The role of business models for technology innovation

– a case study on Power-to-Gas

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Abstract

The thesis contributes to the understanding of business models as performative market devices for development and uptake of technological innovation in low carbon transitions. Transition studies are criticised for neglecting the role of business models as part of socio-technical transitions. Transition research agendas call for taking a pragmatic view on the role of business models. The thesis draws on a framework, based on the multi-layered perspective that views business models as performative market devices. Business models then act as intermediaries to develop and societal embed an emerging technology innovation into the regime.

Using a qualitative approach, this thesis draws on an explanatory case study on the emerging Power-to-Gas technology. By conducting semi-structured interviews with actors from the Power-to-Gas niche community the findings confirm that business models can be used as performative market devices. Thereby they assist the development and uptake of technology innovation through supporting societal embedding. The business model serves as an intermediary for infrastructure matching, expectation and network building of a technology innovation. Further the findings recognise the interconnectedness of socio-technical transitions and extents the framework by incorporating cross-sectoral network building, also called sector-coupling.

Keywords: business models, low carbon transition, performative market device, sector-coupling, power-to-gas technology

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Abbreviations

BM	Business Model
BMWi	Federal Ministry for Economic Affairs and Energy
CE	Circular Economy
EU	European Union
EV	Electric Vehicle
GDPR	General Data Protection Regulation
GHG	Greenhouse gas
MLP	Multi-layered perspective
P2B	People-to-Business
PV	Photovoltaic
PtG	Power-to-Gas
PSS	Product-Service-Systems
SDGs	Sustainable Development Goals

Key Terms and Definitions

Stakeholders	Defined as “any group or individual who can affect or is affected by the achievement of the organisation’s objectives” (Freeman 2010, p. 46).
Sustainability Transition	Radical shifts in socio-technical systems that tackle the challenges brought about by unsustainable consumption behaviour and production processes (Köhler et al. 2019).
Low Carbon Transition	One type of sustainability transition which focuses on shifts in energy production based on fossil fuels and nuclear power, to a production based on renewable resources aimed to decrease GHG emissions (Geels 2008).
Socio-technical Systems	“Accumulations of physical technology [hard infrastructure such as roads, pipes, electricity grids] that are embedded within human systems [soft infrastructure such as regulations] and are operated on behalf of society” (Thacker et al. 2019, p. 324)
Dispatchable Energy	Sources of energy that can be adjusted in their power output on demand.

1. Introduction

This chapter starts with a background description of the subject that is studied in this thesis, followed with the identification of the related empirical and theoretical relevance. The problem statement is then basis for the aim and research questions presented. The delimitations are then presented.

1.1. Background

Environmental sustainability has been a popular topic since the 1972s Limits to Growth by the Club of Rome (Meadows 1972), being promoted by leading global intergovernmental institutions such as the United Nations and political institutions as the European Union (EU). Sustainability related goals are formulated in treaties and agreements, examples include the Paris Agreement and the Sustainable Development Goals (SDGs). The goals and agreements strive for sustainability transition with regards to social, environmental as well as economic sustainability. Especially with regards to the Paris Agreement on limiting climate warming to below 2 degrees, the environmental dimension seems to be at the forefront of sustainability actions to mitigate the consequences of climate change. Particularly sectors with high emissions are challenged to develop and promote innovative, cleaner and climate neutral technologies, products, and services.

The mobility and the energy sector are major contributors to global warming through emissions (IEA 2021). They account for a large extent of the global greenhouse gas (GHG) emissions, with 23 percent for the transport sector and 50 percent for the energy sector (incl. fuel combustion) respectively. Within the EU, the transport sector accounts for about 30 percent (European Parliament 2019), whereas the energy sector (incl. fuel combustion) accounts for 54 percent (Eurostat 2020) of the EU's total GHG emissions. This indicates the negative impact that traditional energy production and transportation systems have on the climate. But conversely, they also outline the potentials inherent to these sectors of becoming major enablers for a global sustainability transition by successfully managing a low carbon transition.

Low carbon transitions are shifts in energy production based on fossil fuels to a production based on renewable resources aimed to decrease GHG emissions (Geels 2008). To ameliorate the emissions of the energy sector the installation of renewable energy plants, the production and consumption of renewable energy have increased steadily throughout the last decades (European Commission 2020). Also, in relative terms the share of renewable energy in the EU energy mix has increased. However, this positive trend does not apply to all member states within the EU. There is a large difference between the share of renewable energy within each member states' energy mix. For example, while Sweden reaches a share of 54,6 percent, the Netherlands only reach a share of 7,4 percent (European Commission 2020).

The transition to renewable energy also bears challenges, which need to be solved and overcome to master a successful low carbon transition (Bundesnetzagentur 2021; Wassermann et al. 2015; Buck et al. 2019). These challenges for shaping the energy transition are multifaceted. They are influenced by overarching megatrends such as digitalisation, automation, electrification and demographic change (European Commission 2019; Buck et al. 2019). Further challenges are energy specific issues dealing with load, reserve, feed-in and dispatch management, decentralisation and changing business models (BMs) (European Commission 2019; Bundesnetzagentur 2021; Wassermann et al. 2015; Mah et al. 2017). Prevailing path dependencies and lock-in of current fossil-based energy systems present further barriers to a quick and smooth transition (Mah et al. 2017).

The challenges imposed on current electricity grids by an energy mix with high shares of renewable energy can be best explained by studying real life events. As previously mentioned, Sweden generates a substantial share of its total electricity from renewables. This comes at a cost. In February 2021 the electricity price in Sweden increased substantially as a result of shortages in production (Cody 2021). The shortages were caused by increased electricity demand due to cold weather and lacking supply of electricity generation by low wind and few sun hours. Reserve capacities and baseload production by lignite, hard coal, biomass and nuclear power plants could not serve the demand. Further the existing grid infrastructure did not have the capacity to meet the peak demand existing in February 2021. As a consequence, firms had to reduce their electricity consumption and (fossil-fuel based) electricity had to be imported, which resulted in high prices for consumers.

This shortage in electricity for meeting peak demand as well as the missing flexibility of existing grid infrastructure underlines the difficulty of being dependent on intermittent renewables. There is a mismatch between the uptake of renewables and existing infrastructure. On the one hand, to become less carbon intensive, the energy sector needs to further expand its efforts in a comprehensive development of renewables (UN 2015; European Commission 2019). But similarly, new forms of flexibility are needed to make use of renewable energy in the most efficient way. Only then a constant meeting of electricity demand can be guaranteed. This twofold and parallel development (of renewables and flexibility) can path the way towards a successful low carbon transition.

Smart Grids, battery technology and Power-to-Gas (PtG) present possible flexibility enablers for large-scale energy storage and grid balancing solutions (Mah et al. 2017; Kopp et al. 2017). Especially PtG technologies present various application examples for the energy as well as the mobility sector (Dunn 2002; Breyer et al. 2015; Vandewalle 2015; Schoenung & Keller 2017). PtG technologies present flexible and long-term storage solutions for energy. PtG is the process of converting electric energy into chemical energy. In a first step electricity is converted into hydrogen in a process called electrolysis. PtG can provide spatial and seasonal operating reserve services (Breyer et al. 2015) for electricity grids by serving as an energy carrier for excess renewable energy (Vandewalle et al. 2015), which is specifically important for an energy mix with a high share of renewables (Belderbos et al. 2015). The technology has implications for the energy sector, but also within mobility sector as different gas solutions can be used to power engines without emitting GHGs. Schoenung and Keller (2017) have looked at the energy sector and the mobility sector and show potentials of hydrogen applications for both. Further applications of PtG as energy carriers can be found for industry applications and self-sufficient housing ideas. The concept of PtG, how it works in detail and contributes to a low carbon transition is presented in Appendix 1.

Low carbon transition is one type of sustainability transition, which is the shift of unsustainable consumption and production patterns in socio-technical systems (Geels 2008). This could also be described as changes in infrastructure and corresponding user practices (Elzen et al. 2004). Though, transition is often related to long term change which thereby must be studied over time. Vital components for the transition process are technology innovations, which can facilitate a low carbon transition. An example is the electric vehicle, which has through introducing the technology changed the emissions from the mobility sector. However, the technology must have corresponding user practices, meaning without enabling usage it has no value.

User practices of technological innovations develop through entrepreneurial processes (Tidd 2001). Through creating BMs for technology innovations, firms and actors will develop value propositions that evoke user practices. Bidmon and Knab (2018) describe BM as intermediaries between technology innovations and society. Another similar viewpoint is represented by Doganova and Eyquem-Renault (2009) who explain that the BM works as a collection of narratives aimed at potential customers, consumers and investors. These narratives are important to showcase the value proposition of a yet not established technology innovation. As user practices are evoked, interactions with the technology innovation occur (Schot & Geels 2008). These interactions shape a market environment through supply and demand, routines, user preferences, price mechanisms and institutions (Smith & Raven 2012). Therefore, an important aspect to consider when studying the development and uptake of technological innovations is the role BMs have in these interactions (Wainstein & Bumpus 2016).

1.2. Problem Statement

The following section introduces the problem statement, first from an empirical viewpoint and then from a theoretical viewpoint.

1.2.1. Empirical Problem

PtG technology can support sustainability transition and has the ability to smooth out the ways for a carbon-neutral energy production and mobility turnaround (BMWi 2020). It is still a niche technology and thus the roles of new entrants, start-ups and entrepreneurs are yet under development. This is highlighted in the research agenda set out by Köhler et al. (2019) who state the need to examine the role of innovators that "develop new products, services and business models, […] or work toward the formation of new industries" (p. 11). Especially the design and role of BMs is unknown. Köhler et al. (2019) call for testing whether BMs can assist sustainability transition or defer radical change through being an inflexible tool in complex changing environments. Emphasise is put on the need to study the broader institutional work which shapes societal discourses and how organisations "lobby for specific policies and regulations, develop industry standards, legitimate new technologies, or shape collective expectations" (ibid. p. 11). All these aspects are important for actors developing technology to bring to a broad market.

Journal articles with regards to PtG are mainly concerned with the technological side of the innovation and up until now, only few examine its commercial potential (Schoenung & Keller 2017; Kopp et al. 2017). Existing studies further outline pathways for future research, and the need for combining technical and business studies. With regards to the business research, they point out the need to look at BMs in diverse sectors and acknowledge that these are not mutually exclusive but can accrue at the same time.

Analysing the role of BMs and the conditions under which they can successfully support innovation development can result in a more comprehensive socio-technical understanding of the PtG technology. Especially for actors within the PtG niche an understanding, extending beyond technical considerations is valuable. For actors involved in PtG projects there is a need to translate technical implications into business related implications. Thereby the focus moves towards considerations for successful market diffusion and applications of PtG. To change the focus, the transition of PtG as a socio-technological process needs to be understood.

PtG technology is an example of a technology innovation evolving in experimental sites and pilot projects, in so-called protected spaces (Smith & Raven 2012; Carvalho 2015). This collection of projects forms an incubation network; an emerging niche (Geels & Schoot 2007). For the technology to become a realistic alternative to traditional modes of energy production it needs to transit from a niche technology to becoming largely applied. Only then it can challenge existing energy and mobility market systems (regimes). This process from the protected area to the regime relies on societal embedding and large-scale application of a new technology (Carvalho 2015). Societal embeddedness can be achieved through successful network building, expectation building and infrastructure matching. Societal embeddedness leads to interaction of users with technology, i.e. it is defined through user practices. However, for new technologies as PtG these practices are unknown.

Without understanding user practices, it is difficult to design BMs and supporting infrastructure (Carvalho 2015; Maia et al. 2015). Without attempts to create BMs for PtG the user practices and supporting infrastructure will not develop. In that sense PtG, as several other innovative technologies at their time (e.g. Steam trains, EVs), faces the classic "chicken and egg" phenomenon, presented by Meyer and Winebrake (2009). The problem which new technologies face is that consumers will not accept new technology and buy corresponding products without the necessary support infrastructure in place to make efficient use of it. Meanwhile, the infrastructure cannot or will not be developed if there are no users who will eventually make use of it. According to Meyer and Winebrake (2009) through successful network building and combined efforts the phenomenon can be resolved.

To conclude, considerable research is undertaken that focuses on technical aspects of PtG as well as its usability, efficiency factors and upscaling potentials. Many technical and engineering related papers have been published, however business oriented and transition related research is lacking. This leads to lack of socio-technical understanding of PtG. By analysing the role of BMs and the conditions (societal embeddedness, infrastructure matching, network building) under which they can successfully support innovation development a more comprehensive socio-technical understanding of the PtG technology can be established for PtG actors. Thereby this thesis also contributes to the more general understanding of processes occurring within the low carbon transition. The role of BMs is the object of discussion in the section on theoretical relevance.

1.2.2. Theoretical Problem

As already touched upon previously technical features of innovation develop in niches. The eventual breakthrough from being a niche innovation to affecting and shifting the regime is called sustainability transition Geels and Schoot (2007). To understand the process and catalysts of transition there is a growing interest in transition research to combine BM and transition theory. A core research objective is to define the role of BMs to "act as a catalyst for system-wide sustainability transition" (Bolton & Hannon 2014, p. 1731). The BMs to achieve sustainability proposed by business literature are diverse. The models proposed commonly strive to tackle ecological challenges and achieve "industrial sustainability" (Bocken et al. 2014, p. 43). The objective of sustainable BMs is to enable sustainable practices based on concepts such as cradle-to-cradle, circular economy, product service systems, blue economy, natural capitalism, eco-innovation or the natural step.

Schaltegger et al. (2016) argue that in sustainability transition new entrants as well as incumbent players utilise BMs to establish and finally commercialise niche technologies. The same line of argumentation is used by Doganova and Eyquem-Renault (2009) stating that the BM is used as a performative market device to bring an innovation to the market. The BM is performative through the creation of narratives that showcase the value proposition and acts as a boundary object to engage multiple stakeholders. The value proposition is regarded as the core of each BM (Osterwalder et al. 2005) and is the basis for the creation of narratives (Doganova and Eyquem-Renault 2009).

Bidmon and Knab (2018) refer to BMs for technology innovation as intermediaries between niche and regime actors. As intermediaries BMs can coexist with and challenge incumbent BMs by describing new value propositions (Schaltegger et al. 2016). The description of new value propositions is creating and demonstrating the feasibility and usability of a "new reality", an alternative to existing BMs (Doganova & Eyquem-Renault 2009). An example for the creation of a new reality within the mobility regime is Tesla's EV. EV related BMs are shaking the pillars of predominant market players and their technology by introducing and building a new reality.

Another example that supports the argument by Schaltegger et al. (2016) is the diminishing market power of traditional electricity producers as energy production is getting more decentralised through the employment of renewables (Bolton & Hannon 2016; Köhler et al. 2019; Bundesnetzagentur 2021). In both examples new and innovative BMs and technologies have gained a foothold in the market. On the one hand EVs, on the other hand the increasing provision of renewable energy in combination with P2B models being established and gaining momentum (Mah et al. 2017).

By combining BM and transition theory in the context of a low carbon innovation, Wainstein and Bumpus (2016) propose a framework to understand how BMs as market devices can act as a driver of socio-technical transitions. They specifically point to the knowledge gap of understanding the role of BMs in business and transition research. Wainstein and Bumpus (2016) call for further studies to showcase the importance of understanding the role of BMs as a driver of low carbon transition.

However, there is criticism on transition research which Wainstein and Bumpus (2016) do not acknowledge in their framework. Cass et al. (2018) argue that transition research is limited in that it only looks at one socio-technical system at a time. Thus, it often does not recognise the influence of intersections between multiple socio-technical systems and the role of these intersections for overall sustainability transition. Following Cass et al. (2018) current research leads to negligence of important influences for understanding how BMs for technological innovations contribute to sustainability transition. However, this section has shown that BM theory is relevant for a deeper understanding of technological transitions and can contribute to transition research. This has been the starting point of this thesis, as the BMs around PtG have not yet been studied, nor how the BMs can work as a market device for PtG technology.

1.3. Aim and Research Question

The thesis aims to contribute to the understanding of BMs as performative market devices for development and uptake of technological innovation. Drawing on a case study of PtG technology, the following research question is used to guide the research:

1. What is the effect of performative BMs on an emerging niche technology?

To answer this theoretical research question the following sub-questions have been identified to guide the empirical research:

a. What narratives of PtG are portrayed by actors involved in PtG projects?

b. How is the narrative of PtG used by PtG actors to engage stakeholders?

1.4. Delimitations

This study focuses on how BM narratives affect the development and uptake of a technological innovation. The technological aspects are not in focus, rather the study focuses on socio-technical implications of BMs.

Furthermore, the thesis only focuses on one emerging technology with potential to contribute to the low carbon transition, which is PtG. Within the PtG sector the thesis is limited to the energy and mobility sectors as these represent the biggest stakeholders and users of the technology. Even though the PtG technology could possibly impact other sectors these are defined as outside of the scope of this research.

