Entrepreneurial use of contexts in technological innovation systems: the case of blockchain based Peer-to-Peer electricity trading systems

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Abstract

The growing deployment of renewable electricity (RE) generation technologies and innovation in balancing technologies such as storage and advanced metering, are enabling the transition to a distributed electricity system configuration. This trend calls for new models for electricity trading that are fundamentally different from the dominant model of centralized production and one-way transmission. An example of a potentially disruptive model, is Peer-to-Peer (P2P) electricity trading based on the blockchain technology, a novel digital infrastructure that allows a network of decentralized actors to trade without the need of a utility or an energy retailer as an intermediary. However, achieving a transition towards a P2P electricity system requires radical socio-technical changes that are often hindered by change averse incumbent actors in the encounter with the entrenched system. To better understand why certain innovations succeed while other fail or stagnate when encountering the incumbent sector, we propose an extension of the technological innovation systems (TIS) framework to emphasize the importance of the context and entrepreneurial activities in the buildup of this novel configuration. We apply the framework to cases of two local P2P demonstration projects, both using the blockchain to promote the radically distributed electricity system, but at the same time developing in different contexts and by different actors. Our empirical results show that both the local context and its successful navigation by entrepreneurs can support innovation processes. However, for achieving a productive encounter with the incumbent electricity sector, the entrepreneurs' ability to find opportunities in other relevant sectors, build a local supply chain that combined local and global knowledge and create cross-scale networks seem to be equally important.

1 Introduction

Reducing dependence on fossil fuel and nuclear based electricity generation implies an increased reliance on renewable energy sources. Such a transition to renewable energy sources not only entails new generation technologies but also opens to new electricity system configurations, some of which are fundamentally different from the large-scale, centralized and unidirectional system dominating at present. In this paper, we reflect on the prospects for a whole-system transformation from the current system to a radical 'Smart-grid' by examining contextual influence in a very early phase of buildup of this alternative configuration. The 'Smart-grid' is a distributed electricity system, supported by a growing number of small-scale generation, storage, and advanced metering technologies integrated into the conventional grid infrastructure, that turns passive electricity consumers into active prosumers—consumers who also produce and sell electricity. In its idealised form, this configuration can create a completely interconnected grid with global reach, a so called "Smart-grid", of prosumers (Hojčková, Sandén et al. 2017). The Smart-grid vision includes the possibility for prosumers to trade electricity in a peer-to-peer (P2P) fashion, that is, directly without intermediaries. This requires a suitable digital infrastructure and one potential candidate is 'blockchain', an internet protocol developed in the financial sector that allows a network of decentralized actors to reach consensus around a shared data state (e.g., transaction data) without the need of a central coordinator or the involvement of an intermediary. Applied to the energy sector, this removes the need for a utility or an energy retailer to be involved in transactions (Burger, Kuhlmann et al. 2016, Murkin J., Chitchyan R. et al. 2016, PwC 2016, Sousaa, Soaresb et al. 2018).

The Smart-grid is but one potential future system architecture. Achieving it involves radical changes compared to the current dominant socio-technical configuration, i.e. the complex and interdependent technical, socio-cultural, institutional, and organisational structure of components that together fulfil specific functions (Geels 2004). It is difficult and time consuming for novel configurations to find ways to fit into, transform and eventually replace established socio-technical structures (often referred to as 'regimes') (Hughes 1987, Kemp 1994, Geels 2004). In infrastructure-dependent sectors, such as the electricity sector, regime shifts could be especially challenging, because of the existing durable and capital-intensive electricity grid and production fleet that generate inertia and obstruct fundamental changes (Frantzeskaki and Loorbach 2010, Markard 2011). However, evidence suggests that certain contexts are conducive to innovation and offer niche market opportunities in which novel configurations can be applied, tested and developed before they encounter the entrenched system and its often change averse incumbent actors (Kemp, Schot et al. 1998, Markard 2011).

For actors engaged in innovating and promoting new solutions with the aim of disrupting dominant sector configurations it is imperative to identify these conducive environments and learn how to strategically navigate encounters with incumbent actors. The Technological Innovation System (TIS) approach offers a structured way to describe and explain the emergence and growth of new socio-technical configurations (Hekkert, Suurs et al. 2007, Bergek, Jacobsson et al. 2008a). This body of work includes analytical frameworks that assist identification of key enabling processes and blocking factors—the TIS ‘functional approach’. It focuses on collective and systemic aspects of innovation, but has been criticised for lacking a more nuanced conceptualisation of the geographical and socio-technical context of emerging configurations (Coenen and Díaz López 2010, Coenen, Benneworth et al. 2012, Bergek, Hekkert et al. 2015, Hansen and Coenen 2015, Truffer, Murphy et al. 2015). Another related critique is that TIS studies lack a micro-level foundation and devote too little attention to actors’ agency and the role of entrepreneurs (Markard and Truffer 2008, Alkemade, Negro et al. 2011, Farla, Markard et al. 2012, Planko, Cramer et al. 2017, Musiolik, Markard et al. 2018). Our study seeks to address both of these concerns by focusing on how entrepreneurial actors engage with and navigate a rich set of contextual factors as they promote a novel configuration.

Situating our discussion in the TIS literature, the theoretical aims of this paper are thus to contribute with contextually anchored analysis of early phase system buildup, by: (i) developing and testing a conceptualisation of influential contextual structures; and (ii) analysing how entrepreneurs utilise the context to stimulate structural buildup, overcome blocking factors and how this—in turn—affects their encounter with the local incumbent sector. Furthermore, our empirical aim is to better understand how these dynamics may influence the prospects for a radical Smart-grid scenario, and shape its trajectory (Hojčková, Sandén et al. 2017).

The empirical case for our investigation is the novel socio-technical configuration of Peer-to-Peer (P2P) electricity trading. We follow two efforts at disruptive innovation, both using the same technology, the blockchain, with a common goal to promote the radical network of prosumers, i.e. ‘Smart-grid’, but, at the time of study, existing only in the form of local demonstration projects. The two emerging systems share certain elements but evolve in different contexts and are developed by different actors. We argue that studying demonstration projects (i.e. small proto-systems) is fruitful analytically as it shows clearly the interplay between entrepreneurial agency, the emerging configuration and context—thus helping establish the micro-level foundation for TIS studies.

2 Theoretical foundations

2.1 Technological Innovations Systems

In the TIS functional approach, an innovation process is conceptualised as a result of multiple entangled processes resulting in the buildup of a new socio-technical system, which may replace or transform an established system. The approach highlights the importance of both the structural buildup (consisting of actors, networks, institutions, knowledge, physical artefacts) and the system's constituting processes (termed 'functions'). These functions carry different weight and matter in different ways during a transition, hence, Table 1 summarises the key functions as we understand them to matter at the early stage of system buildup, based on the various formulations existing in the literature.

Table 1: Functions of the TIS (Bergek, Jacobsson et al. 2008a, Hekkert and Negro 2009, Hekkert, Negro et al. 2011, Perez Vico 2014)

FUNCTION	DESCRIPTION
Entrepreneurial experimentation	This function captures the process of experimenting and implementing new technologies and business models to learn and improve and thus reduce uncertainty.
Knowledge development and diffusion	Process of creating new knowledge in the innovation system buildup through 'learning by searching' and 'learning by doing'. However, in a successful innovation process, knowledge further develops via diffusion and exchange across actor groups through processes of 'learning by interacting', at technology-specific conferences or workshops, or in case of user—producer networks, through 'learning by using'.
Network formation (Social capital development[1])	This function captures the process of building networks and coalitions, in which social relations are created and maintained. Social relations in these networks are built and maintained through trust, mutual recognition, dependence, authority and shared norms.
Legitimation	Process of creating formal and informal institutions to overcome resistance to change. An innovation is accepted and perceived as a relevant and appropriate new technology, application or business model or as a solution to an existing technological bottleneck or business crisis.
Guidance of search	This function accounts for the process of attracting and motivating new actors to enter the innovation system, providing a favourable selection environment for the focal novel configuration buildup, influencing market formation etc.
Market formation	At the stage of experimentation and early buildup, this function captures formation of demand that often takes place by creating niche markets with a competitive advantage for specific applications of the focal technology.
Resource mobilisation	Function that represents the process of accessing necessary resources, in the form of physical, financial and human resources.

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[1] This function has been added by Perez Vico (2014) as social capital development. We chose to name the function as 'network formation', which we find more appropriate as the focus is on the creation of a network of relationships instead of social capital as an asset.

These key processes result from the interplay between the internal state of the novel configuration (the evolving system structure) and supporting and blocking factors in its environment (Hillman and Sandén 2008, Bergek, Jacobsson et al. 2008b, Sandén and Hillman 2011) (Figure 1). For immature systems, external factors are of great importance since the internal structure is not yet well-developed and provides only weak support. As the system grows—with the entrance of new actors, development of physical structures, networks and knowledge, and alignment of institutions—the internal (technology-specific) supporting factors provide stronger internal positive feedback loops (cumulative causation) and thus become more important. Over time the new configuration gains momentum (Hughes 1987) exert increasing influence on its environment. This also implies that structural elements that, initially, were external and part of the context become internalised, hence the system boundary is not stable.

