, depending on grid congestion, generation zones, network load. The Spanish market operator is OMIE.
- Transport of the product. The **Transmission Operators** take care of the operation of the transmission electrical system (the national grid) and are responsible for ensuring grid security and managing energy smoothly. The Spanish TSO is Red Eléctrica de España that has a natural monopoly, so the legislation states that anyone can use their services in exchange for a usage tariff (established by the State).
- Distribution of the product. **Distributors** have the responsibility to expand, maintain, and operate the distribution network that transfers energy to the final consumer. Spanish distributors are Endesa, Iberdrola, Union Fenosa, HC Energia, Enel Viesgo and they have a monopoly on different geographical areas.
- Sale of the product to the final customer. **Marketers or Utilities** supply the electricity to consumers that are free to choose their marketer and agree on a set of contractual conditions.

At least one member representative of each actor in the market was interviewed. All the interviewees declared that the institution for which they work is committed to being part of the renewable energy transition and some classified themselves as “pioneers” others as “proactive”. As a matter of fact, the importance of renewable energy in Spain is growing and this was quite clear to all the actors involved.

Regarding the role of prosumers and RECs in this transition, responses were quite unanimously related to their integration in the system and everyone recognized that “The future is consumer-centric.”

> I think their role is going to be an important role because the energy system is changing. Everybody's talking about the energy transition not only for renewable, or avoiding the CO2 emissions, but also because we need to involve the customer. So, everything is changing, especially transportation with electric vehicles and the charging system for them. (Regime actor)

Regarding the pathway of development of RECs, the general view is that their innovation is still at a pre-development level:

> We are still in an early phase of small pilot testing. So we have several, cheap pilots almost everywhere, but they are still small pilots. So, for sure this is not the moment and probably all the installation for the storage is still very expensive (Regime actor).

> My point of view is they are a promising option but there is a lot of work pending to be developed, so they are still in the pre-development phase because I think it has a lot of big regulation components here that shouldn't be that easy to change (Regime actor).

Regarding the relation of communities with utilities and energy retailers there were no doubts:

> Symbiotic for sure otherwise utilities would be killed. The distributed generation is changing the residual curve at high tensions. It's not about symbiosis or toxicity, it's a question of adapting to the direction in which the world is going, and we need to keep up. We are talking about resilience, accepting this new way of doing energy, end of the story (Regime actor).

Representatives from utilities but also from TSOs and DSOs see a lot of possibilities of collaboration with energy communities. When asked how they would have to change their business models to adapt to the changing market, the responses changed slightly. Some responded that what they offer more than RECs is stability and reliability, therefore this will be their role in their future, since it cannot be substituted:

> We have demonstrated for years that a grid like Spain, that is very reliable, is an essential shoulder also to a system of micro-grids where people can share energy. From our network business is that people can develop or share and participate in different services. But the criticism here is that the grid needs to be reliable in every situation and balance all the energy of the entity that cannot be done in a reliable way, by a lot of independent entities like microgrids (Regime actor).

On the other side, the majority of actors recognized the need to change their business model to adapt to a changing market that is becoming more and more consumer-centric:

> We asked ourselves this question before the others, so we are already entering a transition. We already made our calculations and see the extraordinary opportunity for all. It can be a disruption if you do not move, if you ride the wave is an opportunity (Regime actor).

But also "The objective is to connect prosumers and communities to the energy and transition system and to make this work as a transparent institution (Regime actor)."

The main highlighted drivers and barriers to the development of RECs are institutional and economic, depending on favorable regulation and cheap prices of PV panels. A translation in english from an interview with a regime actor highlighted:

> Technical barriers of connection, since they need to coexist in the context of quality of electricity. It cannot be produced at its own condition because there are precise standards on home appliances. The regulatory barrier is there because communities manage the energy commodity in an extremely regulated way. Without regulation, it would never work. This can be the Spanish case with favorable regulations supporting it. If it will work, maybe they will write European legislation with part of its DNA based on the Spanish regulation (Regime actor).

In conclusion, the regime has a very complex structure in which every entity has a very specific role and needs to strictly collaborate with the others, creating a system of interdependencies between energy actors. All the actors interviewed recognize that the energy sector is changing fast and transitioning toward a more decentralized model of production, nevertheless they envision this change as symbiotic with the regime. They see a symbiotic development in which they can integrate decentralized energy sources in the system by adapting their business model to new market needs and collaboratively offer energy to consumers by collaborating with prosumers and RECs. At the same time they see that the innovation of RECs is still at pre-development, facing several economic institutional and technical barriers of development.

6.3 The niche level

The concept of RECs originated from activists for clean energy and they found that current policies in practice were not good enough or facilitating the transition for consumers; it was more for large companies and investors. A translation from Spanish to English reports:

> It was 2010 at the beginning of an economic crisis, with implications both social and environmental aspects, there was this idea to start something coherent with their values of sustainability, but it wasn't materially possible at that time. Renewable Energy Communities and Cooperatives are manifestations of a movement. At the time it was easy to become a member, with an investment of only 100 euros in equity as a deposit. Som Energia was the first one in Spain. It developed in the context of Spain's socio-economic crisis and with substantial regulatory limitations to put your own solar panel with the SUN tax (Niche actor)

RECs represent real “movements” and this is testified by the fact that they are much more than energy sharing. For example the oldest cooperative of Spain, Som Energia, partners with municipalities to identify cases of poor energy households and tries to cover their bills at a community level; or it allows members with lower income to share their membership with five extra people without extra cost (Kunze & Becker 2014). They also created a twin service Som Mobilitat that offers members car-sharing options and makes it available to poorer neighborhoods (Caramizaru & Uihlein 2020).

The main factors that triggered the development of energy communities can be categorized in three main ideas: independency, environmentalism, and economic benefit. The first idea was expressed through terms like “Energy sovereignty” and “Energy democracy” this also related to a lack of trust in energy companies or better:

> A certain and annoying feeling that we, consumers, are being fooled by large energy companies, which take advantage of the total lack of understanding of end consumers, to charge abusive prices to power and gas. These models wanted to allow consumers to become their own suppliers and, as a result, climb up a position in the supply chain, absorbing the margin that corresponds to retailing companies. Since utilities have been privatized, and a vital supply as power is now purely driven by private profit-seeking strategies, cooperatives can socialize the service and try to improve the situation of end-consumers (Niche actor).

The second reason relates to the fact that “Activists for renewable found that policies in place were not good enough or facilitating for consumers, they were more tailored for large companies and investors. So they created a new model” (Niche actor).

This directly translates into the perception of the relationship between RECs and utilities, which is described as “disruptive” by the niche actors. This is due to the fact that:

We profoundly distrust them (utilities), and we have objective reasons to do so. However, playing Quixote against them doesn’t seem to be a fight we can win. Its development will be accepted by large utilities as long as they continue to make large benefits (Niche actor).