Concerning the theoretical positioning, the literature used is a combination of transition and business studies. Potential other lines of thought that have not been taken into account are innovation studies, economics or more social science related studies. Even though these might also contribute valuable perspectives on the case of emerging technology an inclusion of these would not help to overcome the identified research gap in business and transition studies.

1.5. Thesis Outline

To provide an overview of the thesis outline, the structure is presented in Figure 1. The next chapter presents the results of a literature review and the thesis' conceptual framework. Chapter 3 outlines methodological consideration before the empirical data collected are presented in chapter 4. In chapters 5 and 6 the data is analysed, and findings are discussed before the thesis concludes with chapter 7.

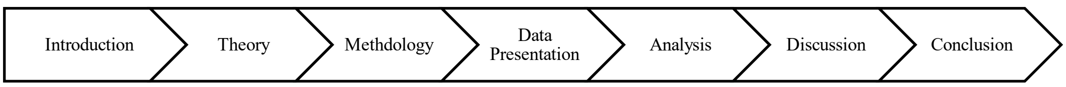

Figure 1: Presentation of Thesis Outline.

2. Theoretical Background and Conceptual Framework

This chapter introduces the theoretical background that leads to the thesis conceptual framework. First, a short description of the positioning of the thesis in relation to the literature will be described, see Figure 2. Then follows a summary of the existing literature within sustainability transition, user practices and BMs. Lastly, the conceptual framework will be presented.

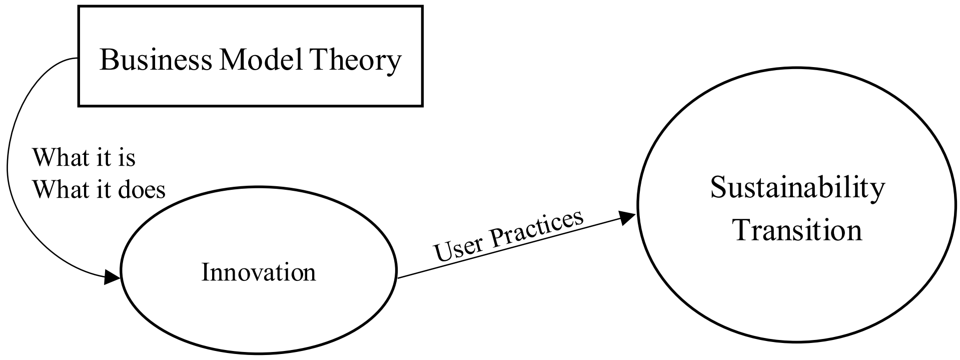

Figure 2: Overview of theoretical positioning (Own Illustration).

As discussed in the problem statement, there is a need for further research combining business studies and transition research. Figure 2 briefly visualises the connection of both research areas. Within transition research, innovations play a crucial role for changing socio-technical systems, which eventually can lead to a sustainability transition. BM theory can help to shift focus from what an innovation is in technical terms, to what it does. This is important for conveying the value proposition to stakeholders. This process is further elaborated in the theoretical background.

2.1. Theoretical Background

2.1.1. Sustainability Transition

Sustainability transition is understood as being a multi-dimensional and co-evolutionary development at which end stands a radical shift of prevailing socio-technical systems (Köhler et al. 2019). An understanding of transition can only be established by studying socio-technical systems over time. Thacker et al. (2019) state that if infrastructure is defined in socio-technical terms then infrastructure can be viewed as socio-technical systems. Thus, changes in infrastructure can be seen explanatory of sustainability transitions.

Socio-technical understanding of infrastructure

There are multiple terminologies and understandings of the term infrastructure (Thacker et al. 2019). The two main understandings are characterised by a social respectively a technical meaning, which create a more elaborated socio-technical definition when combined. The technical meaning refers to hard infrastructure. Examples of hard infrastructure are roads, traffic lights, rails or wires, pipes or broadband. In other words, materials and technological components. The technical meaning associates infrastructure as "accumulations of physical technology" (Thacker et al. 2019, p. 324), characterised by economies of scale and "the resources (such as personnel, buildings, or equipment) required for an activity" (Merriam-Webster 2021, §1). This type of infrastructure is often associated with large scales and high financing costs. The provision of a whole web of the above physical entities, creates an infrastructure system, also called infrastructure network (Cass et al. 2018).

The social meaning of infrastructure refers to soft infrastructure. This relates to the practices which are enabled by infrastructure. This understanding of infrastructure conceives it as a social construct (Star 1999, Thacker et al. 2019). This construct is shaped by the way consumers use the physical technologies, and networks inherent in what is termed infrastructure system and the services it provides to its users. Moreover, soft infrastructure is not only about practices and usage of technical systems, but also characterised by intangible structures, such as institutional reforms and human capital. These components are essential to make the whole system work. The technical components can be understood as hardware, while the social aspects and the practices can be understood as software (Carroli 2018).

Combining the social and technical understanding of infrastructure yields a more sophisticated definition (Thacker et al. 2019). Infrastructure is defined as networks of "complex socio-technical systems, because they consist of accumulations of physical technology that are embedded within human systems and are operated on behalf of society" (Thacker et al. 2019 p. 324). This is in line with the understanding by Carroli (2018) who describes infrastructure systems as socio-technical constructs, woven into our lives. Moreover, five infrastructure categories are outlined: energy, water, (solid) waste, transport, and digital communications, which is in line with the categories Cass et al. (2018) provide. Other aspects that differentiate infrastructure from "normal" products is that they are conceptualised as large, extensive and durable systems (ibid.) and as merit goods (Thacker et al. 2019). Carroli (2018) claims that the predominant view on infrastructure is dominated by a "straightforward response to a clear demand for utilitarian services" (p. 55). In that way conventional infrastructure is seen to serve the purpose of being an economic as well as social driver (Star 1999).

Transition can take multiple pathways from being disruptive, reconfiguring or realigning existing and established socio-technical systems, also referred to as regimes (Geels & Schoot 2007). For each of these transition paths the merit good of infrastructure is needed, merit good, because infrastructures provide essential services to society but are likely to be underdeveloped in a free market (Thacker et al. 2019). Thus, infrastructure development requires public and institutional intervention (Shove 2010; Thacker et al. 2019). For sustainability transition and principally for all radical innovation, infrastructure is a precondition for successful market establishment. Without support infrastructure market penetration of new technologies remains a niche product. In sustainability transition research the prevailing assumption is that "infrastructures evolve gradually and exhibit strong path-dependence" (Cass et al. 2018, p. 161). Another study suggests that while they appear as technical structures, they are not static entities but provisional achievements that are constantly made and remade by social actors (Carter et al. 2015).

Innovations' importance for transition and the multi-layered perspective

Farla et al. (2012) argue for acknowledging the systemic and interrelated nature between socio-technical transitions and innovation processes. The connection is better understood if a multilevel perspective is applied (Kemp et al. 1998). Transition can then be seen as three stages, the niche, regime and the landscape. The niche is a protected space, where technology innovation develops. The regime is an existing and established socio-technical system. The landscape "forms an exogenous environment beyond the direct influence of niche and regime actors", for example through macroeconomic forces and values of society (Geels & Schoot 2007, p. 400). The landscape is dynamic, and "composed by societal values, worldviews, fundamental technological developments and macro-structural economic, social and environmental conditions" (Carvalho 2015 p. 46).

Fuenfschilling and Truffer (2014) argue that depending on the MLP stage the innovation type differs. For instance, in the regime mainly incremental innovations occur. This is due that the social and technical elements of a regime are mainly aligned, meaning that the structure of technology and usage is quite stable. In order for radical innovations to take place often a more protected space is needed where the technology and the social implications can be developed. This leads to that most of these innovations occur in the niche. In a niche, innovation can be endorsed by regulatory support that protects the process from the structural pressures of the regime.

Geels (2002) argues that a radical innovation leads to a socio-technical transition that only affects the regime if it is weakened through landscape pressure. If this radical innovation is able to shift the regime, it will involve changes in technologies, technological artefacts, and social aspects such as user practices, supporting infrastructure, markets and policies. From a sustainability transition perspective radical innovation can be seen as a catalyst to drive sustainability development forward under the condition that it is a sustainable innovation (Berkhout 2014). Changes of the landscape surrounding the regime and the niche could also impact how they interact, as it consists of the "societal values, worldviews, fundamental technological development and macro-structural economic, social and environmental conditions" (Carvalho 2015 p. 46). These changes in the landscape can destabilise existing regimes and results in windows of opportunity for innovation (Geels & Schoot 2007). Any innovator must consider this with regards to the technological innovation's integration into the market.

Up until this point, socio-technical systems have been connected to transitions in general. However, by studying the characteristics of transition certain types of transition can be identified. One of these types is the sustainability transition, which is relevant when looking at the challenges with low carbon transition. The underlying assumption to sustainability transition is that predominant consumption behaviour and production modes in socio-technical systems are unsustainable and thus require innovative development processes. Such a development process can be marked by regime actors restructuring industrial systems and re-conceptualising the value creating logic inherent in existing BMs (Bocken et al. 2014). Literature defines sustainability transition as shifts in socio-technical systems. However, the emphasis is currently too focused on the technical aspects of change, thereby neglecting or missing aspects of socio-technical change (Kivimaa et al. 2021) and social sciences (Shove 2010).

2.1.2. User Practices

Innovation can be seen as a "process of turning opportunity into new ideas and of putting these into widely used practice" (Tidd 2001, p. 19). A key part here is how then a technological innovation will be used in practice. As described by Smith and Raven (2012) the development of technological innovations most often occurs in a protective space or niche. There the development of the technological characteristics is in focus. However, the technological innovations do not have any societal value without its user practices. According to Geels and Schoot (2007) it is in the niche where technology can co-evolve with user practices and regulatory structures. But the real-world interaction between users and the technological innovation takes place outside of the protective space. User practices focus on the interaction between the users and the technological innovation and thus require focus to be moved from the pure technological implications of the innovation. Therefore, user practices are important for the uptake of an emerging technology.

User practices as interactions in multi-layered perspective

User practices are according to Smith and Raven (2012) related to dynamic socio-technical systems and are described in the MLP through the interaction between landscape, regime and niches. Recalling that a regime is "formed by a largely stable set of interacting artefacts, technologies, infrastructures, everyday practices, policies, values and institutions" (Carvalho 2015, p. 46) the importance of interaction is once again highlighted. Carvalho (2015) further outline that this interaction occurs between multiple socio-technical systems, and corresponding products and actors. When user practices are studied in dynamic socio-technical system, they are understood as interactions between technological innovations, the niches, and the artefacts, the regime.

The user practices together with the market characteristics shape an environment through supply and demand, routines, user preferences, price mechanisms and market institutions (Smith & Raven 2012). Depending on the innovation type it is easier or more difficult to successfully introduce a technological innovation. Innovations of more path-breaking kind might require changes in user practices which often increase the difficulty to establish it in the specific environment (Carvalho 2015).

Societal embedding of innovations

Carvalho (2015) argues that for the technological niches to challenge the current regimes they need to gradually support two processes: learning and societal embedding. Learning is about understanding the technical aspects. Societal embedding focuses on the interaction, similar to what has previously been described as a central part of user practices. Societal embedding is vital for the widespread development, uptake and usage of technology within a socio-technical system. It is argued that the societal embedding can be broken down into three interlinked processes: network building, infrastructure matching and expectation building. The societal embedding processes focus on the interaction between the innovation, the future users and the system.

User practices relate to the concept of interaction (Carvalho 2015). It can be used to describe user practices between the technology innovation and the surrounding landscape. The user practices have to be adapted to the innovation but can also be affected by the landscape. Interaction will occur on different levels, both between the technological innovation, the landscape and the regime. Within this interplay the user practices take place and support societal embeddedness of emerging technology.

2.1.3. Business Model Theory

Within socio-technical system, one role of BMs is to make efficient use of or evoke user practices (Shove 2010). The role of BMs is important when studying technological innovation and sustainability transition, as they are one factor that influence change in socio-technical systems. To understand the process and catalysts of transition there is a growing interest in transition research to combine BM and transition theory. A core research question proposed in research agendas is to study the role of BMs to enable sustainability transitions (Bolton & Hannon 2014, Köhler et al. 2019).

Different views on BMs

The concept of BM can be looked at from an essentialist and functionalist view, but also from a pragmatic view (Doganova & Eyquem-Renault 2009). Traditionally, the BM is defined as a description of a business, which supports defining and communicating a "business' value proposition, value creation and delivery and capture" (Bocken et al. 2014, p. 14). A BM can lead to a competitive advantage for a company, through aligning business operations, competitive strategy, product designs, cost structures and value chains (Osterwalder et al. 2005). These traditional views of the BM are defined as the essentialists view (Doganova & Eyquem-Renault 2009). This way of viewing the concept of BM is criticised for being limited as it is based on a description of a business reality. This is problematic when new businesses are considered as the reality beyond the BM is not yet established, i.e. no market share, customers or brand. So rather than describing what the BM is the question should be reformed to what the BM does. In this way the BM becomes performative.

Entrepreneurs have focused on the function of a BM. By this approach the BM is seen as a "method of doing business by which a company can sustain itself" (Rappa 2001, p. 1). This method includes breaking down the value proposition into profitability, market segment and cost structure. Then the BM can be used to explain the value created by a new venture (Amit & Zott 2001). In entrepreneurial literature the BM has thus been used as an internal management tool or a way to find funding and collaborations.

Another way to study BMs is based on the usefulness of them (Doganova & Eyquem-Renault 2009). Here, a lens of the performance efficiency is applied. By this pragmatic approach, the BM can be defined as a market device. Doganova and

Eyquem-Renault (2009) argue to use the BMs as both, a calculative and narrative device. The BM will then be a support to actors, mainly entrepreneurs, that want to bring their innovation to the market.

A mix between different narratives and calculations will enable the BM to endow its performative role through circulating between heterogeneous actors, slowly building the network around the venture. It is used to address a broad group of actors, for example investors, journalists and customers. The BM can be seen as a boundary object, which according to Star and Griesemer (1989) means that it can satisfy both, the addressing of "several intersecting social worlds [. . .] and satisfy the informational requirements of each of them" (p. 393). This is particularly important for emerging technologies because the BM will bring heterogeneous actors together without excluding individual interests (Chesbrough 2003).

Bartel and Garud (2009) have investigated innovation narratives further and show that BMs as boundary objects can be a solution to the challenges of coordinating innovation. The authors highlight how the BMs are coherent, meaning that they can bring individual actors from different contexts together. At the same time, the BM is "pliable enough to let them [the individuals] draw inferences that fit their unique contexts" (Bartel & Garud 2009, p. 111). One can talk about the flexibility and the unity of the boundary object, which can also be seen in relation to BMs. What unifies actors is the theme of value creation, but the BM is flexible and adapted to local frames (Ghaziani & Ventresca 2005). The value creation is based on the value proposition of the emerging technology.

Narrative and calculative aspects of BMs

Returning to the concept of narratives and calculation, the BMs can be seen as stories and the narratives in these stories are specifically connected to numbers (Margretta 2002). Both aspects are important to have a successful BM, because it must present a convincing story, as well as numbers that add up. Narratives can be described as a set of events which helps to structure an initial situation (e.g. an urgent need or a problematisation) in a sequentially manner (Pentland 1999). The narrative consists of a plot that structures the details of the narrative "into a meaningful whole" and creates comprehensibility (Czarniawska-Joerges & Hopfl 2002, p. 168). The BM is broken down into a plot which addresses the initial situation presented in the narrative and creates a story on how to overcome the initial problem or how to meet the initial need. The plot is seen as a conventional theme, which many actors can relate to. Through this function, the plot therefore ensures coherence and comprehensibility of the whole narrative (Bruner 1986).

The calculative role of BMs is related to quantitative numeric valuation; that the numbers add up. However, Callon and Muniesa (2005) have broadened this definition, by including qualitative valuation as well. Then judgement or storytelling can be included in the scope of the calculation, e.g. by adding subjected manipulations and transformations (Callon & Muniesa 2005). To conclude, the BM can be seen as a boundary object, and work as a market device due to its narrative and calculative characteristics (Doganova & Eyquem-Renault 2009).

BMs and the multi-layered perspective

Wainstein and Bumpus (2016) argue that when studying low carbon innovations, the BM theory should be combined with theory on the MLP. Then BMs can be seen as critical drivers for socio-technical transitions, meaning as a market device to take an innovation from the niche to the regime. For the success of the innovation to enter the socio-technical system, the BM must be competitive with the core of each BM being the value proposition (Osterwalder et al. 2005). Innovations can have a competitive advantage, but only if they are using a more innovative BM as market device (Wainstein & Bumpus 2016). However, the BMs will encounter mismatches within different MLP layers. These mismatches can occur in existing infrastructure, policy regulations and current BMs. Existing BMs are maintained as lock-ins, which means that political-economic support is present to maintain them. Landscape pressure can destabilise regimes and opens opportunities for changing the locked-in BMs and the uptake of new technologies (Geels & Schoot 2007).