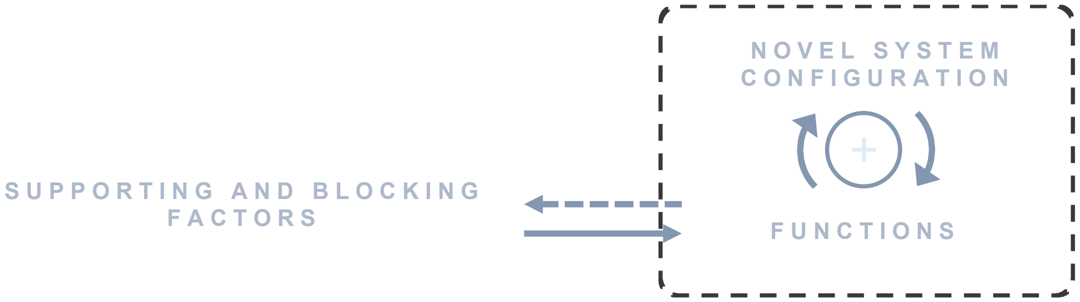

Figure 1 The novel configuration is developed through an interplay between internal and external factors supporting or blocking system growth, or more generally, ‘shaping’ system development (based on Hillman & Sandén 2008, Bergek, Jacobsson, Sandén 2008).

Apparently, the system environment, or context, is of great importance for early development—the ‘shaping’ (Andersson et al 2018)—and overall prospect of a novel configuration. However, in recent years, scholars have argued that the context is under-theorized in the TIS framework. To better understand why certain innovations, develop successfully in some contexts but fail in others, and how the context not only help or hinder novel configurations but also shape them, we review how the literature deals with this ‘context’ (Coenen, Benneworth et al. 2012, Bergek, Hekkert et al. 2015, Hansen and Coenen 2015, Truffer, Murphy et al. 2015).

2.2 Conceptualising the context of TIS

Scholars of TIS often pay empirical attention to how contextual factors influence the processes they study, the literature thus provides quite rich accounts of context-specific processes. But it is much less clear how the ‘context’ is understood conceptually, what is considered important and how and why some factors matter more. There is also need for reflection on how systems are framed analytically and how the setting of system boundaries sheds light on some actors, activities and events, while obscuring other. When reviewing the literature, we find that existing frameworks differ in their assumptions, and the criticism is often related to the analytical biases these incur.

In regional (RIS) and national (NIS) innovation system studies (Lundvall 1988, Cooke, Uranga et al. 1997), the territorial context is crucial, with priority given to the regional or national geographical scale and organisational levels. The TIS framework developed partly in response to RIS and NIS, focusing more on the technology specific factors, rather than factors specific to a geographical area. Although TIS, in its early formulations, emphasised the importance of the external environment, this became somewhat less explicit in subsequent analyses, and TIS case studies in many cases adopted the national scale as system boundary. Hence the recent efforts to *revisit* the importance of the TIS context.

The strongest critique of analytical bias is leveraged by geographers working with TIS. They highlight differences between geographical contexts and place focus on how places can be more or less conducive to sustainability-oriented innovation. Geographers of TIS argue that the system build up depends on processes and interactions at different spatial scales and organisational levels, ranging from local to global (Coenen, Benneworth et al. 2012). Geographical locations contribute to success of innovation processes by providing e.g. local natural resources, favourable policies and visions, industrial specialisation, local knowledge and networks, supporting informal institutions and local user markets (Binz, Truffer et al. 2012, Hansen and Coenen 2015). Nationally focussed TIS analyses may miss how the global level works as an important source of knowledge and production skills (Lee, Szapiro et al. 2018) as well as how multi-scalar actor networks and institutional contexts support or hinder TIS development (Binz and Truffer 2017). Further, a new body of work is emerging on TIS in non-Western contexts and developing economies, with suggestions of how to improve the TIS approach such that it is relevant also in contexts where the ‘regime’ is not monolithic, but many technological or service sectors of society are characterised by being heterogenous and fragmented, where actors navigate a patchwork of (misaligned) institutions and where the societal context at large is fundamentally different from the few countries where TIS studies originate (Edsand 2017, van Welie, Cherunya et al. 2018).

In parallel to the territorially focused innovation system studies, sectorial innovation system (SIS) scholars argue that the industrial sector context (e.g. the electricity sector) is what matters most for innovation processes (Malerba 2002, Stephan, Schmidt et al. 2017). Hanson (2018) and Raven (2007) point to the importance of interactions with other established industries while others stress the interaction dynamics between different technologies (Hillman, Suurs et al. 2008, Sandén and Hillman 2011, Wirth and Markard 2011, Haley 2014, Markard and Hoffmann 2016, Hanson 2018, Mäkitie, Andersen et al. 2018). Yet other innovation scholars stress the key role of society-wide ‘supporting systems’ providing specific system level assets such as the educational, financial or political/judiciary systems providing skilled labour, financial capital and regulative institutions, respectively (Jacobsson and Karltorp, Karltorp et al 2017, Bergek et al 2015). To the supporting systems mentioned in the TIS literature we may add others, such media supporting legitimising and delegitimising processes (normative institutions); research providing formal knowledge; and nature, providing basic physical resources. Even if they are here named ‘supporting systems’, they do not have to support the development of the novel configuration, but may as well host blocking factors.

Bergek, Hekkert et al. (2015) make a first attempt to combine many of these aspects into a more comprehensive framework of contextual factors influencing the TIS buildup. In a similar fashion, we find that the literature provides two main ways in which the context is conceptualised. We propose that these can be integrated into the two-dimensional matrix presented in Figure 2.

Firstly, there is the *spatial dimension of the context*, where contextual factors reside at a certain level along a spatial scale, resulting in a differentiation between factors from the local to the global level, with many possible relevant levels in between—for simplicity these are visualised in our figure as the local[2], national, global. Secondly, factors can be positioned along a *socio-technical dimension of the context*, resulting in a differentiation between factors depending on the configuration of the focal sector, related technologies, related sectors and supporting

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[2] These classical levels and the idea of the ‘local’ are simplifications that in some places result in analytical blindness unless they are unpacked and critically examined. For a case study that illustrates overlapping and messy jurisdictions and social relations shaping electricity provision, see (Nucho 2016)

systems (educational, financial, political/judiciary, media and natural systems etc). To us, this opens up for an analytical and empirical richness, and encourages explorative framings rather than a priori assumptions about what contextual factor will matter.

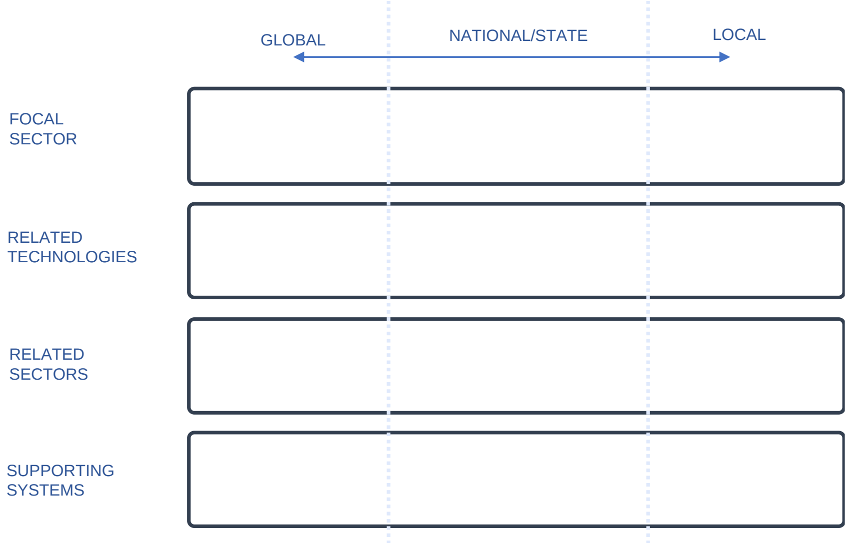

Figure 2 A two-dimensional conceptualisation of the context of emerging configurations.

2.3 Micro-level understanding of the TIS build-up

We now turn to the critique that TIS lacks a micro-level foundation and devotes too little attention to actors' agency and the role of entrepreneurs (Markard and Truffer 2008, Alkemade, Negro et al. 2011, Farla, Markard et al. 2012, Planko, Cramer et al. 2017, Musiolik, Markard et al. 2018). In the TIS functional approach, socio-technical change is studied from a systems perspective. The systems perspective proposes that the novel configuration emerges from a constant interaction between internal (technology-specific) and external (contextual) structures (actors, networks, institutions, knowledge, physical artefacts) and processes (Figure 1). The buildup process is conceptualised by the set of rather abstract functions (Table 1). However, when we look closer at the micro-level of innovation processes, for example in local demonstration projects, we discover the importance of individual actors who are able to utilize available resources and initiate collective action to promote system development. These individual actors are often entrepreneurs who play crucial roles as inventors with a strong incentive to support their emerging technology's introduction to the market.