As a summary: “Energy as business or energy as Service” it was declared. None of the respondents defined the relationship as “symbiotic” but one of them observed some affinities: “They can help each other; they do not remove the role of utility but as today if the utility is also a retailer and TSO then it is also a competitor.”

Regarding their stage of development, opinions were not that unanimous. Some respondents said “Pre-development. Most energy communities are too small to have a serious impact in the energy market” (Niche actor). Some others said they are moving the first steps: “Once energy storage systems are commercially viable, the level of development will be much higher” (Niche actor). Some others said they are growing: “I would say take-off. New technologies are emerging and at better prices. Social conscience is growing up as well” (Niche actor).

Regarding drivers and barriers of their development, the two main factors of influence that were mentioned are institutional and economical. In the Spanish case, legislation is creating a driver more than a barrier:. “Legislation is generating a very big opportunity. So, we hope that it will become a milestone for new development of new decentralized energy production with many prosumers. It is very good news, opening a lot of opportunities for coops” (Niche actor).

Nevertheless, this opportunity leaves a lot of administrative gaps that create difficulties for RECs development:

> In terms of access to financing is limited for small companies, plus banking funds don’t really know how to consider RECs and ask for more guarantees than a limited liability company. So, we need to look for alternative finance like specific funds or ethical banks (Niche actor).

In terms of barriers another recurrent response was the lobbying power of utilities: “Incumbent players are pretty determined to keep the market to themselves. And they know how to lobby and play the game” (Niche actor) but also problems related to the decision-making structure of RECs:

> Communities and cooperatives need to act like normal companies, but their structure is not the same, is much more horizontal and not very hierarchical. This translates into a slow decision making because of the clash between members that are more “firm oriented” that recognise that at the end of the day cooperatives need to act as energy retailers and accept some market rules, and the “dreamers" that are more idealistic. In our cooperative, it works that one member has one vote, and is not based on shares, even if some members are more involved than others (Niche actor).

In conclusion, energy communities and cooperatives emerged from environmentalists movements and a desire for independence of energy consumers. The innovation of RECs is developing in Spain and some actors see its taking-off while some others see it at a pre-development phase. Anyway none of the actors affirmed that the innovation reached its full development. Differently from regime actors, they do not see the innovation of RECs developing collaboratively with the regime since they don’t conceive energy as a business but more energy as a service. They feel threatened by the role of regime actors and their lobbying power that they consider as one of the main barriers of development, coupled with financial and administrative barriers.

6.4 Transition pathways of RECs

At the time of interaction, when the window of opportunity was created, RECs innovation had not reached full development yet. Or at least is not developed enough to take over the regime. All interviewees at the regime level agree on this point and also the majority of interviewees at the niche level. The most important point of discussion of the present research regards the different perceptions of actors at the regime and niche level about the nature of interaction between them since at the regime level the relationship is seen as symbiotic, while at the niche level is seen as disruptive.

This contrast leaves open two possible empowerment of the niche: a fit-and conform empowerment in which niche innovation needs to adapt to the regime rules or stretch-and-transform empowerment in which changes are negotiated between niche and regime actors leading to the creation of new institutions in the regime. This consequently leaves open two possible transition pathways: a transformation pathway and a dealignment and realignment pathway.

In case the nature of the interaction is symbiotic, the innovation of RECs might follow a **transformation** pathway. In this pathway the pressure generated at the landscape level is moderate and it occurs in the early stage of development of the innovation. When the window of opportunity created the innovation is not developed enough to change the regime, but the pressure from landscape triggers anyway a change on the regime, that reorients and transforms as a reaction to the upward pressure of the landscape (Geels & Schot, 2007). This pressure may imply an initial resistance at the regime level, but at some point, it leads regime actors to adapt to the change and re-orient their trajectories (Geels & Schot, 2007).

In the present case the clear support of the European Union and the Spanish government to prosumers and energy communities triggered some gradual adjustments in regime strategies and priorities. This scenario implies that regime actors are aware of the pressure to change from the landscape level and to adapt to the new consumer-centric trend in the industry and that this adaptation involves the integration of decentralized energy sources (that might be independent producers, prosumers and RECs) without radical changes in their business model, only adaptations.

This is in line with the conception of Geels (2014) for which regime stability is the result of the active resistance to change of incumbent, but when incumbents have to deal with disruptive innovation, at one point they need to commit to other strategies to avoid disruption. As a matter of fact, regime actors can be considered incumbents of the market and they can develop several different strategies to change and adapt their business models to avoid disruption and be resilient to change. There was a reflection from one of the regime actors about the changes that utilities will have to face due to this paradigm shift on the consumer side:

> Commodities are products with very low marginality. We are totally inverting the paradigm, we don't sell commodities anymore, we sell something else and commodities become the added value. Today every client that buys a solution of distributed generation, then asks what price would be also to buy energy from you? The energy is the added value while selling a solar panel. I always make this example: Illumia sells batteries for your home appliances (is still energy), Apple sells the iPhone already charged (energy is embedded in it), toys are sold with batteries already loaded. Commodities will be more and more embedded into other services and may be taken for granted. This means that business models could change exponentially. Vertically integrated operators sell electrons and offer other services from solar panels, compressed air to relamping, that are all commodity centric. This is a paradigm shift: I buy distributed generation and since I buy less from the grid you make me an offer for the commodity that I still need to buy for balancing services. It's like leasing a car and buying it all included with insurance. (Regime actor)

Some others reflected on the fact that:

> If utilities are smart they don't take them as competitors but rather they try to partner up. It depends on how open and how innovative the mindset is in utilities. And how much they think in the long term. Usually utilities are at the conservative end and they don't see that is spreading. If they would see an opportunity, they would change the mindset. (Regime actor).

Unfortunately, not all utilities are that forward-looking, but this reflection offers a perspective of a sustainable scenario of cooperation and adaptation to a changing market in a changing world.