Similarly, Bidmon and Knab (2018) refer to BMs as intermediaries between niches and regimes within the MLP and argue that they can also be a means to destabilise existing regime structures. Thus, the regime can be destabilised through landscape pressures (Geels & Schoot 2007), which open up windows of opportunity for BMs "facilitating the stabilization process of technological innovation and its breakthrough from niche to regime level" (Bidmon & Knab 2018, p. 903). Further, BMs can also impact transition without relying on technological innovation by presenting a novel and innovative BM, e.g. exchanging existing BMs through sustainable BMs, however using the same technology. For an illustration of the presented understanding of BMs' role in transitions see Figure 3.

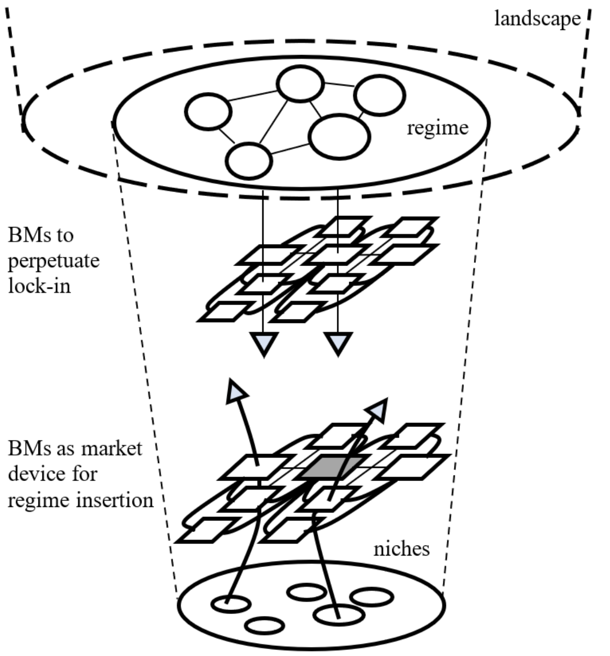

Figure 3: BMs as enablers of sociotechnical transitions acting as performative devices for niche and regime actors. Own illustration inspired from Wainstein and Bumpus (2016).

The framework presented by Wainstein and Bumpus (2016) combines the two research areas on transition and BM theory. The framework served as a starting point for developing the conceptual framework of this thesis presented in the following section.

2.2. Conceptual Framework

To study the thesis aim, understanding the role of BMs in the development and uptake of a technology innovation, a conceptual framework is presented hereafter.

In strategic niche management theory, the uptake of a technology is seen as the development from the niche to the uptake in the regime, which Carvalho (2015) describes as a process of societal embedding. In order for an emerging technology to become societal embedded, related network building, expectation building, and infrastructure matching must occur. These are aspects which can be influenced by using BMs as performative market devices.

The characteristics of BMs as market devices are applied to the MLP by Wainstein and Bumpus (2016) who thereby show how BMs as market devices help to "diffuse technology in mainstream markets" (p. 575). Being used as market devices BMs work as intermediaries between the niche and regime (Bidmon & Knab 2018). In this process, the BM will encounter mismatches with policies, infrastructure systems and current BMs. To achieve the development and uptake, the BM must be competitive and innovative. Moreover, Doganova and Eyquem-Renault (2009) contribution of BMs as performative market devices add another important dimension. They say that BMs consist of narrative and calculative aspects. BMs play a performative role in the innovation process as they carry narratives about value propositions, showcasing what the technology has to offer to its users. This is of importance as for an emerging technology; there is need to engage stakeholders who will help to develop it and contribute to the uptake of it.

PtG technology is developing in local projects. To support the development literature suggests that BM narratives play an important role. These narratives are based on value propositions and calculations. Combining the reasoning by Carvalho (2015) on societal embedding and Wainstein and Bumpus (2016) on the performative role of BMs in transitions the following connection can be identified: BMs as performative market devices and intermediaries link PtG technology development with infrastructure, user practices that produce expectations, and a supporting network. BMs can function as a means to impact lock-ins in current socio-technical regimes as described by Wainstein and Bumpus (2016). By overcoming these lock-ins a technology can become widely used. In Figure 4 the conceptual framework is illustrated.

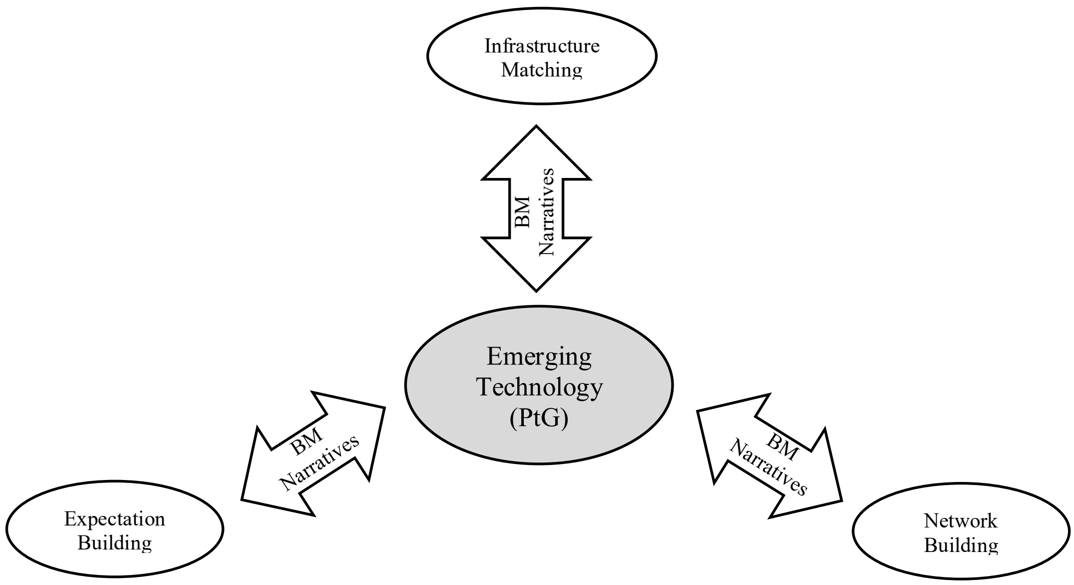

Figure 4:Visualisation of the conceptual framework. (Own illustration).

Figure 4 provides a guidance to understand how BM theory (Doganova & Eyquem-Renault 2009; Wainstein & Bumpus 2016) and transition theory (Carvalho 2015) relate. This helps to narrow the research and provides a starting point for answering the research question on what the effect of performative BMs are on emerging niche technology.

3. Methodology

In this section the methodological choices are presented and described. The chapter starts with the research philosophy followed by the research design. Then follows a discussion of the implications for choice of method. The methods of collecting and analysing data are then accounted for. The chapter finishes with presenting the considered quality criteria and the ethical implications of this study.

3.1. Research Philosophy

In the methodological choice of a study, the research philosophy, meaning the ontological and epistemological views, are important to consider (Bryman & Bell 2015). The different views are closely connected to the choice of method and what assumptions are made. Ontology is how reality is viewed, what is real and what is known about it (Guba & Lincoln 1994). Epistemology is on the other hand how knowledge is viewed, either from an objective or subjective standpoint.

The ontological position for this thesis is grounded in the constructivist approach. Taking a constructivist position, it is argued that reality is shaped by social actors (Bryman & Bell 2015). Instead of social actors being external realities, they are viewed as actors that actively create, design, construct, realign and reconstruct their reality. This position is beneficial when studying the phenomenon of BMs in relation to a new technology. This is because the underlying conceptual framework applied in this research views transition of emerging technology as being the outcome of network building, expectation building and infrastructure matching, which are actively shaped by actors involved in PtG. The constructivist view is furthermore related to the belief that the answer is not to be found by the researcher, rather the truth is constructed by interactions between participants (researcher and respondents) and is continuously changing.

Furthermore, the interpretivist epistemological position is chosen for this study, as it aims to derive an understanding of social action and its course and effect (Bryman & Bell 2015). This is a way of viewing knowledge as a subjective construction rather than objective knowledge. Interpretivism is considered to be suited as the aim of the research is to result in in-depth understanding of the performative role of BMs. This in-depth understanding could have been lost if a positivistic position would have been taken, because positivists view knowledge as objective, or natural construct. Mackenzie and Knipe (2006) also explain that an interpretivist is aware of its own impact on the study, as the study is a subjective outcome by them.

3.2. Research Design

The research conducted is guided by qualitative empirical data collection within the subject of PtG technology. By following a line of inductive reasoning, the aim is to analyse and derive at analytical generalizations from the empirical data collection (Bryman & Bell 2015). Inductive arguments do not provide us with certainty, but they present a probability for likely conclusions. They result in what might be called an educated guess. In unexplored research areas the common approach chosen is inductive (Bryman & Bell 2015). This applies to the thesis' research area, a combination of transition and BM studies and more precisely the performative role of BMs for technology innovation. An inductive approach to this research can be justified to derive conclusions which can in a later stage be used as hypothesis for a deductive approach (ibid.).

3.3. Case Study

The research questions are approached by performing an exploratory case study of PtG technology. This is because the phenomenon of PtG is context specific, leading to a case study approach being most appropriate. As the technology is developing in multiple niches and in several projects at the same time, it has been decided to include several of these in the same study. Applying a holistic view on these projects leads to a case study which can be described as a PtG niche community. Local projects, which all relate to the same niche community, are selected and included in the case study. Yin (2009) argues that a case study is appropriate if the study aims to map out complex contextual relationships between certain phenomena. A case study is characterized by well-defined unit of analysis and boundaries. The unit of analysis in this thesis are BM narratives found within the boundaries of the PtG niche community.

3.4. Literature Review

As a basis for the theoretical framework a literature review has been carried out. Bryman and Bell (2015) explain that the interpretivist epistemological position often includes an initial literature review to obtain a general understanding of the area that is being studied. In line with Given (2008), the literature review has been carried out to create a foundation for the thesis by exploring concepts and phenomenon. The literature review has helped to define the research questions and the aim of the study. For this thesis the focus has been on the narrative literature review, which can be described as a less focused and more wide-range search of literature (Bryman & Bell 2015). The focus has been to get a deeper understanding of the theory by critically reflecting over what it implies, as well as to identify a knowledge gap. The literature review has laid the basis for identifying the theoretical relevance. The literature used consists of peer-reviewed published articles, found through different databases such as Google Scholar, Primo and Web of Science. The articles that have been chosen are either well cited or seen as relevant because of their clear connection to the research area. Furthermore, as time has been limited for this thesis key words have been used to find and narrow down relevant literature. Key words that have been used in combination with each other are: business model, transition, sustainability, innovation, user practices and socio-technical system.

3.5. Data Collection

Here follows a presentation of the data collection, which consist of the interview method, the sampling strategy and the limitations of data collection.

3.5.1. Semi-structured Interviews

To collect data for the case study it has been decided to conduct interviews with actors within the niche community of PtG. According to Bryman and Bell (2015) interviews can be conducted based upon either structured or unstructured strategies. Structured interviews are performed using pre-defined questions and the questions asked do not build upon any of the responses given by the respondent. Unstructured interviews can be seen equal to a normal conversation where the outcome of the interview is hard to predict. Semi-structured interviews are when structured questions are asked but the adherent questions are adapted to what the respondent answers. This technique is according to Saunders et al. (2012) suitable for when qualitative research is performed and focused on a case study design.

Furthermore, semi-structured interviews should according to Creswell (2012) consist of open-ended questions. This is according to Bryman and Bell (2015) helpful when the opinions, views and ideas of the respondent is not known to the interviewer beforehand. Open-ended questions allow for elaboration on previously given answers and follow up questions to further investigate a specific topic or answer. This results in flexibility in the interviews, as the authors can be open to new insights that occur during the interview.

Before the interviews were performed an interview guide was created to support the interviewer, see the Appendix 2. The main questions were created based upon the research questions and the conceptual framework, which are a result of the literature review and the problem statement. The questions are focused around four themes, which are BMs, user practices, infrastructure, and transition. Moreover, some general questions about the respondents were asked prior to the more in-depth questions, both to get a better understanding of the context as well to make the respondent more comfortable.

Apart from the main questions, adherent questions where defined, with the purpose of supporting the interviewer with the direction of follow up questions. In the adherent questions, mainly buzzwords were used to inspire but not limit the interviewer. This was to ensure that the aim of the study was in focus throughout the interviews.

Interviews were performed face to face, over video call and via phone due to both availability and the restrictions that followed the Corona Pandemic. The interviews were conducted in German or English depending on the interviewee's confidence with the English language. As one of the researchers is a German native speaker the language has not represented any barrier to the data collection process. The option to answer in any of these languages was offered to ensure that the respondents felt comfortable and able to present answers in a clear and meaningful way. Furthermore, people in general feel most comfortable talking in their native language. All interviews were recorded after the respondent's consent was given. This was beneficial for the study as it is difficult for the human memory to remember all the answers (Saunders et al. 2012). Furthermore, the researcher could focus on having a qualitative conversation, asking the right questions and listening. After the interviews were performed, the audio files where first transcribed and those recorded in German then translated into English. This method of recording and transcription enables a more in-depth analysis as the data can be studied repeatedly (Saunders et al. 2012). The transcriptions also were of great help to make the empirical data understandable to both researchers, as the language barrier was overcome. A description of the interviews can be found in Table 1 below. Further details and descriptions of the respondents are found in Appendix 3.

Table 1: List of conducted interviews and interview respondents.

Code	Area	Company	Method	Duration
K	Public Administration	Kreis Lippe (Innovation)	Online	00:44:50
T	Academia	TH OWL	In Person	00:56:09
C	Academia	TH OWL	In Person	00:56:09
D	Public Administration	Kreis Lippe (Umwelt)	Online	01:04:58
A	Public Administration	Sandviken Municipality	Online	00:47:19
O	Industry	KVG Lippe	Online	00:34:46
M	Industry	Nilsson Energy AB	Phone	00:34:46
T	Industry	Stadtwerke Lemgo	In Person	01:05:36

3.5.2. Sampling Strategy

To answer the research questions and meet the aim of this study, the sample was selected based on choosing actors that are involved in PtG projects and thereby have expertise on PtG related BMs. As a starting point a non-probability purposive sampling technique was applied. Accordingly, a sample based on the subjective judgement of the researchers has been selected (Bryman & Bell 2015). This technique is further justified by the qualitative approach that the study applies. Yin (2009) explain that is it not necessary in a qualitative study to use a sampling logic similar to quantitative studies, as the goal is not to end up with statistically significant results or conclusions. This sampling technique can according to Saunders et al. (2012) be called judgmental sampling as it is up to the researcher to decide the sample based on their own views. The previous network of one of the researchers has had influence on the sample, as the research idea originated from a discussion between the researcher and representatives from the district of Lippe, which is one of the researcher's previous workplaces. This has led to an initial sample of relevant actors involved in PtG projects.

After the initial interviews the strategy of snowball sampling was applied. That means that the respondents recommended potential actors that they believed where suitable to further contribute to the study. The respondents in the district have suggested other actors from the region, but also recommended approaching experts on a national and international scale. Some have specifically outlined Sweden as an area to look for experts as projects in Sweden appeared to be more mature than those in Germany. Thus, additional actors across Germany as well as in Sweden were approached. In the view of the researchers, this has improved the quality of the study as more relevant perspectives where included, resulting in a more comprehensive understanding of the phenomenon that was studied. These sampling methods resulted in four additional respondents that all had knowledge and were taking part in the process of developing PtG related BMs. A diverse set of actors from PtG projects have been interviewed, the majority of whom work within energy and mobility related areas. Thus, the study is limited in that it only investigates the mentioned sectors, e.g. it neglects manufacturers and actors from other industries.

3.6. Limitations of Data Collection

The research process has been performed under the circumstances that the Corona Pandemic has brought with it. This has had effects on the thesis work process and especially the data collection. All communication between the authors and the supervisor has been performed via e-mail and video calls. One of the authors was situated in Germany, while the other in Sweden. This has resulted in challenges that were new to both authors. The ability to communicate has been dependent on internet connection, which has been of varying quality. Also, being able to understand each other's reasoning has been a struggle sometimes. Body language is harder to analyse over video, and collaborative thinking has been negatively affected. Due to the restrictions of social contact, the data collection has also been affected. In terms of data collection, the interviews have only been performed by one of the authors. The core data collection was performed in the district of Lippe, an area in North-Rhine Westphalia in Germany. Covid restrictions were a barrier for data collection in Germany, as many companies and individuals were not allowed to participate in social interactions at this point in time.