The role of the entrepreneurs in TIS approaches is possibly reflected in the function of ‘entrepreneurial experimentation’ (Bergek, Jacobsson et al. 2008) or ‘entrepreneurial activities’ (Carlsson and Stankiewicz 1991, Hekkert, Negro et al. 2011). While semantically similar, there seems to be a clear difference between these concepts. Bergek et al (2008) views ‘entrepreneurial experimentation’ as a system level phenomenon—at the same time generating variety and reducing uncertainty. Hekkert, Suurs et al. (2007) on the other hand, highlights the micro-level activities, where the role of the entrepreneur is “to turn the potential of new knowledge, networks, and markets into concrete actions to generate–and take advantage of–new business opportunities” through experimentation under different circumstances (Hekkert, Suurs et al. 2007, 421, Alkemade, Negro et al. 2011). Although such a definition seemingly favours a focus on agency, the presence of this function is usually measured quantitatively, by identifying the number of active entrepreneurs supporting the TIS. While counting entrepreneurs can be an important indicator in analysing larger national and global systems over longer time periods, this is not the case for micro-level analyses of local technology demonstrations. Here, Alkemade, Negro et al. (2011) highlights the active role of entrepreneurs as important in the early phases of the innovation buildup, when only a limited number of actors are involved and where it is clearly visible how entrepreneurs in their strategic actions enact substantial agency. Following this view, we don’t locate the entrepreneurial activities only to the function that describes processes of experimentation and implementation of the focal technology, instead we view entrepreneurs as embodiment of the functions and their activities as effort to support the system buildup (Figure 3).

Figure 3 Entrepreneurial activities interpreted as activities building the novel configuration by making use of internal and contextual (compare Figure 1).

Our interest in the roles and activities of entrepreneurs[3] is not about the search for profit, but their activities as (a) 'innovators' (Schumpeter 1934) who introduce new practices that significantly differ from those in the established sectors, and (b) 'system builders' (Hughes 1987, Hellsmark 2010, Musiolik, Markard et al. 2018) actively working on fulfilling key processes in a TIS that is of their interest. The importance of the role of entrepreneurs for the innovation system buildup was emphasized already in the 1980's by the industrial economist Dahmén, who coined the concept of the 'development block'[4] that came to influence the first definitions of technological systems (as a forerunner to TIS) developed by Carlsson and Stankiewicz (1991). Dahmén (1988) considered entrepreneurial activities as central to the creation of a development block that encounters the wider system, i.e. the incumbent sector. In order to understand these encounters, we need to pay attention to the activities of actors and the related meanings and capabilities. In the literature on 'Sustainability Transitions' scholars are increasingly using 'practice theory' to study daily practices as organised ways of doing certain activities (Schatzki 2002, Shove, Pantzar et al. 2012). Hargreaves, Longhurst et al. (2013) understand humans as skilled agents who actively negotiate and perform a wide range of practices, while embedded in webs of social and material relations, and shaped by and reshaped the context of which they are part. In a similar move, we focus on the entrepreneurs' motivation for innovating and their strategic actions and use of resources and relations to stimulate the buildup and garner enough momentum to successfully challenge established configurations. In particular, we examine how entrepreneurs can utilise the context across scales and sociotechnical sector and how this contributes to system buildup and shaping of the internal structure. (Bergek, Hekkert et al. 2015, Hansen and Coenen 2015).

2.4 Encounter with the established sector

In Dahmén's conceptualisation, the new system was seen as developing through transformation processes and through the encounter with the incumbents in the established sector. The

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[3] Obviously, not all entrepreneurs are system builders and other actors also actively build new TIS.

[4] Dahmén defined the development block as a 'set of factors in industrial development which are closely interconnected and interdependent'. Concept of development block builds on 'Schumpeterian dynamics' with focus on transformation of industry and trade, focusing on what is changing the content of wider sectoral system.

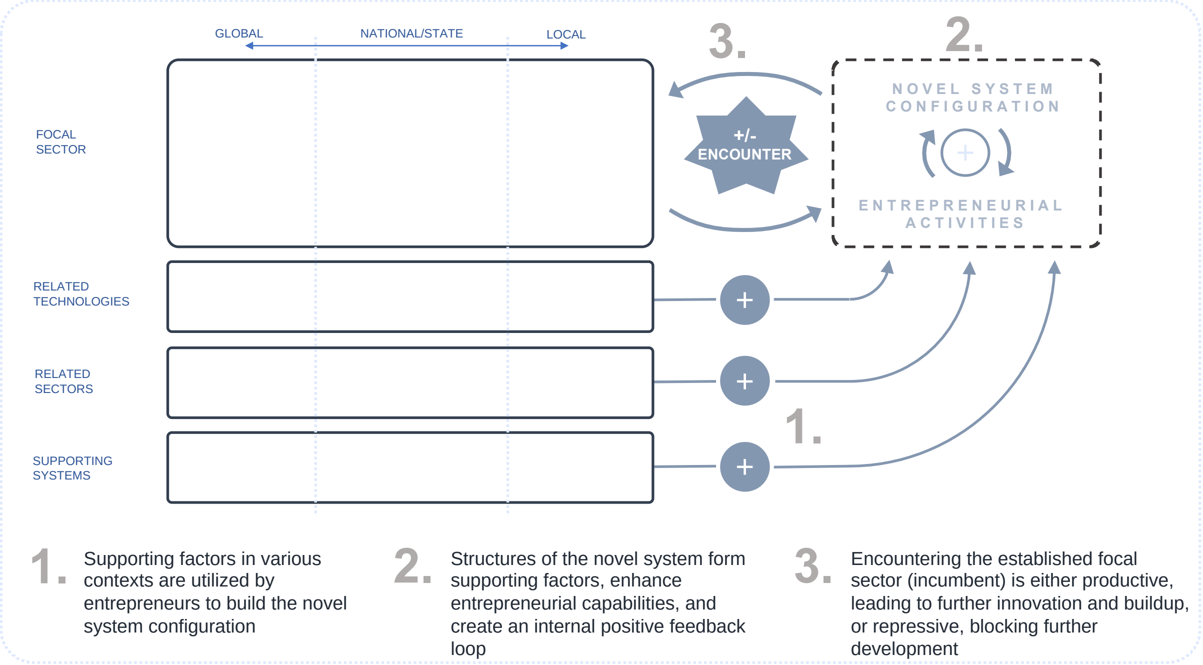
encounter between old and new was understood as a conflict with winners and losers, the outcome depending on a combination of entrepreneurial qualities and institutional setting (Dahmén 1988). This view of the encounter as a conflict with winners and losers has been modified in later innovation system literature, suggesting there are multiple kinds of encounters.

Here, we wish to draw on an idea from theories on the exercise of power to describe these encounters as being productive—in how they enable action—or repressive—in how they block or hinder action (Lukes 2005, Ahlborg 2017). Conflictual encounters tend to be very productive in how they generate strategic responses, emergence of new relations and process, thus creating multiple outcomes, both positive and negative. That is, encounters tend to produce ambiguous effects on the development of the new configuration. In contrast, repressive encounters are characterised by closed-down possibilities, stalemates, actors being incapacitated and innovation processes blocked from continuing.

Turning back to the important role of the context, we argue that entrepreneurs operate in and draw on various contexts at different stages in order to innovate and build their system. A repressive encounter at one place can lead them to shift arena to seek more productive encounters with incumbents elsewhere. Our cases demonstrate that the nature of the encounter is influenced by how entrepreneurs strategically use geographical and socio-technical contexts available to them, and seek new arenas. We can also see how important contextual factors are for the way incumbents behave in these encounters.

2.5 Analytical framework

Figure 4 visualises our analytical framework for studying the influence of micro-level activities in translating contextual factors into key TIS processes.



1. Supporting factors in various contexts are utilized by entrepreneurs to build the novel system configuration

2. Structures of the novel system form supporting factors, enhance entrepreneurial capabilities, and create an internal positive feedback loop

3. Encountering the established focal sector (incumbent) is either productive, leading to further innovation and buildup, or repressive, blocking further development

Figure 4 The framework captures how entrepreneurs mobilise supporting factors from various types of contexts to innovate and build the emerging TIS, with focus placed on how entrepreneurial activities (constituted by meanings, materials and capabilities) matter at the early stages of system buildup and for shaping the encounter with incumbents in the focal sector.