In fact, a lot of energy companies have already started to morph from energy providers to energy service providers (Laclau, 2019). These strategies may regard the integration of decentralized energy sources (DERs) by concentrating on their coordinated control and strategic management. EY, one of the big four of consultancy firms, already asked themselves the question" Do tomorrow's energy customers pose an opportunity or represent a threat (to energy companies)?"(Laclau, 2019). In their analysis generators can adopt two strategies: one regards cutting costs to remain competitive in terms of grid parity, the other one is to carve themselves a new role as providers of reliability and security of the energy supply (Laclau, 2019). This is expressed also in the whitepaper published by the Omnetric Group, a joint venture of Accenture and Siemens, in which the possible strategies that utilities can take to react to disruption are summarized in three main roles (OMNETRIC, 2016):

- They can become a collaborative partner of communities providing consultancy and maintaining a seat at the table in case of new developments
- They can become service providers for communities, in terms of enabling technologies and balancing services to become business partners
- They can become platform providers to optimize energy management and optimize consumption and production of the community while increasing energy security and grid stability at the same time

Networks must abandon the idea of one-way energy flows and concentrate on optimizing multi-directional flows of supply and demand from decentralized sources (Laclau, 2019). A practical example can be found in Repsol, a global fossil fuel company based in Madrid, that recently developed a project called Solmatch. In the official definition, Solmatch is defined as "the first large solar community in Spain" (Repsol, 2020). The project is in line with the goals of Repsol to become Net Zero emissions by 2050 and it includes the design of solar communities in urban centers. It basically adapted the business model to the new window of opportunity of the new shared-self consumption regulation that allows energy sharing in a ray of 500 m. Repsol puts in contact with independent prosumers that agree to have a PV panel installed on their roof (Roofers) and consumers nearby (Matchers), located at a maximum distance of 500 meters so that they can exchange local energy (Repsol, 2020). It is described as a new energy model that brings environmental benefits of consuming local energy and economic benefits to make the most out of the potential of rooftops to become renewable energy assets (Repsol, 2020).

In this case, this conception of community energy fits into the definition of "energy sharing" highlighted in the previous paragraph, in which each prosumer produces its own energy and decides to sell it to strangers and then create a community. This differs from the concept of "collective self-consumption" in which first the community is born and then decisions are made at the collective level on how to administrate the energy sources and the consumption model.

Niche actors do not recognize this model as an energy community because it completely misses the social component of producing and consuming energy together and furthermore completely eliminates the component of independency from utilities and energy retailers, highlighted as one of the main triggers of the development of RECs. They recognise a model of "collective self-consumption" in which the social part involves a collective management of the resources.

Niche actors, in fact, envision a disruptive relationship with regime actors, implying a **pathway of dealignment and realignment.** In this vision, the landscape pressure on regime implies a type of change that is divergent from the present pathway and highlights the problems and flaws of the present regime (Geels & Schot, 2007). The regime starts eroding and the "hollowing out" of the regime leads to a "vacuum", since niche innovation is not yet developed enough to completely substitute it and they are still at the embryonic stage (Geels & Schot, 2007). In order to fill the gaps created in the present system, multiple niche innovations emerge and compete against each other; this period of co-existence of several innovations continues until one gains momentum and becomes dominant. This implies the re-alignment and re-institutionalization of a new regime (Geels & Schot, 2007). In the present case, the falls in the regime are highlighted by the diffused mistrust in the present system. Furthermore, consuming from the grid cannot guarantee a 100% sustainable consumption, since all types of energy are mixed. This created the need of more sustainable and local solutions that were supported also at the landscape level. Consequently, different models of local self-consumption emerged, ranging from sustainable neighbors, smart grids, energy cooperatives, and so on. These different models will coexist for some time until one model takes over as a dominant design and establishes it as a new regime.

During interviews they were triggered to comment on the response of regime actors that describe a collaborative future, they demonstrated to be actually quite threatened by the possible scenario described by utilities.

> The problem is that large utilities are making a large effort in order to convince prosumers to remain with them, offering service packages in which the company acts as the retailer, the installer of solar panels and the ESCO for the O&M of the panels. This way, utilities enter into a segment with higher margins and become service providers instead of retailers and the "independence effect" is lost, since the energy is still under the control of the large utility. They try to change everything so that everything remains the same (Niche actor).

Niche actors are categorical in their opinion, since the activity of RECs was mainly born from the mistrust in actors at the regime level and the need for independence. Ritzer (2019), based on the research of Alvin Toffler, highlights that prosumption was born from the desire to end the capitalistic paradigm of exploitation of the means of work possessed by producers. The whole idea of prosumption represents a way to reverse the complexity of globalized supply chains, scattered around the world, and to decrease the asymmetry of information between buyers and producers. This makes it very unlikely the idea that prosumers will have a symbiotic relationship with utilities in which they adapt to the current system without any compromise.

As the Respol case represents a real-life case of the configuration resulting from a transformation pathway; on the contrary, a dealignment and realignment scenario is represented by the attempt of Grid Singularity to create independent local community exchange of energy. They developed a software called D3A. "With a D3A exchange, households are provided with a choice to buy energy first from neighbors that have an energy surplus, rather than to automatically resort to more expensive energy supplied by the utility at a flat rate. Likewise, households that produce surplus energy are enabled to sell at a higher price locally rather than at the feed-in tariff rate offered by the utility." (Grid Singularity, 2019). This model is able to exclude the role of utilities and let consumers and prosumers to autonomously manage their transactions through smart contracts. Still it does not entail a "collective self-consumption" model, in which energy sources are managed collectively like for example some of the blockchain pilot projects implemented with single communities like Som Energia (Spain) or Jouliette at De Ceuvel (Netherlands).

In conclusion, regime actors envision a transition pathway of transformation, while niche actors envision a dealignment and realignment pathway; both pathways are possible but they are mutually exclusive. This tension that exists between both futures represent a barrier and a fundamental challenge for all actors. On one side, energy companies envision a collaborative future in which they integrate the RECs model into a process of servitization of their business model, for this to happen RECs would need to gave up to their component of independency from energy companies and to some of the social structures entailed in a community model. On the other side, niche actors dream of a future of energy independence and democracy, but for this to happen they would need to eradicate the role of energy companies. Even if both actors are aligned about the need of an energy transition toward a more decentralized model, their vision differs since they have different values, moralities and visions about the energy future. These differences in perspectives and values, implies a misalignment in vision and constitutes a fundamental struggle for the development of RECs. These inconciliable perspectives represent a dichotomy that constitutes a barrier in itself for the development of innovation.

6.5 The role of blockchain

Blockchain is not to be conceived as a fixed technology but can take several configurations and designs to adapt to the function it needs to fulfill. Consequently, there is not only one future scenario that is unlocked by simply promoting blockchain technology, but it needs to be analysed what role can blockchain take in different scenarios, what functions best fits the needs of actors and what design configurations are more suitable to fulfil them.

In a transition pathway of transformation, blockchain can take on the functionality of transparency and certification. In this scenario utilities and retailers can act as mediators between independent prosumers and nearby consumers, by matching their production and consumption curve and creating a new type of community, while providing balancing energy services from the grid, like in the Repsol case described above. If energy retailers act as mediators in the transactions, blockchain can take a certification functionality and prove that the energy is coming from the specific community by matching in real-time data of production and consumption, through the tokenization of electricity. Certification is done through the automatic assignment of a certificate, that comes bundled with the energy transferred and shows when, where, and how much energy was produced. Energy tracking on blockchain is the only possible way to have real proof that the energy consumed comes from the specifically selected community.