3.7. Data Analysis

After the data had been collected, transcribed and translated, it had to be analysed and interpreted. Bryman and Bell (2015) highlight the importance to have significant amount of data when conducting a case study of qualitative design. How the qualitative data then should be analysed is up to the researcher, but the research approach impacts this decision (Saunders et al. 2012). The qualitative approach is the major reason why a content analysis has been chosen for this study, which is used to define different themes and patterns from the empirical data and provides a thorough description of the case (Zhang & Wildemuth 2009). The content analysis can be seen as a tool used by researchers to understand social reality in a subjective but social manner. Working systematically is argued to create a good starting point for the data analysis process.

By coding ideas and concepts that are presented in the qualitative interview data can be categorized based upon similarities and differences (Given 2008). As this is a qualitative research, this categorization is developed during the data analysis, which is different from a quantitative research that first decides on the categories and then collect data. The categories have been chosen based upon the conceptual framework presented in this thesis. Therefore, they are grounded in the research by Doganova and Eyquem-Renault (2009) and Wainstein and Bumpus (2016) about BMs as performative market devices. Categories chosen for coding are BM narratives, user practices, infrastructure and supporting network. Choosing initial coding categories based on the literature review is in line with Zhang and Wildemuth's (2009) reasoning.

Furthermore, the analysis is based on the authors' determination of what is relevant and important to include, which highlights the subjectivity that is present in the study. To not restrict each other, the researchers decided to initially go through the transcripts by themselves to sort the data based upon previous stated categories. Afterwards the notes from each researcher were compared to find similarities and differences. The data was then interpreted and summarized within the categories. By using coding categories, it was easier for the authors to get a better picture of the BM narratives of PtG, and thereby analysing the phenomenon more in depth.

The translation that was performed for most of the interviews can be seen as potentially increasing the subjectivity as the researcher had to interpret the text and embed meaning into it (Bryman & Bell 2015). Interpretations had to be made as several of the English concepts used in the literature review had no direct German translation. Thereby, it can be understood that the ideas and reasoning by the respondents might not completely be described in the same way in both languages.

3.8. Quality Criteria

According to Saunders et al. (2012), to have trustworthy conclusions any choices made must be based on a logical approach. The trustworthiness of a study is often evaluated upon four criteria: credibility, transferability, confirmability and dependability (Lincoln & Guba 1985, in Shenton 2004). By relating these criteria to this thesis, conclusions of the trustworthiness can be described. When conducting a qualitative study, subjectivity has an impact on the conclusions made. As the social reality described can be affected by this subjectivity, Alvesson (2003) points out the importance of aligning the research with the quality criteria.

3.8.1. Credibility

Credibility is referring to how well the research findings are describing reality (Bryman & Bell 2015). Credibility can be increased by applying the technique of triangulation, which according to Bryman and Bell (2015) is describing a concept by using different perspectives. This study has aimed to explain a phenomenon using several perspectives of actors that work within different projects within the PtG community. Including several sources from diverse projects to describe the phenomenon is argued to increase the credibility of this study. Another aspect affecting credibility is in how far the sample size meaningfully represents the total population. Bryman and Bell (2015) argue that theoretically research should be conducted until there is no information missing and the entire population is studied. Due to limitations of this thesis, which consist of mainly time limitations, only eight actors have been interviewed. However due to the diversity of respondents, referring to both geographical location and sector-focus, it is argued that a credible sample of the population has been studied. The performed interviews were recorded, which also improves credibility due to the possibility to cross-check the thesis' findings (Lincoln & Guba 1986).

3.8.2. Transferability

Transferability concerns to which extent the findings of a study can be applied to other contexts (Bryman & Bell 2015). In qualitative research, the transferability is often criticized, especially in the context of a case study design. This is because findings within qualitative research are often context specific. Saunders et al. (2012) reason that case studies are appropriate when a new or theoretical area is studied, as it can result in increased knowledge of that context. The decisions made in this thesis have been influenced by the researchers' subjectivity, which makes this study hard to repeat (Saunders et al. 2012). Shenton (2004) reasons that the transferability can be increased if the sample and the method are well described as well as the provision of a thorough contextual description. This helps the reader to understand what circumstances and assumptions impacted the conclusions. For this reason, the underlying methodological implications to this study are described thoroughly. However, it is only the reader that can value this and decide on the thesis transferability.

3.8.3. Dependability

Dependability focuses on the stability of the research findings. This refers to the question whether the same results would be obtained when performing the study again, including the same method, context and participants (Bryman & Bell 2015). To enhance the dependability, all interviews have been audio recorded, which in comparison with new interviews would identify whether the respondents have the same or new ways to describe the phenomenon. Furthermore, the researchers have presented a work plan at the beginning of the project, which would be beneficial for anyone who wants to repeat the same study. The work plan is a sign of dependability according to Guba (1981).

3.8.4. Confirmability

Confirmability is shedding light on how subjectivity is always influencing the findings of a study (Bryman & Bell 2015). As this thesis is following the interpretivist paradigm, it is impossible to be fully objective. As interpretivists the researchers are aware that the study is impacted by their subjectivity. A way to strengthen the confirmability is by focusing on reflexivity. Reflexivity can be described as being conscious of how the epistemological philosophy, methods, choices and biases influence the study (Lincoln 1995). It is important to understand how the research is affected by its participants, both the respondents and the researchers themselves. Reflexivity is illustrated by acknowledging the uncertainty in the empirical data and in any knowledge claims made (Alvesson 2003). Further the researchers reflect upon the thesis' findings and critically discuss its limitations.

The origin of this study evolved from the interest of the researchers in the PtG technology. The researchers have a positive view on this technology and hope that it will become a more common solution to the low carbon transition through BM development. This positive mindset is identified as a bias for the thesis, by for example highlighting more of the benefits rather than the barriers. However, a critical perspective is applied to how and if this technology can work in today's society. By moving away from the technological possibilities that the technology is associated with, and applying a business perspective, the phenomenon is studied from a wider and more objective viewpoint. Therefore, it is argued that the interest in the technology is not affecting the conclusions of this study per se. Rather this interest can be seen as the initial starting point for conducting the research on PtG.

3.9. Ethical implications

It is important to consider the ethical implications that can arise when conducting a study (Bryman & Bell 2015). Any participation in the study has been completely voluntary, which according to Robson (2016) is part of good ethical standards. Following the recommendation of Bryman and Bell (2015) the respondents were first contacted and informed of the study's purpose and thereafter decided whether to participate or not. Furthermore, all participants were offered anonymity and confidentiality before the interviews started. The interview guide was designed to not derive any sensitive information from the respondents, and the data collected was treated carefully and only in relation to the study. The integrity of the participants was taken into account (Kvale & Brinkmann 2009). This was done through ensuring protection of their personal data in line with GDPR. Each respondent signed a letter of consent confirming that the information provided in the interview can be used for the study.

4. Case Study

In this chapter the empirical data from the performed case study is presented. Here BMs narratives that link PtG technology with user practices, infrastructure and supporting network are presented. For a more detailed background on the choice of PtG and the role of PtG in energy and mobility systems see Appendix 4.

4.1. Empirical Data on Business Models of PtG

4.1.1. PtG Technology and Infrastructure

All respondents point out that hard and soft infrastructure are important to consider when introducing PtG technology to the market. The dependability on infrastructure is high. Several of the respondents point to changes in soft infrastructure in order for the technology to enter the market. Here the focus is on adjusting regulations to reduce regulatory obstacles for the uptake of PtG. Respondent D highlights this by stating that hydrogen cannot be fed into the natural gas grid in Germany due to existing regulations.

Focusing on hard infrastructure, several respondents outline the adjustment of existing infrastructure wherever possible rather than the development of new. This is to avoid high investment costs. The availability of existing pipeline structures for the feed-in of any type of green gas differs around Europe. Central Europe has an extensive pipeline network, while the Nordic countries do not. Next to the pipeline bottleneck (in some countries) several respondents point out that the electric grid is another bottleneck. Mutual agreement is reached on the need for technical infrastructure to become more decentralised to ensure an efficient use of the PtG technology and renewables.

The core problem regarding PtG and infrastructure, the chicken and egg phenomenon, is addressed by all interviewees. However, there is no common opinion on how to solve this. One suggestion to solve this problem is the inclusion of infrastructure within the BM. This means offering the technology as well as corresponding infrastructure as a package, meaning incorporating parts of the value chain. Without the enabling infrastructure PtG is a technology that cannot be used.

Existing BMs on PtG indicate that vertical integration and consideration of the whole value chain are a core value proposition, e.g. in the housing sector (Respondents K, M, D, O). This is further emphasised by using a narrative pointing to the vulnerability of supply chains as a take-away of the Corona Pandemic (Respondent M).

Another example is the establishment of an infrastructure company partly owned by a district, which provides vehicles to rent out to public transport or logistics companies (Respondents K, O, D, T). Thereby investment costs are covered partly by public administration. This "remunicipalisation" is however only regarded as a bridging solution. It presents a way for developing and maturing the technology further so that it can eventually become an economic viable option for private businesses (Respondents O, D, T, A).

4.1.2. PtG Technology and Expectation Building

Change of user practices and willingness

All respondents highlight that PtG technology does not have to imply changes in user practices within the mobility or energy sector. In many cases the gas is only used as a substitute for fossil inputs and does not require any adjustment in behaviour. Respondents T and A state that PtG demands less change in behaviour compared to EVs, considering for example fuelling compared to charging.

Simultaneously, the respondents emphasise the importance of education to avoid a rebound effect. Increasing energy consumption is a major challenge. Even though PtG is carbon neutral it does not mean that it offers an unlimited amount of energy as it is dependent on the parallel development of renewables. Therefore, users must be educated to limit overall energy consumption. One aspect is to encourage consumption when energy supply is high, e.g. turning on the dishwasher during sunny hours of the day (Respondents K, T). This could reduce the need to store energy and increases direct and efficient utilization of renewable sources (Respondents A, K, T). To create a change in user practices of energy consumption, respondent A highlights rethinking infrastructure design, in for example city centres, to push for changed behaviour. One example would be to provide more parking spaces for carbon neutral vehicles.

Some respondents point out the need to educate users on how the technology works. This goes hand in hand with a corresponding reduction of fear and prejudices concerning hydrogen and other gas solutions. Through education, trust in PtG is created and users' willingness to try it out increases. The respondents relate the missing trust to cultural aspects and outline that German people are in general security oriented. The option chosen is often the one that is tried and tested.

However, this phenomenon is not specific to PtG, but to all kinds of uprising technology innovation.

The narratives built around user practices for PtG include that the technology is safe, that it works and does not require changes in user behaviour. At the same time, it offers a set of added values with regards to environmental sustainability. Examples of pioneers and first movers' projects can be used as narratives to convince other potential customers and consumers to make use of PtGs value propositions (Respondents K, T, C, A, M).

Narratives used to create expectations

The respondents highlight different kinds of narratives and value propositions of the technology, depending on their PtG projects. Though one aspect is mentioned by each of the eight respondents: PtG technology has no emissions or is at most climate neutral, i.e. only the CO2 that is taken up in the generation of the gas is emitted. This CO2 neutrality is highlighted by all respondents and represents the core value proposition around which BMs for different applications are built upon. Another narrative that is created around the CO2-neutrality is health-related. PtG is not causing any harmful emissions that affect people's and environment's wellbeing (Respondent A). In the following, BMs and corresponding narratives outlined by the respondents are presented based on two categories. These are BMs related to the mobility and energy sectors, with the energy sector being closely related to the housing sector.

Potential BMs in the mobility sector

The main value proposition of PtG for the mobility sector is a reduction of CO2 emissions by substituting fossil fuels with carbon neutral fuels. The respondents state that even though combustion engines are getting more efficient, no reduction of CO2 emissions have occurred throughout the past years. On the contrary the emissions are still rising due to increasing demand. CO2-neutral vehicles of any kind can reduce emissions and also present a complement to existing EV technology. While EVs are better suited for short distances and small vehicles, fuel cells are better suited for heavy vehicles, trains, airplanes and long distances (Respondents T, K, D, A).

Engines powered by e-fuels (e.g. methane) present a bridging technology and can be used in combustion engines today, provided that a corresponding modification kit is attached to the combustion engine (Respondents T, C). Methane-based PtG applications are in so far superior to natural gas and oil in that the production of it requires CO2 as an input, i.e. it can make use of other industries' waste (breweries, sugar production, biomass plants, etc.). Thereby it creates a closed CO2 loop. Furthermore, it can be distributed in existing pipeline infrastructure and used in existing gas boilers and engines. These aspects lead to much lower investment costs needed to diffuse the technology on a large scale compared to building up new infrastructure and suitable systems for the PtG application of hydrogen (Respondents A, T, C).

When addressing industry, transportation as well as public transport companies, the narrative often refers to potential new taxation and regulations and the "fear" of increasing CO2 prices (Respondents T, D, A, K, C). This means that current vehicle fleets might encounter increasing taxation and/or companies are required to reduce CO2 emissions by law.

Potential BMs in the energy sector

In the energy sector the narrative is built upon the CO2-neutrality as well, but focuses much more on the abilities of PtG to serve as an energy carrier, i.e. a chemical vehicle to store and distribute electric energy. PtG can store energy on a seasonal scale, in large quantities and maintains the energy content over long periods of time, unlike batteries. It enables a utilisation of excess energy, which has previously been lost due to feed-in management by converting it into gas and thereby makes more efficient use of renewable energy sources (Respondents T, M, C, A). The potential of PtG as an energy carrier leads to opportunities; developing new markets for renewable energy production, e.g. in Northern Africa. This is outlined by all respondents.

As an energy carrier hydrogen can be used as a buffer system and substitute existing ones based on natural gas within the energy sector (Respondents K, T, A). Respondent A outlines the challenges that come along with increasing shares of renewables in the energy mix and states that the electricity grid is the bottleneck for making efficient use of renewable energy. Hydrogen has the ability to help overcome these challenges by contributing to stabilising the electricity grid as it provides characteristics for efficient peak shaving ("flatten the curve"), grid balancing and decentralisation of energy production (Respondents T, A, M, C). Hydrogen can be used in grid balancing for different kinds of reserve power: For frequency response reserve, spinning and non-spinning reserve as well as replacement reserve (Respondents T, K, A). Hydrogen can replace existing reserve power systems based on fossil fuels.

Furthermore, hydrogen can serve as a substitute for energy carriers such as coal in steel or concrete production (Respondents C, D, A). In fact, industrial players can decrease their emissions significantly if they incorporate PtG into their production processes.

Moreover, on a smaller scale PtG as an energy carrier has implications e.g. for residential areas or individual households. Respondents T and M outline that the value proposition of PtG creates added value for self-produced energy as it provides the means to store the energy in a more efficient way than batteries can. Thereby a hydrogen system combined with solar panels reduces the need for external electricity and the dependence on weather conditions, thus increases self-sufficiency. The system is sold either as a whole system or as a service (Respondents M and T).

4.1.3. PtG Technology and Supporting Network

The respondents reveal a diverse set of enabling factors for developing and shaping the pathways of the PtG technology. Public administration and politics are regarded as initiators for paving the way for PtG through adjusting soft infrastructure and the provision of initial supporting mechanisms. Thereby the necessary framework conditions for the market are established. Respondent C specifically points to the changing of laws as well as an adjustment of taxation on fossil fuels. Respondent M and O outline the importance of international guidance through the agreement on universal environmental targets and initiatives. Further, the majority of respondents state the need for districts or municipalities to become initiators for the uptake of the technology or even be first movers (e.g. establishing an infrastructure company). Through the provision of subsidies and funding they could also support organisations in the uptake of PtG, create a local demand for products and the supporting infrastructure (Respondents K, T, D, A, O).

In addition to the right framework conditions, the importance of collaborative action through partnerships and cooperation between different sectors is highlighted. This cooperation between sectors, referred to as sector-coupling, generates synergies for all actors involved. It connects the energy, mobility and industry sectors. Sector-coupling is regarded as a driver for PtG, especially for financing the adjustment or establishment of technical infrastructure as well as achieving economies of scale (Respondents T, C, A). Close collaboration between actors from multiple sectors implies the reduction of capital costs per actor. Thereby, sector-coupling may also contribute to the resolution of the chicken and egg phenomenon as high costs for the adjustment or provision of infrastructure can be spread among several actors and industries (Respondents T, A). Recalling the core value proposition of PtG, the CO2 neutrality, the respondents outline that this is only valid under the condition that renewable electricity is used in the production process. Here sector-coupling is a key to achieving and maintaining this neutrality (Respondent T, A, M, D). It is needed to guarantee an efficient production, distribution, application and consumption of PtG. The idea of sector-coupling is demonstrated in decentralised smaller projects (Respondents M, T, K, O), thereby attracting all kinds of stakeholders.