The left side of the Fig. 4 represents the different types of contexts, accounting for both the *spatial dimension* of contexts, ranging from local to global scales and organizational levels, and the *socio-technical context*, categorized as the focal (incumbent) sector, related technologies, related sectors and supporting systems (as described in Fig 2). This contextual schematic helps identify the origins of supporting and blocking factors (e.g. access to financial resources or exclusion from these) and how these are translated into TIS ‘functions’. Our entrepreneurs, together with their human and non-human partners, engage in activities—enabled by meanings, material resources and capabilities. Here we follow practice theory (Shove, Pantzar et al. 2012) to mobilise supporting factors in order to achieve their goals, and—through their actions and relations—build the system structure. Positive internal feedback dynamics (represented to the right in Fig 4) enable actors in their capabilities to act internally, but may also change/ strengthen their capacities in relation to the context, and in relation to the existing focal sector.

3 Research design

By conducting a comparative analysis of two emerging novel system configurations based on the same technology and with similar goals, but embedded in different geographical and socio-technical contexts and being developed by different actors, we intend to contribute to a better understanding of how strategic utilization of the context influences the problem solving that is necessary for a successful system buildup. The following analytical steps guide data collection and analysis and are based on the framework.

3.1 Analytical steps

In order to conduct a micro-level analysis of TIS buildup in unique contexts, we propose the following analytical steps, which correspond to the 3 steps in Figure 3:

1. Identify supporting factors in various contexts that are utilised by entrepreneurs to build the novel system, and blocking factors that they have to navigate.
2. Analyse how the context is strategically used to create elements of the novel system, that create an internal positive feedback loop and help expand entrepreneurial capacities to act.
3. Analyse how the interplay between context and internal system buildup shapes the (dynamic) encounter between novel system and the focal sector and how entrepreneurs and incumbents respond strategically, with implications for further development.

3.2 Case selection

As electricity production from variable small-scale renewable sources is increasing, prosumers need to sell, or alternatively store their electricity, or buy it in case of electricity deficit (Zhang, Wu et al. 2016). The increasing need for exchange of electricity calls for changes in the traditional electricity market business models. A promising new model that could support the creation of a distributed prosumer-based electricity system, comes with the possibility to trade electricity in a peer-to-peer (P2P) fashion, that is, directly without intermediaries.

While a number of existing energy companies have called their models *'Peer-to-Peer'* marketplaces, these however still involve retailers that mediate the market and interaction between the customers, making it *'Peer-to-retailer-to-Peer'* systems. These are for example, The Open Utility in the UK, PowerPeers in the Netherlands or P2Power in New Zealand that are facilitating a virtual market that matches the existing renewable energy suppliers with buyers. Individual electricity suppliers at the household or commercial level are however not able to directly act as sellers or buyers in this platform (Engerati 2016, P2Power 2017). Here, a direct exchange of electricity, that is, real P2P trading, is not enabled because the conventional digital infrastructure for trading needs to be controlled, verified and maintained by one or a small number of centralized actors. This is different in case of the blockchain, a novel digital infrastructure developed in the financial sector that allows a network of decentralized actors to reach consensus around a shared data state (e.g., transaction data) without the need of a central coordinator or the involvement of an intermediary. Applied to the energy sector, this removes the need for a utility or an energy retailer to be involved in transactions (Burger, Kuhlmann et al. 2016, Murkin J., Chitchyan R. et al. 2016, PwC 2016, Sousaa, Soaresb et al. 2018). Theoretically, in such a P2P trading network, small-scale producers act as both prosumers and traders of electricity on a free market. Individual households can become small energy suppliers and every consumer gets the chance to switch their supplier on a minute-to-minute basis. (Murkin J., Chitchyan R. et al. 2016).

At the inception of the study in 2016, there were only two demonstration projects of blockchain based P2P trading systems in the world: the Brooklyn Microgrid in New York, USA and the White Gum Valley demonstration project in Fremantle, Western Australia that were selected as case studies. We selected these case studies based on their similarities and differences, similarities being: (1) blockchain based trading platforms for P2P electricity trading, (2) set of technological components required for this technology to function, (3) key role of small entrepreneurial firms, (4) size and year started, (5) vision of the future electricity system. At the same time, the cases differ in terms of the (1) political, institutional and geographical context, (2) the existing physical setup in which they develop, (3) type of actors who actively engage in these projects.

3.2.1 The Brooklyn Microgrid (BMG)

In New York, the electricity market is a deregulated and electricity generation is provided by 24 mostly privately-owned but also public-authority owned power plants within or directly connected to the New York City. In New York City, ConEdison is the primary state-regulated electric utility proving distribution to the Brooklyn Borough. Although, ConEdison delivers the electricity, since the deregulation, utility companies are no longer the only option for energy supply and electricity consumers can purchase their electricity supply from an Energy Services Company (ESCO) of their choice (ConEdison 2018).

The Brooklyn Microgrid is located in the existing residential areas of Park Slope and Gowanus in Brooklyn on the outskirts of New York City. The project started in the beginning of 2016 as an initiate of a start-up company Lo3Energy that aimed to implement a blockchain-based P2P trading platform in a community microgrid. At the time of the study visit, about 80 prosumers and about 500 consumers signed up as future participants. The vision of Lo3Energy is to create a distributed electricity market system that is framed around localised consumption, production and transactions. Besides Lo3Energy and the local residents, other actors involved are: Siemens, the Brooklyn Borough Presidency, local utility Con Edison, National Grid, Fire Department, the New York city Housing and Transit Authority and Department of Education (Lo3Energy 2017).

3.2.2 The White Gum Valley (WGV)

In Western Australia (WA), the electricity grid is completely isolated from the rest of the Australian continent. The electricity market is highly regulated, with a natural monopoly of state-owned utilities Western Power and Synergy. All the transmission and distribution infrastructure, both newly built as well as existing poles and wires, are owned by the public grid operator Western Power. Synergy on the other hand is the electricity provider and retailer.

Since early 2016, experiments with a blockchain-based trading platform for P2P electricity trading were performed in the White Gum Valley development project, housing more than 150 people. WGV is located in a small coast city of Fremantle in Western Australia. It started as a zero-carbon housing development project that acts as a living laboratory for Australia's first ever residential P2P electricity trading market platform. PowerLedger, a locally based start-up company provides a blockchain-based trading platform that was previously implemented in Busselton Lifestyle Village in Western Australia, which was a small community of thirty houses trading electricity behind the meter. Vision of Power Legder is to create a totally distributed system with prosumers and consumer at the heart of the electricity market. Beside

PowerLedger, a wide range of actors are involved in the P2P electricity trading project such as Curtin University in Perth, the Low Carbon Living CRC national research and innovation hub, housing developer LandCorp, the City of Fremantle and PV and battery system distributor Solar Balance as well as Western Power and Synergy (Diss 2015, accesshousing.org.au 2016).

3.3 Methodology

This study is designed as a comparative case study based on qualitative research design (Flyvbjerg 2006, Yin 2009) that aims to study the build-up process of new socio-technical systems for P2P electricity trading in form of local demonstration projects that attempt to create distributed networks of prosumers. While P2P trading can practically be operationalised without using blockchain as the digital infrastructure, other P2P trading models are not included in our analysis. While this paper studies the emergence of the innovation system for P2P electricity trading via blockchain, the details about the technical performance of the system is beyond the scope of this analysis.

The analysis is informed by data consisting of interviews, participatory observations and desktop research. In total, 28 semi-structured interviews were conducted with various participants directly involved in the P2P electricity trading demonstration projects, including representatives from small entrepreneurial companies, researchers, electricity system operator and retailers, local residents and other key informants. The number of interviews was limited by researcher' time spent in the field and the ability to get access to key informants involved in studied projects. The interviews were recorded, transcribed and analysed using the 'Visualising Understanding Environment' software and content analysis. The process of data analysis involved triangulation processes to improve the validity of the data collected via interviews, observations and secondary case-related documents. Finally, the data was conveyed through a retrospective narrative approach (Clandinin and Connelly 2000).

3.3.1 System boundaries

The technology in focus is the new model of electricity trading, i.e. Peer-to-Peer trading via the blockchain. This study draws analytical boundaries around those elements that are directly influencing or are influenced by the new system configuration developing around the focal technology. While we can clearly define the analytical boundaries, it is more difficult to clearly state which elements are inside and outside our 'boundary' as we describe a process rather than a snapshot in time. During an innovation system builds up, system actors draw on external elements, which can make them internal, i.e. the system configuration develops over time and external elements loosely related initially become strongly connected, eventually so entangled and embedded that they become part of the novel system. Considering our analytical argument, we set the geographical starting point at the local level development projects and from there we explore a variety of contextual factors from other spatial levels and sectors as external factors that can become internalised locally. From a temporal perspective, this study captures the novel system buildup from the inception in 2016 until 2018.