Utilities and retailers can provide balancing services from the grid in case the consumption curve does not match the production curve of the community. In this scenario, the most suitable design for the technology includes a Proof-of-Authority consensus mechanism in which energy retailers represent the authority and act as central hubs in the distributed renewable energy ecosystem. With PoA based blockchains, utilities and energy retailers can integrate small-scale renewable production, distributed generation, flexibility services, and consumer participation in the energy market. In this scenario, the main functionality of blockchain would be to increase transparency and traceability of energy.

Finally, it was expressed the thought that blockchain momentum is now and the need for a decentralized infrastructure might disappear in the future if public bodies might create more rules, standards, and certification for RECs:

> The more we wait the more is the risk that blockchain becomes useless. If we create a certification mechanism that applies the same rules to every community, blockchain loses its purpose. We need to use it now, it's a matter of timing. It's like 5 years ago when Tesla was building electric cars and now everyone does (Regime actor)

Drivers and barriers highlighted by interviewees in this scenario are related with the consequent blockchain functionalities in Table 3. In this scenario blockchain can constitute an enabler in terms of:

- **Tracking the source of energy:** if utilities and retailers want to integrate RECs in their business model and create new virtual energy communities, they need an instrument that is able to track where the energy exchanged comes from
- **Certification:** through the so called process of “tokenization of energy” blockchain can assign a certificate to every energy token exchanged to guarantee from which energy source does it come from, where and when was produced and eventually can be coupled with the existing european energy certification mechanism of Guarantees of Origin (GOs)
- **Increase transparency**: the digital notary of blockchain keeps track of every transaction that happens in the system (both in terms of energy and money flows) and is accessible to all participant anytime

- **Services' integration:** tracking energy (and money) flows with blockchain can help to complement energy services when the RECs are not producing enough to satisfy consumers' demand and directly provide energy from the utility through complementary services. The same is true if the energy produced is higher than the supply, in this case energy can be distributed by utilities through the grid to other consumers.
- **Cheaper, faster and more transparent contracts:** through the use of smart contracts energy exchanges can be regulated through predetermined rules and protocols agreed upon by utilities and prosumers of RECs and once conditions are agreed upon by both parties, contracts are automatically implemented. The enforcement is automatic and does not require third party validators, implying considerable money savings.

Table 3.

Summary of results of regime actors, obtained by relating the highlighted drivers and barriers with possible blockchain functionalities.

Drivers and Barriers	**Blockchain can be an enabler**	**Blockchain cannot be an enabler**
Institutional (regulations)		• Cannot help on the institutional side
Economic (electricity prices)	• Cheaper and faster contracts enforcement	
Technical (technological infrastructure and reliability of the grid)	• Allows transactions of the energy on ancillary services out of communities	
Governance (services to the grid)	• Increase transparency • Services' integration	
Credibility (lack of standardized rules and structure)	• Create rules that are not standardized but tailored to community • Increase credibility of RECs through certification	• Can be substituted by a centralized certification scheme
Certification (proof of transactions)	• Matches production and consumption data in real time • Tracking the source of energy: • Tokenization of energy	

In the hypothesis of a dealignment and realignment pathway, blockchain would take a totally different function by substituting utilities and retailers as intermediaries and allowing for decentralized management of transactions. First of all, it can allow transactions without intermediation:

> Blockchain is, probably, the most important driver in all this, since it may enable off-the-market transactions which are reliable and safe, allowing prosumers to create their own power exchanges, in a completely automated process. Otherwise, if prosumers are required to devote resources to forecasting, trading and settlement, this type of off-the-market arrangements will not be developed (Niche actor).

Furthermore, communities have a horizontal structure that on one side embraces the concept of energy democracy, but on the other side, it makes every RECs different from the other, with unique rules and structures. This lack of standardization and fixed rules may create uncertainty in joining a community for several individuals and prefer to remain with the standardized contract with utilities or energy retailers. Blockchain can help in these terms:

> Well, blockchain can surely be an accelerator because actually all communities are a bit different. Either you create a community model standardized 100% or if they are born as communities without a clear purpose, blockchain can be the fastest way to put all inhabitants of a condominium in accordance with the fact that everyone is earning the correct amount. This is the advantage of a distributed authority that says that what you are doing is approved. Is not a person checking an excel file and every time something is wrong, is communicated to someone else, discussed in groups, and goes through a long decisional process. The rules are defined once for all in the smart contract. If data are inserted correctly, prices are defined correctly then what I see on my energy bill is not a vague ‘50% savings’ that is all true, certified on the blockchain. For now, the term energy community says everything and nothing at the same time because rules are not defined. If you say instead this community has everything certified on the blockchain then you incentivize people to join and respect the set of rules. Blockchain can really give the big missing piece of the puzzle to energy communities: credibility (Blockchain expert)

In this scenario, the most suitable design for this consensus mechanism is Proof-of-Cooperation that allows for efficient use of energy and is based on the principle of 'Collaboratively Validated Nodes' (CVNs) that cooperate to validate transactions and secure the network. This mechanism allows for a decentralized mechanism that is still more energy efficient than Proof-of-Work.

In the past, the need for market intermediaries was necessary to face the complexity of local markets and to enable transactions between different parties. Nowadays, the emergence of digital platforms can offer a new approach to "integration in the market" into "becoming the market" by enabling peer-to-peer transactions (Diestelmeier, 2019). Creating the tools for independence from these actors in the market. In this scenario, blockchain can be a game-changer in terms of the nature of the interaction between RECs and regime actors (in particular utilities) since it can take over their role of intermediators and put in contact prosumers and consumers directly (P2P) like in the case of Grid Singularity. Blockchain adoption has the potential to create cracks in the walls of existing power structures since it eliminates the need of several intermediaries.

Drivers and barriers highlighted by interviewees in this scenario are related with the consequent blockchain functionalities in Table 4. In this scenario, blockchain can enable the scale-up of energy communities in terms of:

- **Increase flexibility:** flexibility is intended in this context as the ability of energy devices to shift energy used based on the production curve to reduce the mismatch between supply and demand. This becomes a crucial feature in a scenario in which the intermittency of renewable needs to satisfy different energy needs of different participants at different times
- **Increase transparency**: the digital notary of blockchain keeps track of every transaction that happens in the system (both in terms of energy and money flows) and is accessible to all participant anytime
- **Provide trust (through digital proof)**: since communities are born as a reaction to the mistrust in utilities and energy retailers, this new form of trust, based on transparency and digital cryptographic proof can serve the purpose of allowing the sharing of a commodity between actors that normally would not trust each other.
- **Allows off-the-market transactions:** normally market transactions would require a great load of market analysis and forecasting, not to mention the need for a number of intermediaries involved in each of these transactions. Through smart contracts, blockchain can allow transactions, in the form of direct exchange of energy and money flows.