Another way to address stakeholders is to refer to pioneers, lighthouse projects, as well as small and decentralised projects. The idea is to create a narrative and present the value proposition of PtG by highlighting best practice examples found in these projects. These can be used for showcasing feasibility and useability; creating sites that demonstrate the otherwise intangible value of hydrogen and other PtG solutions. Potential consumers or investors can study the technology and see that it "works" (Respondents K, T, C, A, M).

Furthermore, the market and consumers (and society as a whole) are another enabler. When the technology has reached maturity, the market will become a major driver (Respondents A, M, T). Consumers and society can push the technology by putting pressure on incumbents to adapt their products and services to contribute to and drive a low carbon transition.

4.2. Summary of Empirical Data

The below Table 2 summarises the empirical data presented in this chapter. The number of respondents that have expressed a specific point is displayed in parentheses. Retrieving the conceptual framework presented in Figure 4 the data is categorised into the three interlinked processes important for societal embedding of a technology. These are connected by BM narratives.

Table 2: Summary of Empirical Data.

Infrastructure Matching
Policy/regulation changes are needed (4)
High dependability on infrastructure (7)
Possibilities to use existing infrastructure (4)
Electric grid capacity is a bottle neck (2)
Infrastructure has to come first (1)
Infrastructure and the technology should be offered as a package (2)
Investment cost are partly covered by public administration (3)
Adapt technology to current infrastructure and usage (3)
Consideration of vertical integration of value chain (3)
User Practices & Expectation Building
PtG do not require changed user practices (5)
Education is needed to avoid rebound effect (6)
Education is needed to reduce fear of the technology (7)
Cultural aspects impact the uptake of new technology (4)
Best practices examples from pioneers and projects (7)
Must create financial value (7)
Grid balancing and energy storage (3)
CO2 Neutrality (7)
Regulation – "Fear" of increasing CO2 prices (2)

PtG as complement for EVs (3)
e-fuels and Methane as bridging technology (3)
Usage of waste (6)
Energy carrier to overcome existing energy challenges (6)
Peak shaving / Operating reserve (4)
Self-sufficiency through decentralisation (4)
Network Building & Enablers
Political support is important (7)
District must be first movers or create demand early in the process (5)
Collaboration though sector-coupling (7)
Pioneers and lighthouse projects (6)
At later stage the market drives the development (5)
Customers/consumers drive indirectly by demand of sustainable solutions (2)

To summarise the empirical data, it can be said that given the right circumstances (i.e. increase of renewables and reduction of regulatory barriers) and developing opportunities, PtG is considered as a major enabler for both, the energy as well as mobility turnaround. Therefore, and here all respondents agree, it can play a crucial role for an overall low carbon transition.

5. Analysis

In this chapter, the findings from the analysis of BMs as performative market devices are presented. It is structured using the three categories identified in the conceptual framework, which are infrastructure, expectations and networks. These categories are connected by the BM acting as a performative device for societal embeddedness. The analysis answers the two identified sub-questions that guided the empirical data collection: a. What narratives of PtG are portrayed by actors involved in PtG projects? b. How is the narrative of PtG used by PtG actors to engage stakeholders?

5.1. Infrastructure Matching

The uptake of the PtG technology is expensive, which leads to the need of BMs for infrastructure developments. Several of the respondents have referred to the chicken-and-egg phenomenon presented by Meyer and Winebrake (2009), meaning that the necessary support infrastructure must be in place to make efficient use of PtG technology. The respondents have presented different views on how this challenge can be overcome and also identified different bottlenecks which impede a resolution of the phenomenon. What they agreed upon however is that the chicken-and-egg phenomenon may only be resolved through collaborative actions between different sectors and socio-technical systems; through sector-coupling, i.e. between energy and mobility sectors. Through collective action between sectors hard (physical) infrastructure for an efficient production, distribution and application of PtG can be adjusted or built.

Political institutions also have responsibility for adjusting the infrastructure, building new infrastructure and the opening up of bottlenecks within the current systems. Following the thoughts by Carroli (2018) infrastructure is not only an economic driver, but also a social driver, it is constructed from physical technology, but only becomes meaningful through social interactions with it. It is a merit good, which enables the usage of products and further factors of production (Thacker et al. 2019). Referring to PtG this would mean that a sufficient technical grid infrastructure would not only have significant economic benefits for sectors directly connected to the production or usage of PtG, but also for the society and the environment. As argued by the respondents, industry and regime actors such as energy producers or transportation companies do not feel solely responsible for building and providing infrastructure. Whereas niche actors and entrepreneurs simply do not have the financial opportunities and cannot bear the financial risks of investing on their own. Thus, infrastructure development that supports the uptake of PtG requires public and institutional intervention (Shove 2010; Thacker et al. 2019), because it provides essential services for society which are likely to be underdeveloped in a free market.

Development and uptake of PtG calls for political and institutional "responsibility to create the framework conditions for an operator to create an economic offer" (Respondent K), to align soft infrastructure for a successful uptake of PtG. It is public administration's responsibility to "set the framework conditions that ultimately open up the appropriate corridors for business and research and development" (Respondent T). Setting the right framework conditions is multifarious. It starts by setting up European quotas or coherent taxation on fossil fuels and increasing CO2-pricing (Respondent M), which then need to be implemented into national law (Respondents K, T, D). The national law then has to be realised and supported on a district and municipal level in which individual projects, organizations or consumers are benefitting. But also creating a demand on the user side is important to establish the technology and make use of the hard infrastructure. This could be achieved through initial subsidies. How this political supporting framework could look is described by one of the respondents:

> "I think politics also plays a big role. The will has to come from somewhere in politics to create certain framework conditions. At the municipal level, this can mean putting funds into the budget to build a fuelling station, for example, or to make infrastructure possible in some way. At the federal and state level, however, it can also be regulations that are anchored in the laws. So, from the pricing of CO2 itself to the subsidisation of electricity from renewable energies." (Respondent D)

But it is not the sole responsibility of public administration and politics to path the right ways for establishing the necessary support infrastructure for a successful diffusion of PtG:

> "As a municipality, we can provide the impetus and promote this concept. But that doesn't mean that we alone are responsible for it, because the motivation must ultimately come from the operators and users." (Respondent D)

The statement made by respondent D highlights the importance of understanding infrastructure as socio-technical constructs. Infrastructure systems should not be studied under the assumption that they "evolve gradually and exhibit strong path-dependence" (Cass et al. 2018, p. 161). The development of infrastructure systems should rather be studied as the outcome of user's responses to infrastructure and the co-evolution and intersectional influences of different infrastructures on each other (ibid.). This leads to infrastructures not being static entities, but socio-technical constructs that shape innovation pathways. Physical components are important, but the users and operators as well as the intersections with other infrastructures make the systems work. That is why sector coupling is highlighted as one of the most important aspects for promoting PtG and building up or adjusting supporting infrastructures. This means that different sectors, from different infrastructural backgrounds (energy, housing, transport, waste) need to collaborate to efficiently shape the pathway for a cross-sectoral production, diffusion and application of hydrogen or other PtG solutions. The institutional bodies such as districts and municipalities thereby function as initiators, facilitators and financial as well as regulatory supporters of this development in its early phases. This is outlined by respondent A:

> "I think that we need to be some sort of early movers and use the municipalities […] to point out the direction and have the political courage to say that we need this change now in order to create a more sustainable and healthy society for the next generation." (Respondent A)

If BMs of infrastructure developments are created, these can be seen as performative market devices that support the uptake of PtG. BMs can in turn lead to enabling subsequent business opportunities. An example of this could be a district owned infrastructure company that sets up the "right" framework conditions. This will be further explained in the next section focusing on the value creation and usage of the PtG technology.

5.2. PtG User Practices & Expectations

The creation of BM narratives through value propositions & calculations

User practices enabled through BMs play a decisive role for the development of socio-technical systems and thus also for the success of any technology innovation brought to the market (Smith & Raven 2012, Tidd 2001). Depending on the technology innovation type it is easier or more difficult to successfully introduce it into the market. Innovations of more path-breaking kind might require changes in user practices which often increase the difficulty to establish it in a specific environment (Carvalho 2015). BMs enable and promote the usage of a technological innovation through presenting a narrative based on value proposition and value creation to users. The core of each BM is that the value proposition must create financial value, i.e. there must be an economic viability for the BM to sustain in the long-run. If this criteria is not met by PtG related BMs there will be no interest in and no widespread diffusion of the technology. This is the basis upon which all respondents have built their reasoning.

Following the pragmatic view on BMs given by Doganova and Eyquem-Renault (2009) it acts as a performative device for entrepreneurs to bring innovation to the market. The performative BM is made up from a calculative and narrative part. The empirical data currently suggests that a stronger focus lies on using the value proposition that guides through the narrative, i.e. building plots and stories based on the zero-emission proposition of the PtG technology. The calculative aspect, showing that the numbers add up, is not yet emphasised strongly within the narrative. This is because "there are still a relatively large number of risks, of a calculative and technical nature" (Respondent A). The BMs of PtG are not yet profitable. Only respondent M has outlined that their BM has reached maturity and economies of scale, hence presenting an economic alternative to existing regime BMs (self-sufficient energy generation, storage and heating). All respondents outlined that profitability is often the key to convincing customers and potential investors and with the numbers not adding up yet, many stakeholders are reluctant to invest.

Qualitative Storytelling – The usage of Internalisation of Externalities

Callon and Muniesa (2005) have broadened the definition of what the numeric valuation within the narrative entails by including a qualitative valuation. Then judgement or storytelling can be included in the scope of the calculation. This is what the respondents have implied as well. Depending on the individual contexts through storytelling and expectation building the respondents try to substitute the quantitative numeric valuation with a qualitative valuation. Mostly this is done by referring to rising prices for fossil fuels or achieving goals and concepts like the SDGs or the European Green Deal and adherence of regulations such as the CVD. Another story told by all respondents is the not unfounded prospects of rising CO2 prices combined with a broadening of affected and regulated sectors which have to bear the levy. The objective of these stories is to outline the future economic potentials of PtG technology, highlighting the fact that while fossil fuels are likely to become more expensive, PtG solutions will become more and more attractive, not only from an environmental and corporate citizen view, but also from a financial perspective.

The respondents unconsciously make use of a theory called internalisation of externalities presented by Unerman et al. (2016). The advocates of the PtG technology outline the financial risks associated with fossil fuel-based energy production, consumption and mobility. They call for substituting current systems that cause negative externalities, thereby saving future costs (e.g. through taxation, fines or mandatory mitigation). By referring to the threat of the pricing of negative externalities, landscape pressure on all carbon emitting sectors is created. Landscape pressure, like the pricing of externalities can destabilise regimes and opens opportunities for change and the uptake of new technologies (Geels & Schoot

2007). The PtG BMs serve as a basis for the creation of narratives to convey a) the threat of externality pricing and b) directly present the solution to circumvent these costs; by uptaking PtG.

Another qualitative story told is the symbiosis which cross-sectoral cooperation and communication can achieve. This is explained by Respondent D as striving for “economic efficiency [which] can often be achieved precisely through cooperation”. Moreover, sector coupling can lead to economies of scale, eventually leading to decreasing prices for both hydrogen, as well as corresponding application devices (Respondents A, T, D). Examples for these application devices are buses, HGVs, electrolysers or hydrogen-powered heating devices.

Through storytelling expectations are created. Part of these expectations are the qualitative numeric stories, which in the near future should be exchanged for actual quantitative numeric valuations. How this future quantitative numeric value creation may look is demonstrated in several pilot BMs unfolding in protected spaces; niches. These are presented hereafter.

Unfolding PtG related BMs

The respondents have outlined that CO2 as an input opens opportunities for a diverse set of industrial actors, e.g. breweries, distilleries, biomass power plants, or sugar production. All of these create CO2 as a by-product of their core production. When captured, this CO2 can be metabolised with hydrogen and creates climate-neutral methane. A closed CO2 loop is created. This is in line with the ideas promoted in the cradle-to-cradle and circular economy (CE) concepts, extending and establishing a resource cycle as efficient as possible. The circularity of CO2 is used as a narrative to address producers as well as potential users of CO2 inputs in their production processes. The value proposition of creating a closed loop resource cycle connected with qualitative numeric storytelling creates expectations for a viable economic BM. In these BMs waste becomes an input which other businesses are willing to pay for. Selling and reusing CO2 contributes to a CE by “reducing the societal production-consumption systems' linear material and energy throughput flows by applying materials cycles, renewable and cascade-type energy flows to the linear system” (Korhonen et al. 2018, p. 547).

With regards to self-sufficient energy systems for housing, two BMs have been presented by the respondents. Both can be defined as product-service systems (PSS) as defined by Tukker (2015). The first is a product-oriented and the second is a use-oriented PSS. The BMs offer a service, which have the value proposition of being more sustainable on an environmental (CO2-neutrality) as well as social (self-sufficiency) level. BMs that offer added value are becoming more competitive than traditional regime BMs. This is in line with Wainstein and Bumpus (2016) who state that BMs can act as a market device if they are competitive and innovative.

Another BM to showcase competitiveness can be found within the mobility sector through the establishment of an infrastructure company. The idea of this company is to design it as a PSS. The objective is to buy hydrogen powered vehicles and organise the necessary support infrastructure to run them. The BM is to rent out the vehicles to local companies. The aim of this partly district or municipality owned company is to reduce the financial burdens for public transport actors and to support the uptake of PtG. The assumption is that even with the provision of subsidies the replacement of the whole vehicle fleet would not be not for small and medium sized public transportation companies. The same is true for logistics companies. Thereby the infrastructure company also helps to societal embed the PtG technology into existing regimes.

Public transport is a task contracted out to private companies by districts. Through the establishment of an infrastructure company private companies have the possibility to rent the vehicles. They then only have to provide the personnel and organisation of public transport, thereby financial risks are reduced and shifted to the districts. It smooths the transition as financial barriers are reduced for private companies, encouraging usage of the technology. The infrastructure company is regarded as a bridging solution. The intention is to hand back the responsibility for the vehicles to private companies as soon as the technology has entered the regime and thereby becomes affordable.

The analysis shows that BMs can be used as a performative device to create value and achieve competitiveness. Different BMs, like CE or PSS enable user practices that make use of PtG value propositions. To facilitate the uptake of PtG, districts and municipalities can establish infrastructure companies. However, the establishment of those BMs and the enabling of corresponding user practices is dependent on a dense network of different sectors. This sector-coupling is elaborated upon in the next section.

5.3. Supporting Network is Key

Socio-technical energy and mobility regimes can be challenged by PtG developed in experimental projects and niches. In these experimental niches PtG incubates and is tested until it eventually presents an alternative to the existing regime (Carvalho 2015). An important factor for the socio-technical configurations to mature is the early inclusion of progressive interaction between different dimensions that affect its future use. In addition to increasing knowledge through education on PtG technology (Respondents K, D), cooperation and collaboration between sectors (Respondents T, C, A, M) are important for its development.

The importance of cooperation and collaboration is defined by Carvalho (2015) as network and coalition building. These coalitions of public and private actors are in addition to the adjustment of infrastructure and expectation building (see previous sections) a third interlinked process for societal embedding of an emerging technology. The respondents add that next to network building within sectors, it is equally important to collaborate between sectors. This is outlined as sector-coupling and regarded as decisive for the success of the PtG technology. However, there is a differentiation between network building and sector-coupling. In networks all stakeholders involved are from one socio-technical system, whereas sector-coupling refers to inter-sectoral coalitions which have the ability to accelerate the uptake and development of PtG. Here, the stakeholders come from diverse socio-technical systems, e.g. from the energy and mobility system. Sector-coupling represents the creation of coalitions of private actors from diverse socio-technical systems. It can then be understood as a connecting entity between networks situated within different socio-technical systems. This finding is visualised in Figure 5 below.

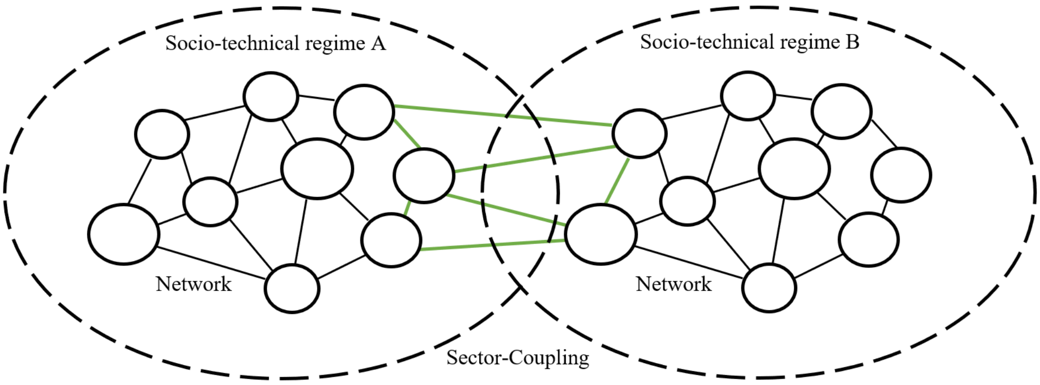

Figure 5: The idea of Sector Coupling is to create coalitions of private business between two or more networks of different socio-technical systems (regimes), e.g. energy and mobility. (Own illustration).