4 P2P electricity trading system buildup

In the following result section, we describe the early stages of TIS buildup in our Australian and US case respectively. The processes are analyzed from the perspective of the entrepreneurs who acted as innovators and system builders and we show how they addressed context-specific problems, mobilized resources and attempted to establish new actor networks in their ambition to promote P2P electricity trading—resulting in more or less productive encounters with the incumbent electricity sector. The case comparison illustrates how strategic actions and responses involved in taking the step from niche market experimentation to disruptive innovation are central to developing the TIS structure and functions, as well as shaping the encounter with incumbents.

4.1 The White Gum Valley Project

4.1.1 Finding a local niche market

In White Gum Valley, the story of P2P electricity trading started with local knowledge development and diffusion processes, as the PhD student Jemma Green, at Curtin University Sustainability Institute (CUSP) in Perth identified a new solution for installing solar PV in new density housing developments. In 2015, she published about the 'citizen utility' governance model for apartment housing,[5] to allow for a more citizen-based management of solar and battery systems in strata titled[6] density housing developments. In these developments, residents usually have no commercial incentives to invest in solar systems due to the split-incentive issue[7] (Green and Newman 2017). Green found a way to overcome this disincentive and help develop the market for solar PV. Her research about citizen utilities was place-specific, addressing a niche market opportunity in the *embedded networks* behind the utility meter[8] in the context of WA. Here, the increasing demand for solar PV for behind the meter self-consumption was

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[5] *Citizen utility* is a consumer, producer and electricity system manager in one. It is the foundation of the blockchain-based P2P system developed by Power Ledger.

The *strata utility governance model* (Green, Newman 2016) incentivizes solar and battery storage systems in strata developments by forming a microgrid or embedded electricity network where the shared small-scale electricity infrastructure could be owned and managed by the development's strata company, acting as a small-scale utility. Such an arrangement implies that with a microgrid of solar and storage in strata developments, the tenants and apartment owners pay their electricity bill to the strata company, instead of an energy retailer, which provides the strata company additional revenue that can be utilized to compensate strata costs, maintain the energy infrastructure assets or contribute to fund the future replacement of it (Green and Newman 2017)

[6] Strata title is a combination of individual ownership of part of a property (such as an apartment), and a shared ownership of the rest of the 'common property' (such as foyers, driveways, gardens) through a legal entity called a strata company. (https://www.strata.community/understandingstrata/what-is-strata)

[7] The *split incentive issue* in strata developments is the mismatch between the investor and the beneficiaries of the renewable energy infrastructure resulting in no commercial incentives to invest in solar technologies because there is no effective way to share the benefits, risks and the costs of the energy assets and generated electricity. The split incentive issue has been problematized in Jemma Green's research in which she also emphasized that without an energy storage that enables sharing of solar energy, it is not possible to attain an optimum value for the shared generation infrastructure.

[8] Keeping electricity 'Behind the meter' refers to individually generated or stored electricity that is kept on a residential or commercial property without crossing the utility metering system to the regulated electricity infrastructure managed by the electric grid/utility.

driven by the abundance of sunshine, high electricity prices, and increasingly affordable solar and battery systems.

The ‘citizen utility’ model supports the growth of behind the meter self-consumption—which creates complications for the incumbent electricity sector in WA as customers chose to defect from the grid—in new density housing development, thus addressing targets of increasing energy efficiency in the WA housing sector. In 2015, Jemma Green recognized this as an opportunity to develop P2P electricity sharing and actively searched for a housing demonstration project to implement the strata utility governance model and turn the new knowledge into entrepreneurial experimentation. Green identified a sustainability housing development in the White Gum Valley (WGV) led by LandCorp, a state-owned incumbent housing development company. The WGV was a density housing[9] project with focus on tree retention, energy and water efficiency, diversity and density in Fremantle, a city south of Perth. The city prides itself for being a leader in sustainability, with ambitious density housing goals, influencing the guidance of search for solar PV and P2P electricity sharing, and a favourable local environment for Green’s research. Negotiations and network formation between Jemma Green, CUSP researchers, developers from LandCorp and the city of Fremantle led to local legitimation processes reflected in a clear support from the Mayor of Fremantle and the decision to integrate solar and battery systems and trial the strata utility governance model in one of the demonstrations in WGV, the “Gen Y” multi-residential dwelling. This opportunity to trial Green’s model helped mobilise necessary physical resources in the housing sector in form of an embedded solar distribution network.

Green then approached Solar Balance, a local engineering company with years of expertise in implementing solar and battery systems in embedded networks and microgrids, in order to gain the technical expertise and develop the knowledge essential for application of the P2P trading

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[9] The housing sector in WA was historically dominated by low-density residential developments, making Perth one of the most geographically spread out cities on earth. The WA government has set density targets, i.e. build more apartment houses to accommodate the growing population, limit urban sprawl and decrease car-dependence as well as create more walkable and liveable neighbourhoods near local services (Newman and Kenworthy 2007, Matan and Newman 2012).

model in embedded networks. Financial resource mobilization took place as the researchers at CUSP, developers at LandCorp and engineers at Solar Balance combined their expertise to—successfully—apply for a financial grant from the Australian Renewable Energy Agency (ARENA) to purchase batteries, the most expensive part of the physical infrastructure. With more money in the project new actors decided to enter, expanding the local actor network, creating legitimacy and mobilising additional physical resources for the project. Two more developers in the WGV, the Access Housing and the Yolk Development Group, decided to integrate solar and battery systems and trial the governance model in two more apartment housing developments. During this initial period of experimentation, Green was instrumental in driving the process, bringing actors together and forming the necessary local supply chain that could operationalise the research concept and turn it into an entrepreneurial experiment.

As the technical details of the shared solar and battery systems were being worked out, Jemma Green and Solar Balance discovered a knowledge gap and potential problem related to how to fairly price the electricity flows in the embedded networks. In other words, the technical set-up of solar and battery systems had to be complemented with a fair accounting system. The identification of this knowledge gap led Green to search for a technological solution outside the Australian housing and electricity sectors.

4.1.2 From local solution to global ambitions

Locally available knowledge was not enough to solve the problem of how to fairly price electricity behind the meter in apartment housing. It turned out that the potential solution came from a different sector developing at the global level. The WGV experiment underwent a transformation—from local niche solution for P2P electricity *sharing* to a P2P electricity *trading* system with disruptive ambitions—once the successful local-level system buildup started to draw on global resources and knowledge.

In 2008, the creation of the first cryptocurrencies, traded with the help of the blockchain technology, led to a global growth in new businesses that aimed to disrupt various sectors by providing P2P exchange of cryptocurrency and other assets in a decentralised network without middlemen. Disruption was also the goal for Ledger Assets, a Perth-based technology company developing blockchain based solutions. As blockchain was still in its early days, Ledger Assets was actively looking for investors and market niches where it could implement its technological expertise and business ideas. In 2016, Green beside being a PhD student at CUSP, also served as a councillor in Perth City Council and representatives from Ledger Assets approached her to discuss applications of blockchain in Perth's parking system. During the discussion, Green explained the strata utility governance model and the problem they faced with fair accounting, whereupon the software developers from Ledger Assets saw a potential for blockchain to solve the billing issues, by acting as a distributed ledger that, theoretically, delivers low-cost, frictionless accounting, possibly also for electricity transactions. By forming a network with Ledger Assets, the WGV experiment mobilised new technical knowledge and a new technological component: the blockchain.

At the time, in 2016, blockchain technology, initially applied in the financial sector, showed a lot of potential but had very few applications in the energy sector. With help of Ledger Assets, Green understood the potential of combining her research with the blockchain technology and brought in energy sector specialists from consultancy company Future Effects to explore the opportunities in the electricity sector. The local network formation processes led to the creation of a new actor, the Power Ledger, with Green and representatives from Ledger Assets and Future Effects as directors and board members. The creation of a new company increased the ambitions, launching the idea of P2P electricity trading across the regulated electricity grid, moving from behind the meter to across the regulated electricity grid. Hence, the initial intention to solve a local problem morphed into an ambition to solve issues in the dominant electricity system in Western Australia and globally. While the 'citizen utility' research concept remained integrated in the Power Ledger's vision, the company's ambition came to encompass the 'democratisation of power', i.e. the creation of consumer-centric electricity systems.

However, in 2017, the use of blockchain technology in electricity trading was still immature and required further experimentation. Power Ledger thus started seeking for financial resources to support testing the business model and conduct additional demonstration projects. As a business built around blockchain, Power Ledger used a novel type of fundraising: the Initial

Coin Offering (ICO)[10]. The ICO was highly successful and resulted in raising 34 million AUS dollars. With the success in tapping into financial resources at the global level, Power Ledger enhanced their legitimacy and became part of the 'hype' around blockchain as the WGV project received substantial media attention and interest from the global audience.