- **Allows to decrease transactions costs:** blockchain eliminates the need of several intermediaries to validate and enforce a transaction, through the implementation of Smart Contracts with specific consensus rules; this can decrease costs substantially
- **Enhances a democratic and decentralized decision making:** this technology is particularly fit for a horizontal structure of decision making since it can allow designing the system based on different consensus mechanisms, as explained in the previous background section. The problem is the trade-off between more "democratic" consensus mechanisms in which everyone can approve the transactions that are therefore more or less energy-intensive mechanisms that select a limited number of users (based on selected criteria) that can approve transactions.
- **Allows to track consumption and share benefits:** in the two possible models of energy sharing, the first one in which everyone owns the same share of energy and the second one is that everyone owns an amount of energy based on its shares, anyhow consumption of all members might not match its due share. Tracking energy flows is extremely complicated but blockchain can track both the amount produced and the one consumed by all members and match them in real-time with their owned share of energy produced, automatically.

It needs to be pointed out that in this scenario there are some crucial barriers that blockchain cannot help to overcome:

- **Institutional barriers:** "How good is the lobbying capacity of blockchain?" was asked during interviews. Of course blockchain cannot have an impact on the institutional side. It could potentially make data collection and reporting easier to administrative authorities, but only if the system is integrated with the present data collection and reporting methods, this is not the case yet and probably the technology of blockchain won't be institutionalized for a long time.
- **Conflicts in decision making:** even if it can serve as a tool for decision making is unable to solve conflicts that the horizontal decision-making structure brings with it. In particular, it is possible to insert a predefined set of rules or conditions in a smart contract, and blockchain ensures they will be respected all the time but cannot facilitate the process of agreement on this set of shared rules of the community

Table 4. Summary of results of niche actors, obtained by relating the highlighted drivers and barriers with possible blockchain functionalities.

Drivers and Barriers	Blockchain can be an enabler	Blockchain cannot be an enabler
Institutional (favourable regulations) and Financial (no incentives)		• Cannot help on the institutional side
Economical (energy prices)	• Reduces time and cost of transactions (and bureaucratic processes)	
Technical (technologies and infrastructure)	• Increases flexibility	
Social and ideological (increased willingness of independency)	• Enhances a democratic and decentralized decision making	
Organizational (managing more people in a horizontal organization)	• Increases transparency • Provides trust (through digital proof) • Enhances a democratic and decentralized decision making • Allows to track consumption and share benefits	• Solve conflicts in decision making
Governance (power dynamics with lobby of utilities)	• Allows off-the-market transactions (P2Pr)	
Increase in penetration of electric vehicles (EV)	• Allows to manage millions of transactions from decentralized sources	
Credibility (the concept is still not mainstream)	• Create rules that are not standardized but tailored to community	
Social side of community	• Creation of community currencies	

Results are summarized in the following Figure 11:

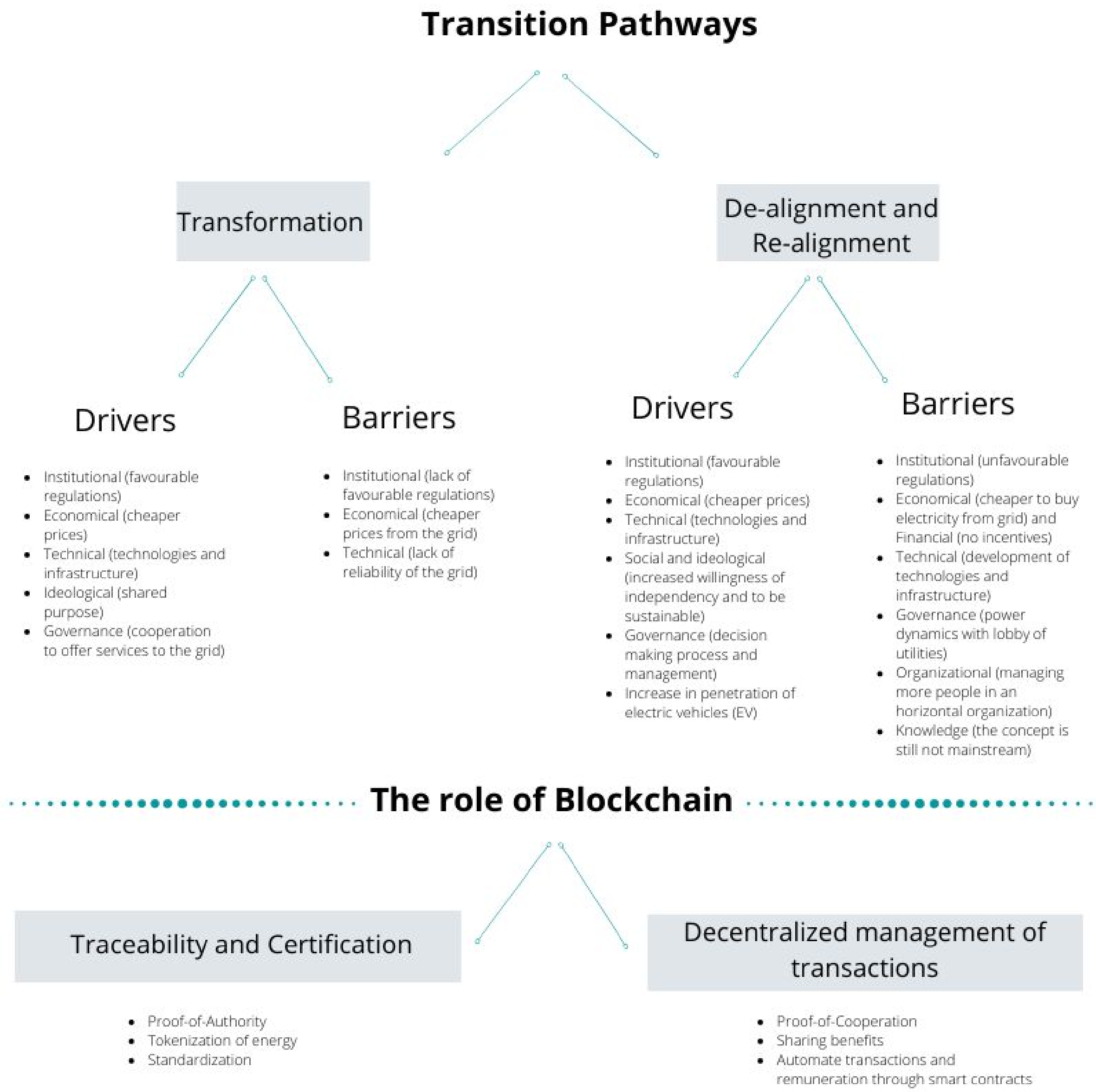

Figure 11:

Summary of results at 3 levels, in order to answer the three research questions.

7. Discussion

This session aims to reflect on results and on the theoretical and societal implications they have. A short paragraph is included to briefly reflect on the implications of COVID-19 on the development of RECs. Finally a reflection about the limitations of the present research is expressed in the last subsection. This is complemented by a session about possible related future streams of research.