Sector-coupling is showcased in many lighthouse projects as well as small and decentralised projects presented in the empirical background and by the respondents. These multiple local projects collectively form an emerging niche community of PtG by creating networks. For a widespread uptake of PtG these niche projects need to be scaled-up and eventually substituted with comprehensive sector-coupling in the regime.

Many respondents have called for the need of changed business environments to ensure the uptake of PtG technology. This could for example be an adaption of policies and regulations to decrease institutional barriers impacting the uptake of PtG. All individual actors that develop PtG in small local projects have little impact on regimes which "employ political economic resistance to sustain their technological lock-in" (Wainstein & Bumpus 2016 p. 575). If PtG actors and stakeholders can come together through a united narrative that forms a strategic niche, the regime can be influenced as pressure can be brought to bear and destabilise it. BMs can have the unifying effect needed to create this strategic niche. They can act as a boundary object (Star & Griesemer 1989), bringing the actors together in networks, while the actors can still maintain their individual value proposition. The BM as a performative device can thus not only be used to address multiple stakeholders but can bring individual actors from different contexts and sectors together. These characteristics make BMs a useful device to facilitate the mentioned sector-coupling which is outlined as a key for achieving profitability of PtG technology.

The importance of a supporting network has been central in the case study, as individual actors from industry and regime do not feel sole responsibility for providing the infrastructure and environment that benefits PtG technology. As niche actors themselves many of the respondents do not have the power nor the financial ability to invest on their own and are open for collaborations. The risk of investment has to be divided. The network can offer both, increased ability to influence the regime, as well as enabling the uptake of the PtG technology. Further, through the establishment of a network and sector-coupling, infrastructure can be developed in joined activities. This is in line with Thacker et al. (2019) who state that for an innovation to successfully enter the market, supporting infrastructure is vital.

5.4. Summary of Analytical Findings

To conclude, the analytical findings are summarised in the below Table 3. The findings presented contribute to the understanding of BMs as performative market devices for development and uptake of technological innovation, i.e. societal embedding of technology innovation into a socio-technical regime. This is connected to Carvalho's (2015) description of societal embeddedness which points to the importance of infrastructure matching, expectation building and network building. These can be achieved through using the BMs as a performative device.

Table 3: Summary of Analytical Findings.

Summary of Analytical Findings
Infrastructure Matching
- Chicken-and-egg phenomenon can be resolved through sector-coupling or the establishment of an infrastructure company
Expectation Building
- Expectation building through BM narratives play a decisive role for the uptake of PtG in socio-technical systems
- BMs are constructed of narratives that rely on storytelling
- Internalisation of externalities used for creating qualitative calculations
- Usage of sustainable BMs to promote PtG (e.g. PSS and CE)
Network Building
- Sector-coupling is the key for a uptake of PtG within several socio-technical systems
- Socio-technical systems intersect, i.e. dependent on each other for a diffusion of PtG
- Narratives stressing sector-coupling contribute to societal embedding technology innovation
- BMs contribute to societal embedding technology innovation

6. Discussion

In this section the findings, categorised into infrastructure matching, expectation and network building and their relation to the literature, are discussed. The main research question is the starting point for this discussion, which is: (1) What is the effect of performative BMs on an emerging niche technology? The effect of BMs has been analysed based on the three categories of societal embeddedness. This chapter concludes with a discussion on the limitations of the study.

6.1. Business Models as Performative Market Devices

The findings show that the value of BMs for emerging technology is their ability to be used as performative market devices for technology stakeholders. The BM narrative is used to demonstrate the value proposition. Also, it demonstrates the need for a corresponding network to enable the value proposition, thereby supporting the findings from Doganova and Eyquem-Renault (2009). By creating a narrative and providing qualitative calculations – eventually becoming quantitative calculations – BMs can outline the value of emerging technology. The construction of a narrative based on a coherent story enables actors to shift the focus from technological components to value propositions; from what it is (technology) to what it can do (value proposition). This shift means that the BM as a performative market device will enable user practices and make the technology societal embedded, a process described by Carvalho (2015). When the narrative showcases what the technology can do, it starts to engage users who see the (future) value creation.

The findings indicate that the calculative part of the BM is, due to the infancy of technology, often of a qualitative nature. This means it is based on reasonable assumptions, e.g. increasing taxations on fossil fuels and CO2 prices as well as effects of economies of scale and the development of more efficient technological components. These assumptions are presented in scenarios and are connected to an emphasis for the need of an enabling network, including regime actors.

6.2. How Business Models are used to Engage Stakeholders

The case study shows that the BM is performative by being used as a boundary object, flexible enough to adjust the narrative and calculations depending on the stakeholder addressed. When a BM narrative is created it is important to base it on a coherent story so that all stakeholders can eventually arrive back at the core value proposition of the technology. For PtG technology the core value proposition on which the narratives for the different BMs have been built upon is the CO2 neutrality. The narrative emphasises the CO2 neutrality and provides a coherent story that showcases the technology's feasibility for different applications. The feasibility is demonstrated by using narrative elements and qualitative calculations and by connecting these to existing best practice examples, often found in niches made up from local projects. In these niches the value proposition can unfold and eventually mature into an economic viable business (Carvalho 2015).

The inclusion of best practice examples as part of the narrative enables actors to test the reasonable assumptions made within the qualitative calculations and add actual quantitative calculations. This means that the assumptions can be backed up with actual calculations, showing that the numbers add up under certain conditions. BM narratives outline scenarios based on potential costs for negative externalities. These narratives have the power to create traction for regime actors, e.g. public transport companies who face the threat of increasing fossil fuel or CO2 prices. These "threats" are referred to as landscape pressures, which can destabilize a regime and make it amenable to change. This change can come about through changes in existing BMs, or from the introduction of new BMs (e.g. based on CE or PSS) and the corresponding establishment of enabling and supporting networks.

BMs are used as a device to address the importance of network building and sector-coupling in two ways. First, sector-coupling becomes an important part of the narrative transmitted to the various stakeholders addressed. Unlike the criticized "silo thinking" in existing transition research (Cass et al. 2018; Carroli 2018) the findings of this study suggest that the networks developed for emerging technology are cross-sectoral. Thereby the actors within the PtG niches acknowledge the interconnections of socio-technical systems. The BM becomes a performative market device being the foundation for the creation of narratives to enable sector-coupling. These narratives emphasise the interconnectedness and need for integrative problem solving between sectors. The BM narratives establish a common ground on which sector-coupling can develop and support the development of emerging technology from the niche to the regime. It is important to recognize that emerging technology requires interaction between multiple sectors and thus can affect multiple socio-technical regimes.

Second, the performativity of BMs to support network building and sector coupling creates a niche community. By presenting coherent and meaningful BM narratives previously independent local projects can be connected. This connection has the potential to develop a niche community rather than a map of independent islands. Again, the importance of acknowledging the interconnectedness of socio-technical systems is visible; Independent projects might research and work with the same technology, but on their own and within different sectors (e.g. mobility and energy projects). The BM narratives help to connect the projects by outlining the junctions and connections between the different sectors. Furthermore, the narratives specifically outline the dependence of the BMs success on effective cross-sectoral network building and collaboration.

These findings support previous research (Köhler et al. 2019; Cass et al. 2018; Carroli 2018) that emphasise the weaknesses of existing transition models and theories such as the MLP (Geels & Schoot 2007). Transition literature regards transitions as trajectories that exhibit strong path dependency, recognizing only one regime at a time. Intersections and dependencies between regimes from different socio-technical systems are not acknowledged. Moreover, they often fail to include a business study perspective. Wainstein and Bumpus (2016) have picked up on this criticism and combined the MLP with a business studies approach, arguing that BMs can be used as a performative device for socio-technical (low carbon) transitions. The framework presented by Wainstein and Bumpus (2016) recognises the influence of other socio-technical regimes but does not emphasise the potential of BMs to function as intermediaries for network creation.

6.3. The Extension of Business Model Theory

This study extends the framework presented by Wainstein and Bumpus (2016), see Figure 6a, and confirms the characteristics of BMs to serve as a market device to drive transitions. Figure 6a is extended by adding analytical components recognizing the importance for cross-sectoral network building. As outlined by Doganova and Eyquem-Renault (2009) a BM can be used as a performative device and act as a boundary object to address multiple stakeholders. The findings show that the underlying value propositions of emerging technology forms the core of the narratives that are used to address various actors from different sectors. For PtG this is CO2 neutrality as the core value proposition, which is interesting and important for actors within the mobility and energy sector.

BMs can be used as what Bidmon and Knab (2018) refer to as intermediaries and Doganova and Eyquem-Renault (2009) as boundary objects between niches and regimes within different socio-technical systems. Thus, it is argued that the framework by Wainstein and Bumpus (2016) can be extended by adding a component that acknowledges the ability of BMs to act as boundary objects between socio-technical regimes. Thereby, the importance of sector-coupling for emerging technology in a low carbon transition is recognized in the case study.

In Figure 6b an extension of the framework is presented by adding three additional components. First, BM narratives can act as boundary objects which can be used to address stakeholders from multiple socio-technical systems as suggested by Doganova and Eyquem-Renault (2009). Second, there are intersections between socio-technical system developments as highlighted by Cass et al. (2018). These intersections are parallel developments in diverse sectors which can be bundled and by joining forces can then create a symbiosis. Third, collaboration between actors from different socio-technical systems is a vital component for a successful low carbon transition. This sector-coupling is facilitated by BM narratives based on the same core value proposition, e.g. CO2 neutrality. Narratives are slightly modified depending on sector and addressed actor. Narratives represent the connecting entity that are threading through BMs based on the same emerging technology in different socio-technical systems.

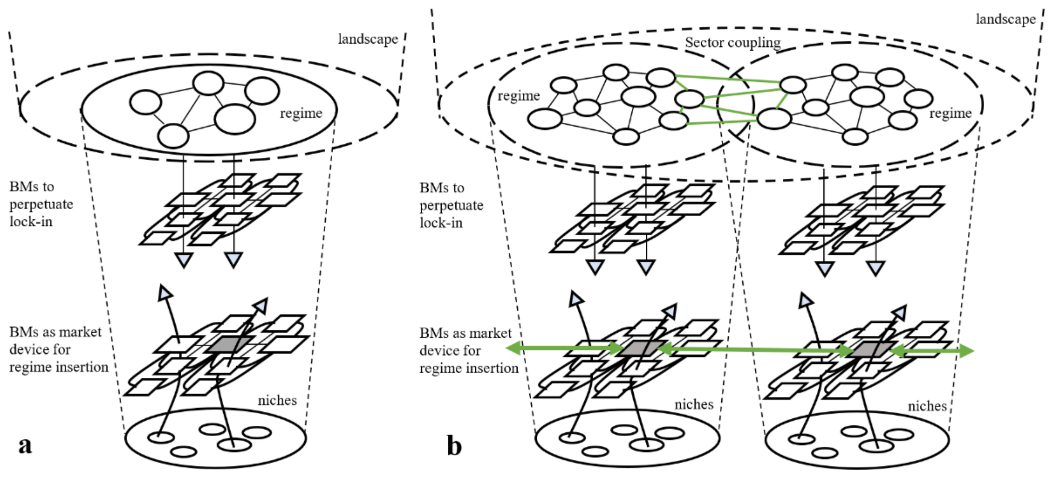

Figure 6: a. BMs as enablers of sociotechnical transitions acting as performative devices for niche and regime actors. Inspired by Wainstein and Bumpus (2016). b. BMs as performative devices and connecting entity for sociotechnical transitions within multiple regimes. (Own illustration).

By widening the framework, we incorporate the criticism on existing transition literature which is neglecting the influence of intersecting socio-technical regimes. In addition, it acknowledges the performative roles of BMs to act as boundary objects and intermediaries between multiple sectors. Figure 6b can be showcased best by drawing on an empirical example such as the previously presented BMs based on CE. Here CO2 from industrial production processes is used as an input for energy generation. Both the industry and energy sector have an incentive for utilising the CO2 to either decrease their carbon footprint or produce carbon-neutral gas. In a later stage the gas can be then used for carbon neutral mobility or as an input for industry again. This shows that different sectors are affected by one technology, PtG, and to use the inherent potential of carbon neutrality need to collaborate to make efficient use of it. Therefore, sector-coupling is important.

Nonetheless, the figure presented is a simplified illustration of the above discussion and we are aware that there are limitations to its expressiveness as its simplicity cannot show the full dynamics inherent to the processes of transition. One example is the negligence of the dynamics of the societal embedding process. Still, we believe that it presents a good overview of our findings. When viewed in connection to our discussion it provides a helpful framework for the understanding of BMs as performative market devices for development and uptake of technological innovation.

6.4. Limitations

The qualitative analysis of this thesis has resulted in valuable insights into the role of BMs, but this type of study has some limitations (Lincoln 1995), presented in this section. The research design, methodology and analytical framework have impacted the findings and conclusions and influenced the collection and interpretation of empirical data. This section aims to account for these limitations by critically viewing the methodological choices of the study and how they impacted the results. The findings will be evaluated with regards to three aspects: credibility, generalisability, and validity.

The choice of performing an exploratory case study, has enabled the researchers to develop an understanding of the PtG technology and collect information from sources with a variety of perspectives. Performing a case study has been beneficial as the information on PtG technology is context specific. Emerging technology is developing in niche projects, and thus the researchers collected information through interviewing actors involved in these niche projects. However, this method has its limitations.

In terms of the credibility of the results, it is important to understand that the data has been collected from respondents drawing on experiences within their specific projects. The thesis' findings and conclusions can be criticised for being drawn from the relatively small amount of data (eight interviews). It could be the case that another person has different perspectives on BMs of PtG, which are not captured in this study. The results are also affected by the researchers own perception and perspective, which impact the way the results have been perceived. It is important to highlight that personal expectations on the data collected might have influenced the interpretation. Another aspect to emphasise is that the researchers come from a business background with limited skills in related research areas such as transitions research or engineering and technological related fields of study. Especially with regards to technological features of PtG the researchers were limited and thus might have missed important aspects that are decisive for future economic viability of PtG related BMs. If the study was performed by other researchers, the results might differ due to other interpretations of the data.

Flyvbjerg (2006) states that statistical generalisability is not relevant when conducting a qualitative study. Instead, this study has achieved conceptual generalisability, as the results can be applied to projects that have a similar context. The results from the empirical data are, as pointed out, context specific. The number of interviews performed covers only a small share of actors working within PtG related projects and industries. Further the respondents only represent views for a few specific projects and not the whole PtG niche community. Still, the respondents interviewed contributed with different viewpoints as they are involved in diverse projects which are independent from each other. The aim of selecting a heterogeneous sample project was to reduce bias, which in turn increases the validity and the generalisability of the results. It can be said that these results are valid for similar projects and therefore are transferable to those.

The analytical framework of studying BMs as performative market devices in relation to technology innovation has led to conclusions that are not context specific but can be applied to other emerging technologies. The findings are generalisable and can be applied to other technological innovations which aim to contribute to low carbon transitions. The analytical framework has been helpful to analyse the integration of BM theory and transition theory by helping to focus the study on BMs as performative devices and societal embedding. Nonetheless, other relevant aspects unintentionally excluded from this framework might result in different conclusions to this study. The findings presented in the discussion regarding the development of BM theory is highly abstract. It should be used with caution in further studies. Bearing this in mind the findings provide a valuable contribution for the understanding of BMs role in low carbon transitions.

7. Concluding Remarks

This final chapter concludes the thesis by addressing the aim, presenting the major findings and providing suggestions for further studies.

7.1. Conclusion

The thesis contributes to an understanding of BMs as performative market devices to explain the development and uptake of technological innovation. The research area is relatively new and connects transition and business studies. The starting point has been existing criticism on transition theory and BM theory. First, transition theory is criticised for neglecting BM perspectives as well as missing the inclusion of junctions and connections between transitions in different socio-technical systems. Transition research with an emphasis on business studies is underdeveloped. However, the business administration field can contribute valuable perspectives to the discipline of transition research. Second, the traditional view on BMs is criticised for being a static description of a business, which highlights essential characteristics and functions. Applying a pragmatic perspective, BMs can be seen as a performative market device. In their framework Wainstein and Bumpus (2016) combine transition studies and the pragmatic view of BMs and demonstrate the role of BMs as market devices. This thesis has led to an extension of Wainstein and Bumpus (2016) framework that acknowledges the previously identified research gap.