At this stage, the actor-network was predominantly local, while key functions, especially mobilisation of technological and financial resources, and building legitimacy, developed through cross-scale processes and by drawing on external networks. But the global promotion of PowerLedger resulted in opportunities to expand trials beyond Freemantle and WA, engaging in entrepreneurial experimentation and new knowledge development and diffusion in other geographical contexts.

4.1.3 Productive encounter with the local electricity sector

To this point, a new supply chain for P2P electricity trading in the WGV was built without having to interact with the local electricity sector. No significant blocking factors were experienced in the system buildup process while the P2P electricity trading was kept in the embedded networks of apartment houses, beyond the reach of the incumbents. However, as the ambition in the WGV project shifted from enabling P2P sharing inside the apartment houses to a vision of trading between buildings across the regulated electricity grid, the interactions with the incumbent electricity sector became more frequent and some friction and problems emerged.

In early 2018, the existing regulations in the local electricity system didn't provide favourable conditions and incentives for the innovation of P2P electricity trading. The grid infrastructure between the buildings in the WGV area was owned by Western Power, the state-owned grid operator, and managed by state-owned utility Synergy, which implied that operationalising trials across the utility grid would require market deregulation and full contestability in the WA

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[10] An ICO is similar to an IPO and has recently been used extensively by cryptocurrency ventures to raise funds from individual investors and enthusiasts and bypass the otherwise regulated capital raising process that is a criterion from banks or venture capital investors.

energy market in order to enable small-scale electricity producers to become retailers.[11] However, under the political leadership in WA in 2018, such changes did not seem to be on the agenda. Furthermore, the utility network fees were too high to make P2P trading across the utility grid economically profitable, especially for small residential consumers. The high network charges included debt for previous significant investment in bolstering grid infrastructure and long-distance transmission, a financial situation that did not reflect the increasingly local and distributed character of the grid.

Despite the fact that the existing regulatory structure in the WA electricity sector didn't provide the guidance of search for P2P trading in the incumbent electricity sector, the incumbents' reaction to the encounter with the newcomer was to join the WGV actor network. While the success of the WGV project played a key role in attracting the attention of incumbents, the decision by Western Power and Synergy to become involved was primarily influenced by a *destabilisation* of the sector caused by high electricity prices, shrinking feed-in-tariffs (REBs),[12] and an increasing share of rooftop solar generation and battery systems. These factors incentivised prosumers to keep electricity production and consumption behind the meter and defect from the grid. Western Power and Synergy observed potential advantage from the P2P electricity trading model as a new opportunity to re-engage with customers and increase the utilisation of the conventional grid infrastructure. Over time they joined the P2P electricity trading project and actively participated in the negotiations about the regulatory aspects of P2P electricity trading.

As the P2P trading system was being integrated in the apartment houses in the WGV development, the WGV actor network mobilised additional financial resources from the federal government to trial and expand the P2P trading across the regulated grid. The grant for a so called 'Smart Cities and Suburbs' project was dedicated to support the move beyond embedded

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[11] As of 2018, prosumers with capacity below 50MW per year can't sell their surplus electricity without Synergy.

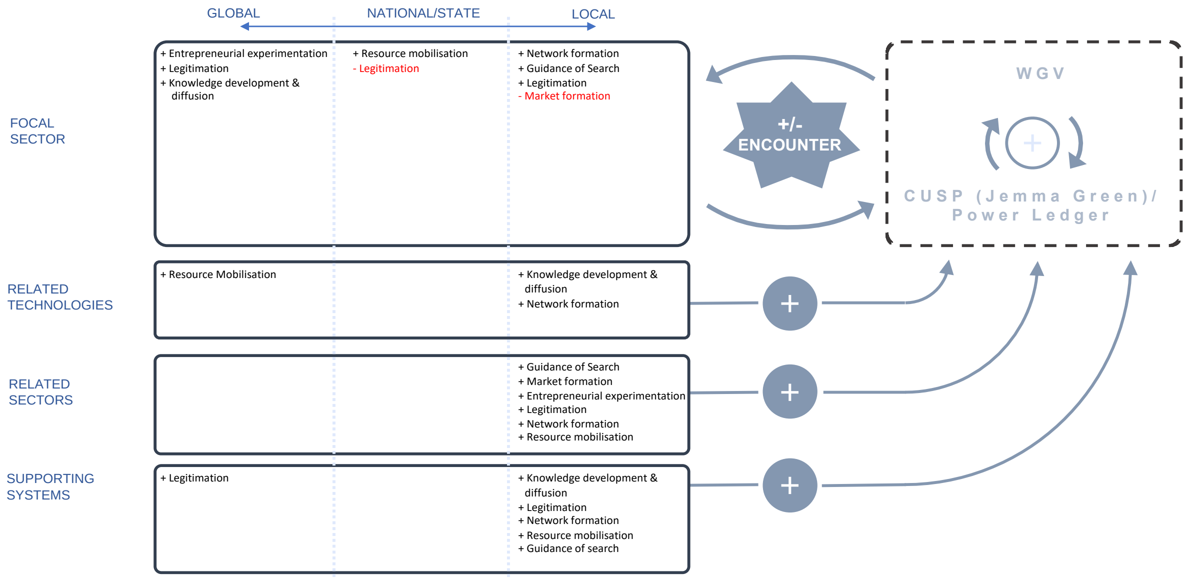
[12] Renewable Energy Pay Back Scheme was initially 40 cents per kWh and dropped to 7 cents for a kWh as of 2018, while the grid electricity price goes up to 30 cents for kWh.

networks in WGV and “assess how cities of the future can integrate data and blockchain technology to integrate energy (and water) systems infrastructure” across the city of Fremantle (reference: Smart Cities Grant report). The additional financial resources from the national government didn’t result in a regulatory change, but further supported the local network formation, and its institutionalisation into a ‘consortium’ of actors, consequently contributing to further legitimation processes related to P2P electricity trading.

Following the establishment and negotiations in the consortium, Western Power and Synergy granted an exception in the tariff structure to make P2P electricity trading economically more viable for the residential customers and to explore the potential of P2P electricity trading in the WA’s context. Such a regulatory exception temporarily removed the main institutional obstacles and enabled CUSP to conduct more P2P related research and Power Ledger to trial their technology across the regulated electricity infrastructure, but creating a clear vision of how to scale up to P2P electricity trading across the grid, shaping the local guidance of search in favour of P2P trading systems.

In short, in the case of WGV, the encounter with the local electricity system was productive due to a number of processes, presented in Figure X. At the time of encounter, the experiment with P2P electricity sharing in WGV had already developed a fairly mature TIS structure through interactions with other sectors, technologies and supporting systems locally. In addition, the entrepreneurial actors had strategically drawn on cross-scale networks and their local embedding to mobilise resources and knowledge to build up enough strength and legitimacy to attract the support of the national policymakers and the local incumbent actors. That the incumbent chose to engage with, rather than block, the new actors was also influenced by the unfolding crisis in the local electricity sector caused by growing grid defection on the consumer side.

While the P2P electricity trading system buildup seems to have gained momentum in WA, the market creation process in the context of the local electricity sector is not yet initiated. In the trials in embedded networks in housing apartments, the residents are customers and thus given, whereas in the ‘real’ P2P electricity trading network across the grid, an explicit customer market is yet to form.


	GLOBAL	NATIONAL/STATE	LOCAL
FOCAL SECTOR	+ Entrepreneurial experimentation + Legitimation + Knowledge development & diffusion	+ Resource mobilisation - Legitimation	+ Network formation + Guidance of Search + Legitimation - Market formation
RELATED TECHNOLOGIES	+ Resource Mobilisation		+ Knowledge development & diffusion + Network formation
RELATED SECTORS			+ Guidance of Search + Market formation + Entrepreneurial experimentation + Legitimation + Network formation + Resource mobilisation
SUPPORTING SYSTEMS	+ Legitimation		+ Knowledge development & diffusion + Legitimation + Network formation + Resource mobilisation + Guidance of search

4.2 The Brooklyn Microgrid Project

4.2.1 *Identifying a local niche market for a global technology*

In contrast to the Australian experience, the initial phase of P2P electricity trading system build-up in Brooklyn, New York, was technology driven and focused on finding a local niche market for a new ‘global’ technology. The entrepreneurs strategically selected the neighbourhoods of Brooklyn in New York as a place where their ‘solution’ could be developed and used locally available resources to initiate the system buildup, while promoting their P2P model globally.

The story of the Brooklyn Microgrid dates back to 2012, when the New York City (NY) was severely affected by Hurricane Sandy and a number of suburbs experienced blackouts that lasted for weeks, in some cases for months. The events following the hurricane served as a catalyst for institutional changes and innovation with the aim to improve the aging electricity infrastructure. In 2014, Governor A.M. Cuomo announced the Reforming the Energy Vision (REV) a plan to build a clean, resilient and affordable energy system for all New Yorkers (NYSERDA 2017). A crucial part of the REV strategy is building community microgrids, for which the New York state offers public funding via the NY Price Community Microgrids Competition. Since the inception of the REV policies, microgrid development projects have been flourishing across the state (Wood 2016).