7.1 Implications of results: the dichotomy between two futures

The most interesting result of the analysis is the divergence in the view of different actors about the pathway of development of communities. In the view of regime actors, this development will be symbiotic with the regime system and will result in a transformation of the regime to adapt to the innovation and a transformation of the innovation to adapt to the regime. In this scenario, RECs initiatives would be integrated into the centralized model of energy distribution already in place, with retailers and utilities offering special contracts to prosumers to resell their energy through the grid and compensate them with a reduction in their electricity bills.

Utilities are quite sure that their model will not be disrupted because the RECs' model does not allow 100% independence from the grid and still needs the reliability of balancing different energy sources in the grid. Besides reliability, they count on more social acceptance of the idea compared to the one of RECs and they believe their model gained trust from citizens and society.

Furthermore, they can count on the economy of scale because of their dimension, something that RECs will never be able to achieve to the same level, because, by nature, the community model is limited in dimension. Finally, their dimension and resources imply a very high lobbying power that communities do not possess. Anyway, they envision a necessary change in their business model and transition from a commodity provider toward a service provider, they will not be any more centered on selling energy, but selling PV to prosumer and contract them to resell their energy through the grid. They will be compensated in their energy bills and receive the energy they need when the sun is not shining. Some utilities are even planning to become centralized intermediaries between prosumers, that offer the guarantees of peer-to-peer transactions for local energy exchange at a distance lower than 500 meters, as permitted by regulation.

This scenario would imply a substantial change of the RECs model as well, implying a loss of independence from the grid, a more centralized model, and the absence of the social dynamics of prosumers in a community. The main drivers and barriers in the development of communities are mainly institutional (in terms of policy and financial incentives), economic (cost of technologies and cost of producing electricity compared to sourcing it from the grid) and technical (in terms of infrastructure, storage, and management technologies), but niche actors highlight also lobbying power of utilities as one of the main barriers of their development. In particular, they are worried that utilities would readapt the concept of RECs to their model (instead of the other way around) and deprive energy sharing of its social component. The fact that actors at the regime level consider this relation as symbiotic, represents for the niche actors, one of the main threats to the development of RECs: to be integrated in the retailing model and being forced to lose the main component of communities that is their independence. Independency from energy retailers and utilities is also considered the main factor that triggered the development of communities in the first place, therefore it seems inconceivable with a symbiotic relationship with these actors in the market. In the view of niche actors, the innovation of RECs implies disruption of the old paradigm of a centralized model of energy distribution and implies more independence from regime actors.

They envision a pathway of dealignment in which the regime develops problems and flaws and different models of niche innovation compete until one establishes as dominant and gives rise to a pathway of realignment around a new regime. In this scenario blockchain can help overcome some barriers in terms of time and costs of transactions, reliability of the grid, transparency and trust. It is interesting to see how in this scenario blockchain can fulfill several functions that were fulfilled by utilities before. Blockchain can therefore represent a digital enabler of their scale up in some aspects. Anyway, blockchain cannot help in any possible way to counteract the lobbying power of regime actors. Regulation has the power to set the rules and conditions of this integration. Therefore, the future pathway of development of RECs is mainly influenced by how regulation will approach the subject matter. Nowadays regulation limits the off-grid shared self-consumption to a range of 500 meters and still does not provide an independent legal entity to RECs that do not have fully developed administrative procedures, different from the ones that independent companies have to go through. Furthermore, financial incentives are still limited to special dedicated funds to which communities can apply.

The problem is that utilities have way more lobbying power and resources than communities. A solution to this problem envisioned by several actors at the niche level was to create an alliance of RECs to join the efforts and play the game altogether as one. Efforts in this direction have been made already with some associations that allow to pay a membership fee and be part of a network of cooperatives. A well successful example is ReScoop, the European federation of citizen energy cooperatives that joined the efforts to increase their lobbying capacity as a union.

7.2 Theoretical and societal contribution of results

Findings are in line with the findings of Verbong and Geels (2010), that theorized three possible scenarios of development of the European electricity system. They theorize a transformation pathway in which a hybrid infrastructure develops through the collaboration of utilities and prosumers and a dealignment and realignment pathway dominated by distributed local generation. They consider this pathway as the hardest to realize due to external vested interests and the need of a totally new infrastructure (Verbong & Geel, 2010). Furthermore, they also consider a third scenario of a reconfiguration pathway for the emergence of a “Supergrid " that connects all the European grids (Verbong & Geel, 2010). This scenario is not considered in the present research since the stage of development of RECs is not perceived as developed enough to take over the regime, in the view of interviewees.

These findings again highlight the limitations of the MLP perspective in dealing with different perspectives about the development of innovation, making it difficult to assess which one is the one that the innovation will follow in its development. The present research reflects on different perceptions of actors about the two types of interaction that this transition might have: disruptive or symbiotic with the present regime. Actors are aligned in the vision that a transformation of the system will happen, but they do not agree about how this transformation is going to happen. When these perceptions diverge there is no way to assess which one is more likely to happen, but it can surely be assessed that the conflict in perceptions represents a barrier in itself in the development of innovation from the niche to the regime level. This research therefore aims to complement the MLP model, by adding a new perspective related to perceptions of actors at different levels and this represents its theoretical contribution.

The present research is not limited to explore the two different transition pathways, but it analyses the role of the technological innovation of blockchain in both of them. This might have managerial implications both for regime actors in the energy industry, but also for niche actors at the community level, that can incorporate blockchain technology and its different functionalities in their strategies. Results of this research possess also social relevance since they contribute to the field of (digital) social innovation and explore the sustainable community model, and one possible digital tool to enable it.

Results can have implications not only in terms of the transition toward a cleaner energy system but also for transitions toward a more sustainable system in general. It has been demonstrated that the community model can be a catalyst of positive behavior change (Hewitt et. al, 2019; Bauwens & Devine-Wright, 2018; Walker, 2008), hence, if blockchain reveals to be an enabler for the scale-up of the community model for RECs, it can be applied to several other types of sustainable communities. This represents the social relevance of the research since renewable community energy initiatives have the potential to change the energy system of a region (or country) though the bottom-up approach in which grassroots experiments are scaled up (Hansen & Coenen, 2015). As demonstrated by the analysis of Bauwens and Devine-Wright (2018) members of communities are more supportive of renewable energy projects in general and this implies that the transition from a fuel-based energy system can be stimulated through the development of community energy initiatives (Bauwens & Devine-Wright, 2018).

Nevertheless, this research showed that there is no single formula to apply to all scenarios, and is not possible to simply promote the use of blockchain as an enabler, but rather highlighted the challenge in terms of policy and design of a technology in support of different future scenarios.

7.2 Implication of the COVID-19 crisis on the present research

Even if this research was started before COVID-19 was considered a pandemic and before it was declared a sanitary and economic crisis, it is necessary to briefly reflect on the implications of the present crisis on the innovation of RECs. This reflection is done without prediction, only based on available data at the present moment of writing.