The framework developed by Wainstein and Bumpus (2016) regards BMs as performative market devices acting as intermediaries between niche and regime (Bidmon & Knab 2018) for the uptake of technological innovations in a low carbon transition. By following the thesis objective to demonstrate the performative role of the BM for an emerging technology the findings have provided some unique insights: This study adds cross-sectoral components to the framework as a result of its findings from performing a case study on the emerging technology of PtG. The findings confirm that BMs can be used as performative devices and act as boundary objects for the development and uptake of emerging technology as suggested by Doganova and Eyquem-Renault (2009). The importance of BMs to function as a boundary object has been specifically highlighted in the analysis and discussion.

Recent transition studies suggest that there are cross-sectoral influences and intersections between transitions in different socio-technical systems (Cass et al. 2018; Köhler et al. 2019). Acknowledging this and incorporating the ability of BMs to act as boundary objects, this study shows that the BM can act as an intermediary to enable the uptake of technology innovation. That means, BMs based on the same technology can be adjusted to address actors within different socio-technical systems through the use of narratives and thus are able to connect these. Thereby cross-sectoral coupling is enabled, which is regarded as important for the societal embeddedness of emerging technology in the low carbon transition. Through adding the idea of sector-coupling to the framework it showcases that low carbon transitions are not path dependent but are the outcome of intersecting socio-technical system changes. These findings answer the thesis' research question and demonstrate the effect of performative BM for an emerging technology.

For actors within the niche communities these findings are relevant as they show that by using BM narratives and applying a business perspective, they can escape the field of demonstration and focus on the application and diffusion of technology. Furthermore, the importance of BMs for addressing investors, users, authorities and other potential partners has been shown, as they can act as an intermediary and connecting entity to create networks for the development and uptake of technology. Thus, the BM becomes an enabling device by shifting the focus from a technical to a socio-technical perspective. This socio-technical perspective is needed to successfully tackle the challenges inherent in dominant energy and mobility regimes to support a low carbon transition.

This thesis gives valuable insights to niche communities of emerging technology by emphasising the importance of creating coherent BM narratives to societal embed the technology. Theoretical relevance is created through validating the pragmatic characteristics of BMs to support the uptake of technology innovation in low carbon transitions. Moreover, it contributes with new insight by highlighting the importance of BMs for cross-sectoral collaboration, thereby acknowledging the interconnectedness of slow carbon transitions.

7.2. Further Research

This thesis develops an increased understanding on how BMs used as performative market devices can enable the development and uptake of technological innovation. This is shown through a case study on PtG technology. Further research could apply the same framework and methodology to other technological innovations. Thereby validity and generalisability can be increased, and the extension of the Wainstein and Bumpus (2016) framework can be either confirmed or criticised and adjusted.

Furthermore, one of the limitations of this study is the relatively small number of projects and actors included. Therefore, further research with a more extensive data collection that represents a bigger share of the population is suggested as it could result in more generalisable results.

Another research direction to validate the findings on the performative role of BMs is to conduct a longitudinal study. Applying a longitudinal approach, the role of BMs and the expectations connected to those can be tested throughout the process of uptake of technological innovation. Thereby the different scenarios and assumptions which were outlined by the respondents can be tested, verified, adjusted, or falsified. This is especially important, as most calculative narratives presented were based on qualitative rather than quantitative storytelling. As the projects mature more data could be collected to study if reality (quantitative calculation) is in line with expectations (qualitative calculation).

This study has been performed within the business administration field and focused on a BM viewpoint. However, it would be interesting to follow up this qualitative study with a quantitative study. One suggestion is to use an economics approach to study the interaction between economic theory and transition research, which is supported by Köhler et al. (2019). Here, the influence of negative externalities on transitions would be of interest to study further as the pricing of negative externalities was highlighted by several interview respondents within this study.

References

Alvesson, M. (2003). Beyond Neopositivists, Romantics, and Localists: A Reflexive Approach to Interviews in Organizational Research. Academy of Management Review. vol. 28 (1), 13–33. https://doi.org/10.5465/amr.2003.8925191

Amit, R., & Zott, C. (2001). Value creation in E-business. Strategic Management Journal 22, 493–520.

Bartel, C., Garud, R. (2009). The role of narratives in sustaining organizational innovation. Organization Science. 20 (1), 107–117.

Belderbos, A. Delarue, E. & D'haeseleer, W. (2015). Possible Role of Power-to-Gas in future Energy Systems. Proceedings of 12th International conference on the European energy market (EEM), Lisbon, 2015. 1–5.

Berkhout, F. (2014). Sustainable innovation management. The Oxford handbook of innovation management. Oxford University Press. Oxford, 290-315.

Bhide, A. (2000). The Origin and Evolution of New Businesses. Oxford University Press.

Bocken, N. M., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. Journal of cleaner production. 65, 42-56.

Bolton, R. & Hannon, M. (2016). Governing sustainability transitions through business model innovation: Towards a systems understanding. Research Policy, 45 (9), 1731–1742. https://doi.org/10.1016/j.respol.2016.05.003

Breyer, C., Tsupari, E., Tikka, V. & Vainikka, P. (2015). Power-to-Gas as an Emerging Profitable Business Through Creating an Integrated Value Chain. Energy Procedia, 73, 182–189. https://doi.org/10.1016/j.egypro.2015.07.668

Bryman, A. & Bell, E. (2015). Business Research Methods. 4th edn. Oxford: Oxford University Press.

Buck, M., Graf, A. & Graichen, P. (2019). European Energy Transition 2030: The Big Picture. Ten Priorities for the next European Commission to meet the EU's 2030 targets and accelerate towards 2050. Agora Energiewende.

Bundesnetzagentur (2021). Monitoringbericht 2020. Bonn.

Callon, M., Muniesa, F. (2005). Economic markets as calculative collective devices. Organization Studies. 26(8), 1229–1250.

Carvalho, L. (2015). Smart cities from scratch? A socio-technical perspective. Cambridge Journal of Regions, Economy and Society. 8(1), 43-60.

Carroli, L. (2018). Planning roles in infrastructure system transitions: A review of research bridging socio-technical transitions and planning. Environmental Innovation and Societal Transitions. 29, 81–89. https://doi.org/10.1016/j.eist.2018.06.001

Cass, N., Schwanen, T. & Shove, E. (2018). Infrastructures, intersections and societal transformations. Technological Forecasting and Social Change. 137, 160–167. https://doi.org/10.1016/j.techfore.2018.07.039

Chesbrough, H. (2003). Open Innovation: The New Imperative for Creating And Profiting from Technology. Harvard Business School Press, Boston.

Cody, J. (2021). Sweden Wrestles with Power shortage as Cold weather hampers supply. Climate change dispatch. https://climatechangedispatch.com/sweden-wrestles-with-power-shortage-as-cold-weather-hampers-supply/ [2021-04-07]

Creswell, J.W. (2012). Educational research: planning, conducting, and evaluating quantitative and qualitative research. 4th ed. Boston: Pearson.

Czarniawska-Joerges, B., Hopfl, H. (2002). Casting the Other: The Production and Maintenance of Inequalities in Work Organizations. Routledge, London.

Delmar, F., & Shane, S. (2003). Does planning facilitate product development in new ventures? Strategic Management Journal. 24, (12), 1165–1185.

Diermann, R. (2020-11-14). Entwicklung von grünem Ammoniak. Dieser ökologische Energieträger schlägt sogar Wasserstoff. Der Spiegel. https://www.spiegel.de/wissenschaft/technik/gruenes-ammoniak-dieser-oekologische-energietraeger-schlaegt-sogar-wasserstoff-a-5012251f-35e9-4430-b122-ddaa3d4758f1 [2021-03-03]

Doganova, L., & Eyquem-Renault, M. (2009). What do business models do?: Innovation devices in technology entrepreneurship. Research policy. 38(10), 1559-1570.

Dunn, S. (2002). Hydrogen futures: toward a sustainable energy system. International Journal of Hydrogen Energy, 27 (3), 235–264. https://doi.org/10.1016/S0360-3199(01)00131-8

DVGW. (2020). Eine Übersicht der Power-to-Gas-Projekte in Deutschland. https://www.dvgw.de/themen/energiewende/power-to-gas/interaktive-power-to-gas-karte [2021-04-05]

Elzen, B., Geels, F. & Green, K. (2004). System Innovation and the Transition to Sustainability. Edward Elgar Publishing. https://doi.org/10.4337/9781845423421

European Commission. (2019). The European Green Deal. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. COM(2019), 640 Final

European Commission. (2020a). A hydrogen strategy for a climate-neutral Europe. COMMUNICATION FROM THE COMMISSION TO THE

EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. COM (2020), 301 Final

European Commission. (2020b). Renewable Energy Progress Report. REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. COM (2020), 952 Final

Eurostat. (2020). How are emissions of greenhouse gases by the EU evolving?. European commission. https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-4a.html [2021-04-07]

Farla, J. C. M., Markard, J., Raven, R., & Coenen, L. E. (2012). Sustainability transitions in the making: A closer look at actors, strategies and resources. Technological forecasting and social change. 79(6), 991-998.

Federal Ministry for Economic Affairs and Energy (BMWI) (2020). The National Hydrogen Strategy. BMWI, Berlin. https://www.bmbf.de/ files/bmwi_Nationale%20Wasserstoffstrategie_Eng_s01.pdf [2021-04-05]

Freeman, R, E. (2010). Strategic Management: A Stakeholder Approach (digitally printed version). Cambridge University Press, UK.

Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. Qualitative Inquiry. 12 (2), 219–245. https://doi.org/10.1177/1077800405284363

Fuenfschilling, L., Truffer, B. (2014). The structuration of socio-technical regimes—Conceptual foundations from institutional theory. Research Policy. 43(4), p. 772-791.

Fraunhofer ISE (2021). Energy Charts - Stromproduktion in Deutschland Januar 2021. https://energy-charts.info/charts/power/chart.htm?l=de&c=DE [2021-02-23]

Ghaziani, A., Ventresca, M.J., (2005). Keywords and cultural change: frame analysis of business model public talk, 1975–2000. Sociological Forum. 20 (4), 523–559.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research policy. 31(8-9), 1257-1274.

Geels, F.W., Schoot, J. (2007). Typology of sociotechnical transition pathways. Research Policy. 36 (3), 399–417. https://doi.org/10.1016/j.respol.2007.01.003

Geels, F. W. (2018). Low-carbon transition via system reconfiguration? A socio-technical whole system analysis of passenger mobility in Great Britain (1990–2016). Energy research & social science. 46, 86-102.

Given, L. (2008). The SAGE Encyclopedia of Qualitative Research Methods. 2455 Teller Road, Thousand Oaks California 91320 United States: SAGE Publications, Inc. https://doi.org/10.4135/9781412963909

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. ECTJ, 29(2), p. 75.
Guba, E.G. & Lincoln, Y.S. (1994). Competing paradigms in qualitative research. Handbook of qualitative research. Thousand Oaks, CA, US: Sage Publications, Inc, pp. 105–117.
Honig, B., Karlsson, T. (2004). Institutional forces and the written business plan. Journal of Management. 30 (1), 29–48.
IEA. (2021). Global energy-related CO2 emissions by sector. Paris: IEA. https://www.iea.org/data-and-statistics/charts/global-energy-related-co2-emissions-by-sector [2021-04-07]
Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. Technology analysis & strategic management. 10(2), 175-198.
Kivimaa, P., Laakso, S., Lonkila, A. & Kaljonen, M. (2021). Moving beyond disruptive innovation: A review of disruption in sustainability transitions. Environmental Innovation and Societal Transitions. 38, 110–126. https://doi.org/10.1016/j.eist.2020.12.001
Kvale, S. & Brinkmann, S. (2009). InterViews: Learning the Craft of Qualitative Research Interviewing. SAGE.
Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., ... & Wells, P. (2019). An agenda for sustainability transitions research: State of the art and future directions. Environmental Innovation and Societal Transitions, 31, 1-32.
Kopp, M., Coleman, D., Stiller, C., Scheffer, K., Aichinger, J. & Scheppat, B. (2017). Energiepark Mainz: Technical and economic analysis of the worldwide largest Power-to-Gas plant with PEM electrolysis. International Journal of Hydrogen Energy, 42 (19), 13311–13320. https://doi.org/10.1016/j.ijhydene.2016.12.145
Langendahl, P.-A., Roby, H., Potter, S. & Cook, M. (2019). Smoothing peaks and troughs: Intermediary practices to promote demand side response in smart grids. Energy Research & Social Science, 58, 101277. https://doi.org/10.1016/j.erss.2019.101277
Lincoln, Y.S. (1995). Emerging Criteria for Quality in Qualitative and Interpretive Research. Qualitative Inquiry, vol. 1 (3), pp. 275–289. DOI: https://doi.org/10.1177/107780049500100301
Lincoln, Y.S. & Guba, E.G. (1986). But is it rigorous? Trustworthiness and authenticity in naturalistic evaluation. New Directions for Program Evaluation, vol. 1986 (30), p. 73– 84. https://doi.org/10.1002/ev.1427
Mackenzie, N. & Knipe, S. (2006) Research dilemmas: Paradigms, methods and methodology. Issues in Education Research. 16(2), pp.193–205.
Maia, S.C., Teicher, H. & Meyboom, A. (2015). Infrastructure as social catalyst: Electric vehicle station planning and deployment. Technological

Forecasting and Social Change, 100, 53–65. https://doi.org/10.1016/j.techfore.2015.09.020
Meadows, D.H. & Club of Rome (eds.) (1972). The Limits to growth: a report for the Club of Rome's project on the predicament of mankind. New York: Universe Books.
Merriam-Webster. (2021). Infrastructure. https://www.merriam-webster.com/dictionary/infrastructure [2021-05-04]
Mah, D., Wu, Y.-Y. & Ronald Hills, P. (2017). Explaining the role of incumbent utilities in sustainable energy transitions: A case study of the smart grid development in China. Energy Policy, 109, 794–806. https://doi.org/10.1016/j.enpol.2017.06.059
Osterwalder, A., Pigneur, Y., & Tucci, C. L. (2005). Clarifying business models: Origins, present, and future of the concept. Communications of the association for Information Systems. 16(1), 1.
Rappa, M. (2001). Business Models of the Web. http:// digitalenterprise.org/models/models.html [2021-05-03]
Robson, C. (2016). Developing your Ideas. Real World Research.
Saunders, M., Lewis, P. & Thornhill, A. (2012) Research Methods for Business Students. 6th edn. Harlow; New York: Pearson.
Schnettler, A., Pflug, V., Zindel, E., Zimmermann, G., Olvera, O.R., Pyc, I. & Trulley, C. (2020). Power-to-X: The crucial business on the way to a carbon-free world. Siemens Energy. https://www.siemens-energy.com/global/en/offerings/technical-papers/download-power-to-x.html [2021-02-10]
Schoenung, S.M. & Keller, J.O. (2017). Commercial potential for renewable hydrogen in California. International Journal of Hydrogen Energy, 42 (19), 13321–13328. https://doi.org/10.1016/j.ijhydene.2017.01.005
Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. Technology analysis & strategic management, 20(5), 537-554.
Shenton, A.K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. Education for Information. 22 (2), 63–75. https://doi.org/10.3233/EFI-2004-22201
Shove, E. (2010). Beyond the ABC: Climate Change Policy and Theories of Social Change. Environment and Planning A: Economy and Space. 42 (6), 1273–1285. https://doi.org/10.1068/a42282
Smith, A., & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. Research policy. 41(6), 1025-1036.
Star, S.L. (1999). The Ethnography of Infrastructure. American Behavioral Scientist, 43 (3), 377–391. https://doi.org/10.1177/00027649921955326
Star, S.L., Griesemer, J.R. (1989). Institutional ecology, 'translations,' and boundary objects: amateurs and professionals in Berkeley's museum of vertebrate zoology, 1907–1939. Social Studies of Science. 19, 387–420.

Thacker, S., Adshead, D., Fay, M., Hallegatte, S., Harvey, M., Meller, H., O'Regan, N., Rozenberg, J., Watkins, G. & Hall, J.W. (2019). Infrastructure for sustainable development. Nature Sustainability. 2 (4), 324–331. https://doi.org/10.1038/s41893-019-0256-8

Tidd, J. (2001). Innovation management in context: environment, organization and performance. International journal of management reviews, 3(3), 169-183.

United Nations (2015). Transforming Our World: The 2030 Agenda For Sustainable Development. United Nations.

Vandewalle, J., Bruninx, K. & D'haeseleer, W. (2015). Effects of large-scale power to gas conversion on the power, gas and carbon sectors and their interactions. Energy Conversion and Management, 94, 28–39. https://doi.org/10.1016/j.enconman.2015.01.038

Wainstein, M. E., & Bumpus, A. G. (2016). Business models as drivers of the low carbon power system transition: a multi-level perspective. Journal of Cleaner Production. 126, 572-585.