In the context of WA, the perceived need for more solar in (the related housing sector) apartment buildings created a niche for P2P trading in the WGV, and the REV initiative in NY provided support for community microgrids, which seemed like a suitable niche (in the focal electricity sector) for P2P electricity trading in the BMG. After the event of Hurricane Sandy, entrepreneurs from a start-up company Lo3Energy worked with knowledge development related to their vision to build a local resilient distributed electricity grids supported by blockchain- based P2P electricity trading platform. The changing electricity system in NY and the REV initiative were attracting new actors and guided Lo3Energy to take advantage of the niche market of community microgrids to experiment with their business model. The changes initiated by the REV thus motivated Lo3Energy to tap into the, expecting to easily gain social legitimacy, financial resources and opportunities for entrepreneurial experimentation. Unlike in the case of the WGV that initially started as an exclusively local development, Lo3Energy from the very early stages, utilised global developments in blockchain technology to promote their idea, as blockchain could potentially overcome the biggest barrier in enabling a local microgrid, namely how to manage billing in an increasingly distributed grid infrastructure.

While not being from Brooklyn originally, Lo3Energy strategically picked the areas of Park Slope and Gowanus in Brooklyn as sites to initiate the BMG, to test the P2P trading in the setting of a community microgrid. These areas seemed suitable for the BMG project not only because they were affected by the blackouts after the Hurricane Sandy, but also because of the strong community and sustainability values as well as high penetration of rooftop solar panels. In contrast to the case of the WGV, where the customer market for P2P trading was provided by the local housing sector in form of residential customers, Lo3Energy entered the existing areas in Brooklyn with the intention to form a customer market for their technology. Lo3Energy started approaching residents and small businesses in the neighbourhood, raising user awareness and diffusing knowledge about the opportunities offered by P2P electricity trading. By involving residents and businesses in Park Slope and Gowanus, Lo3Energy was able to access physical resources in form of rooftop solar systems and increase knowledge development by accessing real-time metering data from residents for proof-of-concept purposes. In addition, by educating the local communities about P2P trading and the role of blockchain, Lo3Energy attempted to legitimise their technology, create the local knowledge, establishing local networks.

Following initial discussions with the local community, two local residents, a prosumer, Eric and his neighbour Bob, a consumer, were approached to demonstrate the first direct transaction between neighbours via blockchain, in April 2016. A short movie about the first P2P transaction on President Street in Brooklyn went viral and gained much attention from the global media, contributing to legitimation processes. Lo3Energy used the first P2P transaction as a main promotion point for their business model.

4.2.2 Repressive encounter with the local electricity sector

While the local context in NY seemingly created a favourable selection environment for P2P electricity trading via blockchain, the entrepreneurs soon encountered problems that developed into a repressive encounter with the incumbent electricity sector in NY.

Firstly, the system buildup of the BMG project was hindered by difficulties to form a local actor network. Despite the direct engagement with the residents, the local community had weak expectations from P2P trading via blockchain. This was influenced by strong legitimacy of the dominant electricity sector amongst the communities in Brooklyn, customers of the incumbent utility ConEdison often found their existing electricity provider more trustworthy than small electricity retailers (ESCOs) and new companies offering innovative services in the electricity sector. Lo3Energy did not manage to gain the legitimacy or establish an active collaboration with the residents in the area.

Second, access to financial resources for the BMG project from the state level was paradoxically hindered by the REV itself as the NY Price for community microgrids was only available for utility-led project proposals. The REV initiative provided utilities like ConEdison operating the grid in Brooklyn with a chief position and control over the innovation process by selecting what businesses and entrepreneurs to engage with and receive financial support, while the BMG was not one of them. The initial expectation that REV would establish an innovative niche market, the institutional design positioned incumbents as the ones controlling the process and setting the boundaries for the ‘niche’.

Beside the weak structural buildup and inability to access local funding, the selection environment provided by the REV initiative over time appeared less favourable than Lo3Energy initially assumed. Similarly to the case of the WGV, a number of sector-specific regulations created system-level roadblocks for the P2P electricity trading system buildup. For example, by regulation, prosumers in NY are obliged to exclusively sell their excess electricity to the accredited utilities, and they are also incentivized to continue trading with the utility through net-metering[13], which is exclusively provided by the utilities. Net-metering offers prosumers an attractive way to reduce their electricity bill, hence prosumers are strongly incentivised to feed electricity back to the utility grid instead of keeping it on their property, in the community or selling it to their neighbours, making P2P trading less attractive than the existing trading structure. In addition, the rooftop solar system size is restricted to 110% of the historically calculated on-site electricity needs, which restricts prosumers from significant financial gains from their individual systems. Furthermore, solar systems can only be installed by home owners while tenants are not enabled to benefit from the behind the utility meter on-site electricity. And while in the of the WGV, the regulatory barriers for P2P electricity trading model were overcome through a crisis in the existing electricity system, this was not the case for the BMG as the incumbent sector didn't seem to be under pressure to realize the promise of P2P electricity trading.

Barriers also appeared in relation to Lo3Energy's effort to build a physical islanded microgrid in the area. While Lo3Energy was developing the technology that enables P2P electricity trading as a virtual accounting layer of the transactive grid, it also needed to be complemented by a physical microgrid infrastructure. The existing electricity grid in the area of the BMG is old, not being able to operate in an islanded mode. Transforming a conventional grid infrastructure into an islanded transactive microgrid require specific technical components such as smart converters, microgrid controllers and batteries. Despite the fact that Lo3Energy formed a partnership and mobilised financial and technical support from Siemens, the incumbent electricity sector did not give Lo3Energy access to the utility-owned grid infrastructure, which hindered progressing from the stage of 'proof-of-concept' to real P2P trading in a community micro-grid. As such grid restructuring requires an approval from the Public Service Commission, the energy system regulator in NY. And while Lo3Energy entered into negotiations with the Public Service Commission to change the current regulations and enable

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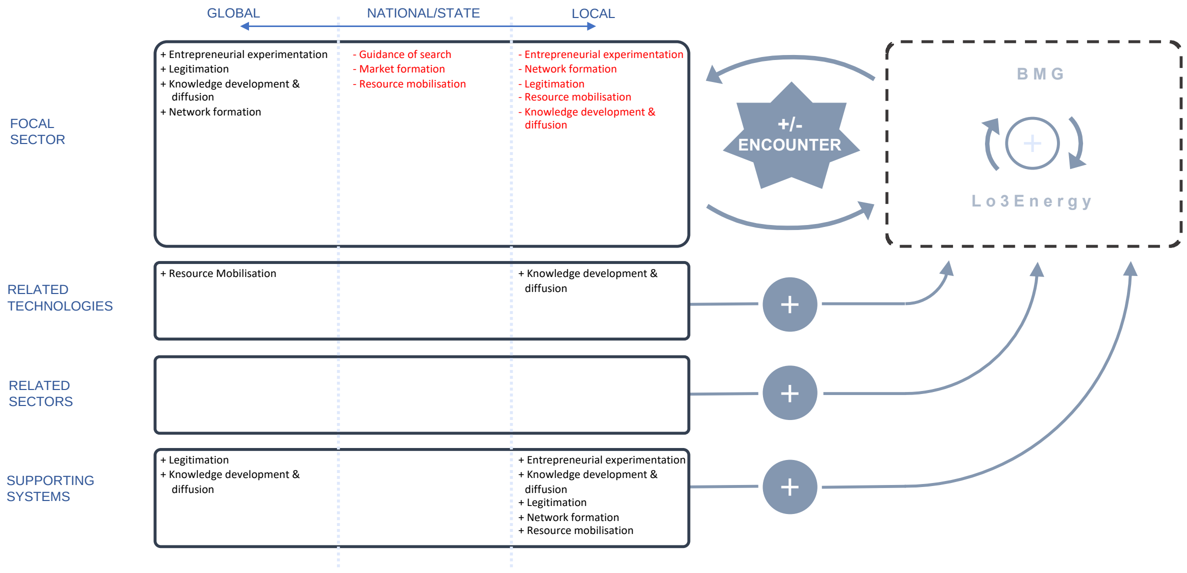
[13] A financial mechanism that pays prosumers a retail price for feeding their solar energy into the utility grid.

the BMG to move beyond the proof- of-concept, the trial was on hold and the entrepreneurial experiments and knowledge development necessary for a further system buildup could not be achieved. The very institutional context that attracted Lo3Energy to enter the local context eventually posed the biggest barriers to them and guided their search to other contexts.