The COVID-19 crisis necessarily represents a barrier for the development of the RECs model in the short term. This is because even if renewables have increased their penetration in the electricity mix (since they are generally given priority), the entire industry that supports the development of renewable energy is entering a slowdown. Every economic crisis forces institutions and individuals to concentrate on the core activities for survival and tend to remove the focus from longer terms perspectives like long term investments and innovation. Furthermore, the negative prices of oil might represent a disincentive for long term investments in new renewable generation assets. This can also imply lower energy prices from utilities and remove the economic incentive to establish RECs.

Looking at this from another perspective, the main decline in electricity consumption comes from manufacturing and industrial facilities, while the residential consumption of electricity is increased. The reduction of demand had also an impact on the energy mix (that varies region by region) and of course also on energy prices. This had a major hit on utilities and poses the question if they will have the resources to dedicate to innovation while they need to focus on survival as well. Another factor that might threaten their core model is that some states are elaborating national policies to forbid disconnection during public health emergencies for people that are not able to pay their energy bills.

Furthermore, this crisis is bringing more and more awareness of the interconnections between people and ecosystems and hopefully might serve as an opportunity to rebuild the present system on more sustainable foundations. Especially the crisis will lead to rethink the globalized economic model. Communities and cooperatives have proposed a more local or regional model that is also more resilient. Is a “vintage” that has been used for centuries and is taking over again. Maybe the pandemic has highlighted the inefficiencies of a globalized system and can blow the wind of the “third wave” of prosumers mentioned by Alvin Toffler.

7.3 Limitations of the present research

The main limitations of the present research lie in the methodological concerns of validity and reliability. Dealing with highly abstract concepts of perceptions of actors interviewed, obviously has shortcomings in terms of reliability and validity. This is due to the fact that the process of coding interview’s responses and making them fit into categories requires a certain degree of interpretation and this can expose it to personal biases. This is also due to the fact that all coding processes were performed by only one individual, making it impossible to confront different options. Furthermore, some of the interviews were translated before being transcribed and this could have implied the loss of different cultural shades reflected in the language.

It was very hard to depict the vision of entire regime institutions, since normally they are big organizations formed by different people with different opinions. Therefore interviewing only some members of each institution does not imply that the vision of the specific institution is precisely represented. As an attempt to overcome this, the theoretical sample has been selected aiming to incorporate both official and unofficial, written and spoken, enthusiastic and skeptical, general, and specific views in order to obtain a complete and more nuanced picture (Åslund, 2016) and increase reliability through data triangulation.

7.4 Future research

The concept of collective self-consumption can be applied also to companies. Companies in a way can represent some sort of communities: resources are shared between employees that are individuals who act collectively to obtain a collective outcome. It would be interesting to expand the present research to consider the growing trend of self-consumption of renewable energy by corporates (RE100, 2019) that have more resources and developed networks than communities and cooperatives.

If companies will start to self-generate energy and maybe sell the excess to the grid, this may (or may not) imply a different threat of disruption for utilities and their business model, since they have higher resources and lobbying power compared to RECs. An interesting cue for future research might be the new forms of self-generation of renewable energy sourcing of companies and the implication that they have on the business models of utilities.

8. Conclusion

The aim of this research was to answer the research question: *What designs and functionalities can blockchain assume to be an enabler of different transition pathways of renewable energy communities and cooperatives (RECs) in Spain?*

In order to answer this question, three main points need to be made clear: which transition pathway will the innovation of RECs take in its development, what are the drivers and barriers of this development, and to what design and functionalities can blockchain assume to leverage the highlighted drivers and overcome barriers. The process undertaken to answer the research question was qualitative inductive research, based on mixed sources like grey and white literature review and semi-structured interviews with relevant actors in the Spanish energy ecosystem.

Results highlighted the different perspective of regime and niche actors on the future pathway of development of RECs. While actors agree that the innovation is still at its early phase, they have contrasting views on the nature of interaction between the niche innovation and the regime. This delineates two possible pathways of development. In case the innovation at the niche level develops symbiotically with the regime, innovation will follow a transition pathway that only slightly modifies regime, but it mainly adapts to it.

In the case the relationship with the regime is conceived as disruptive the innovation will develop through a dealignment and realignment pathway through which the regime develops problems and flows and several models of niche innovation develop and compete until one is mature enough to prevail and lead the regime toward a process of realignment toward a new configuration. These different scenarios imply different drivers and barriers that can be fulfilled by blockchain with different designs and configurations.

In the first scenario of transition, blockchain could serve as a database to coordinate millions of distributed sources, with an established centralized authority that validates transactions, in a Proof-of-Authority consensus mechanism. Blockchain could also help to track the provenance of energy production and certify that users are receiving locally produced energy, by virtually matching production and consumption data in real-time. Furthermore, blockchain can allow service integration, to complement the intermittency of renewable generation of RECs and can allow for cheaper and more transparent contracts for consumers and prosumers.

In the de-alignment and re-alignment scenario,blockchain can serve the purpose of a decentralized database, with a decentralized model of trust, that follows the rules of a Proof-of-cooperation consensus mechanism. This mechanism embraces a more democratic approach in which nodes cooperate to validate transactions without the need of a centralized authority. Blockchain cannot give communities the social acceptance from civil societies but can surely provide a level of credibility with fixed rules that each member agrees before entering a community and that are automatically enforced through smart contracts without exception. This can also provide some ease in the horizontal decision-making structure, by providing a fixed protocol of rules that are agreed upon by all members and automatically enforced. It cannot provide the reliability of utilities but can support flexibility through aggregated demand response, coordinating consumption, and tracking different users' consumption profiles. Finally, it can offer a new digital model of trust in which a centralized authority is not needed, and peer-to-peer transactions are managed transparently and protected by cryptographic proof. Furthermore, even if blockchain cannot allow communities to achieve economies of scale, it could reduce costs substantially by eliminating transaction costs that necessarily arise from the third party's intermediation..

In conclusion blockchain adoption is not the panacea of all evils, it needs to go hand in hand with regulation and social acceptance to be an enabler of the scale-up of the RECs model. Furthermore, blockchain is not a fixed design or configuration, but it can be adapted to the situation and the needs of different actors, therefore performing different functions in different scenarios of development of RECs. This research aimed to shed light also on the different possible roles that blockchain can have since:

> It is important that we keep talking about it (blockchain). If it will demonstrate to be beneficial, we will use it, if not we will drop it. But we need to talk about it to understand it better and understand if blockchain can truly serve the purpose or not. Otherwise we will keep going with micro tests and pilots like now, everyone talks about blockchain but they do not know what it truly can do. The concept is still obscure and linked to cryptocurrencies, knowing what you can do with blockchain is a totally different thing. Knowing the difference between shared ledger and blockchain is already something (Regime actor).