4.2.3 Moving from local to global

Though Lo3Energy struggled to mobilise resources and form an actor network around P2P electricity trading in NY, they continued the system buildup elsewhere, thereby creating a free-floating innovation process tapping into global networks and resources, with localised applications. Even though the marketing of the concept started with the transaction between two residents in Brooklyn, the simulation of the first ever P2P electricity transaction was a legitimation success, creating positive expectations at the global level, especially among communities of blockchain-enthusiasts. The BMG was thus able to attract collaboration with Karlsruhe Research Institute in Germany to develop and diffuse knowledge as well as enable experimentation and implementation of the P2P trading platform in Germany. Furthermore, the BMG project was able to gain private financial support and expertise from major private companies with global markets such as Siemens, Breamer Energy ventures, and Centrica. The stalemate in NY led Lo3Energy to realise the need to move their technological solutions elsewhere to experiment in various regulatory environments, collaborate with other electricity utilities and access different types of electricity grid infrastructures. By early 2018, they had initiated collaborations with other utilities and communities in Germany, other states in the US, Australia and UK and expected to initiate trials of their P2P electricity trading platform. They saw the network formation and international support as key to enhanced legitimacy and experiment with their P2P trading model in other contexts, as a way to maintain the innovation buildup momentum and to improve the changes to eventually achieve the institutional change in NY, needed for the BMG to be operationalised. The BMG system buildup processes are summarized in Table X.



5 Discussion

We now discuss our theoretical contribution and empirical findings in relation to the existing literature and reflect on what the case comparison has to teach us about the prospects of a radical transition to a Smart-grid system configuration.

5.1 The role of context and micro-level activities in the system build-up

In this paper, the TIS framework provided a useful analytical lens to study local level demonstration projects. While most analyses focus on a later stage of system buildup, we conduct a micro-level analysis of early experiments and shaping of novel socio-technical system configurations in becoming. This allows us to explore the role of individual agents, such as entrepreneurs, and how they strategically utilise favourable settings and draw on cross-scale supporting factors and processes to stimulate innovation, solve problems and gain strength. Previous TIS literature highlights the important role of the context, as well as that of entrepreneurs, but these have been kept analytically separate. We contribute to the existing literature by analytically linking these, which helps us get a deeper understanding of why specific innovation systems succeed to develop structurally, embed in the geographical context, and gain momentum—while others fail and stagnate—as they encounter the incumbent sector they are trying to transform.

The case comparison shows the importance of a conducive local environment providing guidance of search towards the novel configuration as previously emphasized by Coenen, Benneworth et al. (2012), but illustrates how entrepreneurs make use of cross-scale networks and other arenas and sectors to mobilise resources, knowledge, gain legitimacy and policy support development (Binz and Truffer 2017). We make sense of the different 'contexts' identified by previous literature by suggesting these can be analysed along their spatial and sociotechnical dimensions. In line with Hargreaves, Longhurst et al. (2013), we emphasise the *agency* of actors—in our cases entrepreneurs—who actively negotiate and perform their activities, while *embedded* in webs of social and material relations. Their motivations and capacities are shaped by the plural contexts of which they are part, and they try to reshape these contexts through their strategic actions. Our empirical evidence both in WGV and BMG points to the crucial role of entrepreneurs as system builders, as their efforts to innovate and overcome hindrances drove the formation of actor-networks, brought in necessary resources and support (Markard and Truffer 2008, Alkemade, Negro et al. 2011, Farla, Markard et al. 2012, Planko, Cramer et al. 2017, Musiolik, Markard et al. 2018).

However, identifying seemingly conducive contexts for innovation is not always enough to successfully induce the system buildup processes, as the encounter with the locally embedded incumbent sector can be repressive. Our empirical cases show that system builders can improve their bargaining position in the encounter with incumbents by finding opportunities in other related sectors, previously emphasized by (Bergek, Hekkert et al. 2015, Hanson 2018, Mäkitie, Andersen et al. 2018)—locally or elsewhere—which can be particularly helpful in the initial phase of the system build up as means to enable real-world application and experimentation. But whereas strategic utilisation of supporting factors in other sectors or geographical contexts can serve as means to strengthen and maintain the momentum in the system buildup, these are probably not sufficient for achieving a productive encounter with the local incumbent sector. To this end, building the local actor network and creating a local supply chain—drawing on a combination of local and global knowledge—appear as critical, but also, that the position of incumbents is destabilised somehow. Clearly, the positioning of both entrepreneurs and incumbents matters. Local embedding—having local connections, being familiar with the sectoral and institutional context—facilitated for our Australian entrepreneurs to translate their ideas into an advocacy coalition and a to demonstration of the technical configuration as such. The crisis in the WA electricity sector contributed to the productive encounter, which opened the way for wider ambitions to innovate and disrupt electricity markets around the world. In contrast, in NY, the REV initiative seemingly opened to external innovators, but de facto prioritized the local utilities and allowed them to steer the process and control the experimentation on the grid. In response to the locked situation, the entrepreneurs found it more fruitful to try other geographical settings and seek more productive encounters elsewhere.

This highlights how entrepreneurs make use of spatial and organisational levels for different reasons. Local embedding and success can trigger global ambitions and further experimentation in other geographical contexts, while actors embedded in a global TIS of the key technology (e.g. blockchain) are less vulnerable to unsuccessful local encounters and can cope with the local inertia by using the global and national sectors and supporting systems to move and replicate their emerging novel system configuration in other localities.

5.2 Implications for the future 'Smart-grid' configuration

Our findings have implications for the Smart-grid scenario and trajectory. Our analysis confirms the assumption made by Hojčková, Sandén et al. (2017) that Smart-grid scenario involves a combination of niche accummulation and hybridisation as its successful buildup relies on achieving the collaboration between incumbents and new entrants especially from other sectors. The incumbents that contribute to the Smart-grid system buildup, however don't have to come from the electricity sector but instead from another sectors, such as the housing sector, that provides a niche for an innovation that is otherwise likely to be repressed in the encounter with the regime it is aiming to transform. In other words, the entrepreneur-driven Smart-grid related developments need to find a niche opportunity for initial testing and experimentation to build the strength before engaging with the incumbents from the electricity sector.

Furthermore, our analysis confirms the importance of the local governments and entrepreneurs from novel firms in developing the Smart-grid system, however we also find that they play different roles in the system buildup process. Our cases show that local and national governments play a key role in providing the legitimacy, in form of favorable policies, and by providing financial resources, but it is the new entrants such as entrepreneurs that can navigate the contextual opportunities and mobilise collective action to form networks that support the system buildup. And while the incumbent utilities seem to be supporting Smart-grid related innovation in the effort to better accommodate distributed renewables in the existing grid, they tend to hybridize it to maintain their position in the transition process, potentially hindering developments towards the idealised Smart-grid configuration that fundamentally questions dominant practices and routines.

This challenges the possible assumption about the Smart-grid scenario, which at the first glance could be envisioned as the most realistic path, but in fact leads to a lot of friction as compared to the alternative trajectories of a global Supergrid or a fragmentation into Off-grid systems, because it builds on existing structures, while incorporating novel elements. It therefore requires complex negotiation processes as it radically challenges incumbents' roles as intermediaries controlling the trade platforms. This is not the case for the Supergrid scenario, which entails a process of replacing fossil fuel-based generation with green technologies, without challenging centralised control, nor is it the case for the Off-grid scenario that leaves the existing system behind and builds a new one instead in parallel.

6 Conclusions

The purpose of this paper was to analyse the innovation system build-up process towards the 'Smart-grid system configuration and examine the role that agency and context play in this process. We applied the TIS approach and demonstrated its usefulness in analysing local demonstration projects as novel socio-technical systems. This was achieved by extending the TIS framework with a categorisation of the context and its relationship to agency that revealed important insights in the analysis of early innovation system build-up at the level of local experiments. Hence, we were able not only to confirm the importance of the context and the role of entrepreneurs in the early stages of the innovation system buildup but also analytically link these previously separate analytical concepts to the TIS framework.

It is important to note that the conclusion from our analysis are specific to the selected local demonstration projects. Although they are likely to have some more general validity, especially for similar projects, there is a need to further studies in different parts of the world, driven by different actors. Furthermore, while the results might be generalizable to other small demonstration projects, this might not be the case as systems grow and mature. Additional studies are therefore needed to reassess our conceptualization of the TIS framework for studying system build-up processes at other levels of aggregation and maturity.

While our insights about micro-level innovation system buildup can be useful to get a deeper understanding of the transition towards a Smart-grid system, further research attention should be directed to the individual expectations and roles within actor networks supporting Smart-grid-related developments to better manage the friction and navigate the complex negotiation process. Furthermore, more empirical work is needed to better understand the role of the prosumers, who are expected to play a key role in the idealized Smart-grid scenario. The P2P electricity trading developments in our selected case studies suffered from no direct involvement of prosumers, who are at the same time seen as the core of this system configuration. The involvement of prosumers will become increasingly important as development projects scale-up to real-world applications across the regulated electricity network, directly affecting the first P2P network participants. The characteristics of prosumers who are willing to contribute to experiments will therefore be important for the success of the transition towards the Smart-grid system.

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