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11. Appendices

11.1 Interview guide blockchain experts

1. CONTEXT AND INTRODUCTION

-For which company/institution do you work?
-What is your role in the company?
-What is the mission of your company?

2. THE ROLE OF BLOCKCHAIN IN ENERGY

-What role will blockchain take in the energy transition in your opinion?
-Do you think that blockchain has the potential to enable the scale-up of the energy community model?

3. DESIGN

- What are the features of a suitable blockchain design that can facilitate the development of prosumers and energy communities (in terms of overcoming barriers and leveraging drivers)?
-How would the design of the technology look like in terms of consensus mechanism, protocol, private vs public etc..?
-Which stakeholders need to be involved to create a system that integrates communities in the energy sector?

11.2 Interview guide regime actors

1. INTRODUCTION

-For which company/institution do you work?

-What is your role in the company?
-What role will your company/institution take in the energy transition?
-How is your company/institution adapting to the trends of decarbonization, decentralization and digitalization of the energy industry?

2. PATHWAYS

-What role will prosumers and energy communities take in the energy transition?
-Do you envision a future in which energy communities will be integrated in the energy system?
-How does the current mechanism of compensation for grid services work?

-How do you envision their pathway of development?
-At what stage of development do you think it is the innovation of renewable energy communities? (predevelopment, tak-off, acceleration, stabilisation)
-Would you define the relationship between energy communities and your utilities and energy retailers having a disruptive or symbiotic nature?
-Do you see your business model at risk of disruption? What steps need to be taken to avoid disruption?

3. DRIVERS AND BARRIERS

-What do you think will be the impact of the abolishment of the "sun tax" in Spain and the new regulation about shared self consumption? (window of opportunity)
-What do you think will be the main drivers of their development?
(governmental subsidies, lower costs of PV and turbines, increased demand for more locally produced energy)
-What do you think will be the main barriers to their development?
(coal power lobby, no coordination/integration in the grid, no subsidies, no demand for locally produced energy)

4. BLOCKCHAIN

-Do you think that blockchain technology can possibly have a role in their development?If yes, what role?
-Do you think blockchain can help to overcome the highlighted barriers?
-Do you think blockchain can help to leverage on the highlighted drivers?

11.3 Interview guide niche actors

1. CONTEXT AND INTRODUCTION

-For which company/institution do you work?

-What is your role in the company?
-What is the main reason that triggered the development of energy cooperatives in the first place? What would you say is their mission?

2. PATHWAYS

-In your vision, will renewable energy communities have a substantial role in energy provision in the future?
-Do you envision a future in which energy communities will be integrated into the energy system?

-How do you envision the pathway of their development?
-At what stage of development do you think it is the innovation of renewable energy communities? (predevelopment, take-off, acceleration, stabilization)
-Would you define the relationship between energy communities and utilities and energy retailers having a disruptive or symbiotic nature?

3. DRIVERS AND BARRIERS

-What do you think will be the impact of the abolishment of the "sun tax" in Spain and the new regulation about shared self-consumption?
-What do you think will be the main drivers of their development?
(governmental subsidies, lower costs of PV and turbines, increased demand for more locally produced energy)ù
-What do you think will be the main barriers to their development?
(coal-power lobby, no coordination/integration in the grid, no subsidies, no demand for locally produced energy)

4. BLOCKCHAIN

-Do you think that blockchain technology can possibly have a role in their development? If yes, what role?
-Do you think blockchain can help to overcome the highlighted barriers?
-Do you think blockchain can help to leverage on the highlighted drivers?

11.4 Codes resulting from niche actors' interviews

Category	Code	Node	Number of coded factors

Creation of RECs	Reasons	Environmentalism	4
		Money savings	1
		Independency	7
RQ1: Pathway of development of RECs	Future role in the system	Integrated	9
		Not integrated	0
	Impact new shared self-consumption regulation	Sufficient to create a window of opportunity	7
		Not sufficient to create a window of opportunity	2
	Present state of development of RECs	Development	0
		Predevelopment	9
	Relationship with utilities	Symbiotic	1
		Disruptive	8
RQ2: Factors of influence in their development	Drivers	Institutional (favourable regulations)	6
		Economical (cheaper prices)	4
		Technical (technologies and infrastructure)	2
		Social and ideological (increased willingness of independency and to be sustainable)	7
		Organizational (decision making process and	1

		management)	
		Increase in penetration of electric vehicles (EV)	1
	Barriers	Institutional (lack of favourable regulations)	6
		Economical (cheaper to buy electricity from grid) and Financial (no incentives)	3
		Technical (development of technologies and infrastructure)	1
		Governance (power dynamics with lobby of utilities)	4
		Organizational (managing more people in an horizontal organization)	2
		Credibility (the concept is still not mainstream)	3
RQ3: The role of blockchain in development of RECs	Can be an enabler in terms of:	Increase flexibility	1
		Increase transparency	1
		Provide trust (through digital proof)	1
		Allows off-the-market transactions (peer-to-peer)	3
		Enhances a democratic and decentralized decision making	3

		Matches production and consumption data in real time	1
		Allows to track consumption and share benefits	2
		Reduces time and cost of transactions (and bureaucratic processes)	1
		Creation of community currencies	1
	Cannot be an enabler in terms of:	Institutional barriers	2
		Solve conflicts in decision making	1
		Energy efficiency	1

11.5 Codes resulting from regime actors' interviews

Category	Node	Node	Number of coded factors
Energy transition	Role of institution	Proactive	2
		Leadership	3
RQ1: Pathway of development of RECs	Future role in the system	Integrated	5
		Not integrated	0
	Impact new shared self-consumption regulation	Sufficient to create a window of opportunity	1
		Not sufficient to create a window of opportunity	0
		Don't know	4

	Present state of development of RECs	Development	1
		Predevelopment	4
	Relationship with utilities	Symbiotic	5
		Disruptive	0
RQ2: Factors of influence in their development	Drivers	Institutional (favourable regulations)	4
		Economical (cheaper prices)	3
		Technical (technologies and infrastructure)	2
		Ideological (shared purpose)	1
		Governance (cooperation to offer services to the grid)	1
	Barriers	Institutional (lack of favourable regulations)	5
		Economical (cheaper prices from the grid)	1
		Technical (lack of reliability of the grid)	4
		Credibility (lack of standardized structure)	1
		Certification (lack of proof)	1
RQ3: The role of blockchain in development of RECs	Can be an enabler in terms of:	Create rules that are not standardized but tailored to community	1
		Increase credibility of RECs through	1

		certification	
		Provide trust (through digital proof)	1
		Allows transactions of the energy on ancillary services out of communities	1
	Cannot be an enabler in terms of:	Connecting million entities (for now is just pilots)	2
		Can be substituted by a centralized certification scheme	1