Wassermann, S., Reeg, M. & Nienhaus, K. (2015). Current challenges of Germany's energy transition project and competing strategies of challengers and incumbents: The case of direct marketing of electricity from renewable energy sources. Energy Policy, 76, 66–75. https://doi.org/10.1016/j.enpol.2014.10.013

Yin, R.K. (2009). Case Study Research Design and Methods. SAGE Publications, Inc. http://www.madeira-edu.pt/LinkClick.aspxfileticket=Fgm4GJWVTRs%3D&tabid=3004 [2021-03-27]

Zhang, Y., & Wildemuth, B. M. (2009). Qualitative analysis of content. Applications of social research methods to questions in information and library science. 308, 319.

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Appendix 1 – PtG Technology

PtG is a technology where electricity is converted to gas (Schnettler et al. 2020). The gas can take different shapes, however in all PtG processes the conversion from electricity into hydrogen is undergone. Using a process called PEM-electrolysis[1] electricity is used to segregate water (H2O) into its elements hydrogen (H) and oxygen (O). Either the hydrogen is used as such or as an input for further PtG conversion. The advantage of the PEM electrolysis is its high flexibility as it can be switched on and off without preheating. Therefore, it can respond directly to the volatile loads of wind and solar.

Electrolysis as such is not new, it was discovered as early as 1800 by Alessandro Volta (ibid.). However, it was not considered an economic viable option for the generation and storage of power. Wherever needed, mainly hydrogen produced from fossil fuels (called grey hydrogen) is used for industrial processes. Another barrier for clean hydrogen is that even today grey hydrogen is cheaper than green hydrogen. This shows that PtG technologies are not contributing to a decarbonisation generally, but only under the condition that the electricity used for PtG processes comes from renewable power sources. In the following the two other common PtG procedures are explained.

Using the widely known Haber-Bosch process another PtG technology – Power-to-Ammonia – synthesises hydrogen and nitrogen into ammonia (NH3) (Diermann 2020). Due to its low molecular weight and its chemical characteristics the storage of hydrogen is expensive. Ammonia in comparison can serve as a carrier for hydrogen, having a higher energy density in relation to the volume, as well as a lower liquification temperature (-33 degrees compared to -253 for hydrogen). Further, ammonia can be stored in bigger and thinner-walled, and thus cheaper containers.

The third presented PtG technology here is the Power-to-Methane technology (Burkhardt et al. 2015). Again, hydrogen is required as an input and carrier of chemical energy. In a procedure called biocatalytic methanisation hydrogen and carbon dioxide (CO2) are processed by microorganisms (archaea). The result of the

[1] Currently there are four types of electrolysis with the proton exchange membrane (PEM) electrolysis being the most advanced technology out of the four.

anaerobic digestion of hydrogen and carbon dioxide by the archaea is the production of methane (CH4). Methane can be used as biofuel, having the advantage that it can be mixed with or even substitute conventional LPG and CNG gas. Thus, it can use the existing gas and fuelling infrastructure and be used in existing gas-powered engines with the advantage of it being carbon neutral.

The briefly described PtG technologies are all directly connected with the production of green hydrogen. The precondition for PtG to become an enabler for a sustainable energy transition is the use of green hydrogen, i.e. hydrogen produced with energy from renewable sources. The usage of grey (coal), blue (natural gas), or pink (nuclear) hydrogen is not considered in this thesis. Whenever referring to hydrogen production and the electricity used for the process it is assumed, that green electricity from renewable sources is used. It can be argued that pink hydrogen is not emitting any emissions, however due to its origin from nuclear power it is also not considered in the scope of this paper.

Appendix 2 – Interview Guide

Introduction

- Credits/Thanks for the interview opportunity and readiness to talk
- Introduction of interviewer and context (SLU, Master Thesis, Topic)
- Explanation of Thesis Topic and Aim:
  - The influence of business models on the development of technological innovations in sustainability transitions
  - Method: Case Study on PtG, by interviewing actors within the PtG sector, add-on best practice examples
- Ask for permission (GDPR) to record the interview: With regards to the creation of a later transcription and analysis of the interview content a transcription is essential. Is this in accordance with the interviewee? Interviewee can be anonymised if wished for
- Transition to Topics I, II or III: Short presentation of interviewee – Who are you? Relation to mobility/energy sector? Relation to PtG? Where in the process of implementing PtG are you in?

Topic I – Energy (Business)		
Content/Rationale of Question	**Main Question**	**Adherence questions (Follow-up)**
Kick-Off Question & Status Quo: Current status of transition process	How would you explain the prevailing conditions for energy production, and distribution?	Where does the electricity come from? What problems are being faced? How stable are the grids?
Transition	Which role do renewable energy sources play?	Problems with increasing shares of renewables? Is there a lack of infrastructure that stands in the way of low carbon transition? Future plans for renewables?
Agency/Network	Who produces renewables? Who is responsible for the renewables?	More actors on the market? How does the market change? Future management plans for renewables?

Infrastructure	Is existing physical infrastructure sufficient for dealing with renewables?	Capability of dealing with new modes of gas? Redevelopment or adaption of existing infra.?
Transition: Which role does innovation (PtG) play	What role do new technologies like PtG play in planning?	How is PtG promoted?
Business Model (and others)	What barriers are present for market introduction? Which challenges have you faced up to now?	Role of Business Models? User behaviour? Infrastructure? Agency? First Movers? Risks?
Business Model	How can PtG become a competitive alternative to existing modes of production & storage?	What is the value proposition? How can the value be captured?
Business Model	How do you envision the BM to be successful to enable large-scale market diffusion?	How can the BM be used as an enabler to shift PtG from niche to regime?
Agency	Who enables PtG? Which role do policy, regulation and subsidies have?	Who promotes PtG? What promotes PtG? Role of Business Models? User behaviour? Infrastructure? Agency? First Movers?
Transition	How can PtG change existing regimes?	Business Models? User behaviour? Infrastructure? Agency? First Movers?
User Practices	Who will be the users of the technology?	Who will be the customers? What kind of business model and market structure will most likely develop, e.g. B2B, C2B, B2C
Potpourrie & Outlook	What will the PtG technology and market look like in 10 years?	Business Models? User behaviour? Infrastructure? Agency? First Movers?

Topic II – Mobility (Business)

Kick-Off Question & Status Quo: Current status of transition process	How would you explain the prevailing conditions for alternative mobility?	How does the infrastructure look like? What problems are being faced?
Role of innovation	Which role does PtG play?	Is it even considered? Why is it not considered? (Barrier)
Business Model (and others)	What barriers are present for market introduction? Which challenges have you faced up to now?	Role of Business Models? User behaviour? Infrastructure? Agency? First Movers? Risks?
Infrastructure	What role does infrastructure play for PtG applications in mobility? Infrastructure systems sufficient/existent?	Lack of infrastructure? Will you be a part of developing that infrastructure?
Transition	Under which conditions do PtG engines become a real alternative?	Who is the enabler PtG? Role of Business Models? User behaviour? Infrastructure? Agency? First Movers?
Agency	Which role do policy, regulation and subsidies have?	Funding for experimental/pilot projects? Provision of market initiatives and infrastructure?
Business Model	How can PtG become a competitive alternative to existing mobility solutions?	What is the value proposition? How can the value be captured?

Business Model	How do you envision the BM to be successful to enable large-scale market diffusion?	How can the BM be used as an enabler to shift PtG from niche to regime?
Transition	How can PtG change existing regime?	Business Models? User behaviour? Infrastructure? Agency? First Movers?
User Practices	Who will be the users of the technology?	Who will be the customers? What kind of business model and market structure will most likely develop, e.g. B2B, C2B, B2C
Potpourrie & Outlook	What will the PtG technology and mobility sector look like in 10 years?	Business Models? User behaviour? Infrastructure? Agency? First Movers? Is it profitable?

Topic III – Enablers (Actors)

Kick-Off Question & Status Quo: Current status of transition process	How would you explain the prevailing conditions for energy and mobility transitions?	How does the infrastructure look like? What problems are being faced?
Role of innovation	Which role does PtG play?	Is it even considered? Why is it not considered?
Business Model	What is the rationale behind the experimentation/pilot project/study undertaken now?	Which aim are you following?
Business Model (and other)	What barriers are present for market introduction? Which challenges have you faced up to now?	Role of Business Models? User behaviour? Infrastructure? Agency? First Movers? Regulation? Risks?
Infrastructure	Infrastructure systems sufficient/existent? Is there a lack of physical infrastructure that stands in the way of PtG?	What is your reasoning around the lack of infrastructure? Will you be a part of developing that infrastructure?
Transition	Under which conditions do PtG solutions become a real alternative?	Who is the enabler PtG? Role of Business Models? User behaviour? Infrastructure? Agency? First Movers?
Business Model	How are expectations for a large-scale PtG application built?	
Business Model	Which narrative is built? How is this narrative, value proposition to address different stakeholders?	Who are the main stakeholders?
Business Model	What is PtGs value proposition, how does it create value, how is it delivered and captured?	
Business Model	How can BM enable innovation to move from a niche (protected space) to the regime (broad market)?	Specific: What role plays the narrative of PtG here? What is the major obstacle?
Agency/Networks	How are networks for a large-scale market diffusion of PtG created and managed?	Who initiates? Why? Motivations?
Transition	How can PtG change existing regime?	What potentials are there for: Business Models? User behaviour? Infrastructure? Agency? First Movers?

User Practices	Who will be the users of the technology?	Who will be the customers? What kind of business model and market structure will most likely develop, e.g. B2B, C2B, B2C
Outlook	What will the PtG technology and mobility sector look like in 10 years?	Business Models? User behaviour? Infrastructure? Agency? First Movers?

Appendix 3 – Interviewees

Interviews have been conducted with actors from PtG projects and related sectors to understand the role of BMs for its development. They are presented hereafter:

Interviewee K: The interviewee works for the district Lippe as Head of the local innovation hub, which serves as a real-world laboratory to connect communities, research, politics and municipalities.

Interviewee T: The interviewee is a trained engineer and works as a research assistant at the local technical university. He has been engaged with research on PtG for more than 10 years. Further, he is chairman of a local public utility company and member of the green party, for which he also holds a seat in the county council.

Interviewee C: The interviewee holds a degree in future energies and works as a research assistant for the local technical university. He is currently researching on the potentials of biocatalytic methanisation. Special research focus is on integrated energy management (sector-coupling).

Interviewee D: The interviewee works in the environment department as mobility manager for the district of Lippe. He is member of the project team Hy-Drive, which is assessing the potentials of hydrogen-fuelled vehicles in the district.

Interviewee O: The interviewee is CEO of the biggest local public transport company in Lippe, which is partly owned by the municipality. Therefore, it often serves as a real-world laboratory for testing of new mobility solutions and offerings.

Interviewee A: The interviewee is sustainability development manager at the science park in and for Sandviken Pure Power and chairman of Hydrogen Sweden.

Interviewee M: The interviewee is co-founder of Nilsson Energy, a manufacturer of integrated hydrogen solutions for self-sufficient housing. The company works in multiple experimental projects in Sweden and around Europe.

Interviewee P: The interviewee is responsible for the electricity and gas market at a public utility company in Germany, challenged by the low carbon transition. It contributes by focusing on Power-to-Heat systems (using natural and green gas).

Appendix 4 – Empirical Background

Throughout the last decades new means for energy production as well as for powering engines in transportation and the mobility sector have emerged (BMWi 2020; Bundesnetzagentur 2021; Buck et al. 2019; Maia et al. 2015). Existing mobility and energy systems and incumbents in the respective industries are challenged by the emergence of new technologies. Examples for the emergence of new technologies are EVs in the mobility sector and renewables such as on and offshore wind turbines, PVs, hydropower and biogas plants and concentrated solar power (CSP) in the energy sector. These transitions to new technologies require redevelopment of infrastructure, both hard ones such as technology, but also soft ones such as rules, regulations, routines (Köhler et al. 2019; Carroli 2018).

In the energy sector existing infrastructure, such as electricity grids, transformer stations, high voltage networks, i.e. the modes for transporting electricity from its production site to the end consumer, increasingly face challenges posed by the decentralisation of renewable energy production (Langendahl et al. 2019). Existing electricity infrastructure has not been built to cope with the fluctuating energy production emerging through renewables (ibid.). Within the mobility sector existing technical infrastructures such as roads, rails and fuelling stations can still be used. However, modifications are needed, such as extensions for EVs charging or the adjustment of fuelling stations for alternative fuels, e.g. hydrogen, biogas, or methane.

A further challenge is the dispatchable generation of electricity, which refers to the capability of a power generation unit to be utilised on demand by grid operators (Bundesnetzagentur 2021; Mah et al. 2017). Reserve electricity generation units (e.g. gas power plants) can be dispatched according to market needs. Albeit renewable energy sources such as wind power and PV have many advantages, they are non-dispatchable, i.e. their electricity production cannot be steered by operators. These energy sources are dependent on weather, wind and sunlight.

Depending on weather conditions wind turbines and PV sometimes produce too much (excess) or too little electricity to meet electricity demand (Bundesnetzagentur 2021). Grid operators have to maintain dispatchable production units which can quickly be rammed-up or down to meet current demand.

Moreover, it is needed to efficiently make use of intermittent renewable energy sources in times of high production. Traditional energy production via nuclear power plants, hard coal, ignite-fired power plants, oil and gas represent relatively steady and linear power production over time. This is called baseload generation. The renewable energy production implies large fluctuations depending on wind conditions and hours of sunlight. This problem is illustrated in Figure 7 below.

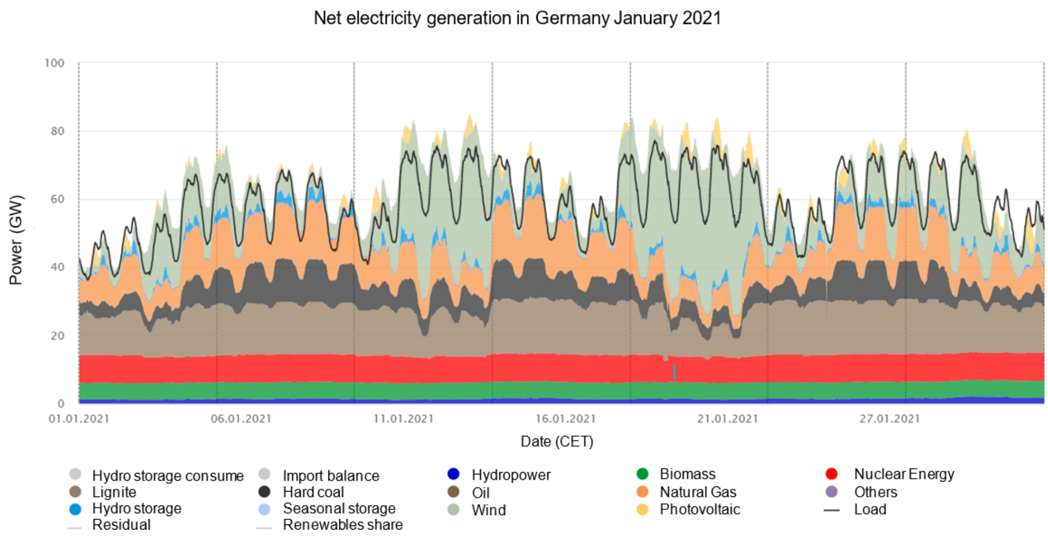

Figure 7: German net electricity production in January 2021 per energy production mode (Fraunhofer ISE 2021).

The Figure illustrates the electricity production per source of energy in January 2021 in Germany. It is shown how energy production from wind and PV is fluctuating depending on weather conditions and time of day. Hard coal, gas and hydro storage are also fluctuating, but these are managed depending on the share of renewables and consumption forecast, i.e. in times of increasing electricity generation through wind power, production in gas, hard coal and hydro storage plants is ramped down. In times of low or no power generation through wind power and solar, production in gas, hard coal and hydro storage plants is ramped up. Nuclear, biomass and lignite plants take much longer to ramp up and down, thus they produce a static load over time and cannot be used for managing grid loads.

Next to illustrating the energy production per energy source over time, Figure 7 also shows the load, i.e. the amount of energy retrieved from the grid for consumption. As can be seen the load is usually below total electricity production, which leaves grid operators with two options. One is to export the excess electricity, the second to regulate and manage electricity production, so called feed-in management (Bundesnetzagentur 2021; Kopp et al. 2017). Feed-in management is defined as curtailing the energy production from the grid. It is only applied for renewable energy sources, because they are easy to connect and disconnect from the grid. Whenever feed-in management is used compensation payments have to be paid to the owners of the renewable energy plants for unrealised sales. The downside is that a lot of energy which could have been produced by renewables is lost. With an increasing number of on and offshore wind turbines, as well as PV and biomass plants the energy lost is increasing. Correspondingly the compensation payments to owners of renewable energy plants are increasing.

Figure 8 illustrates the development of production losses of renewable plants in Germany due to feed-in management by the grid operators. Here, an increase in production losses over the last decade is visible. Such a trend is visible across the whole of Europe, depending on the share of renewables in the electricity mix (European Commission 2020b). In Germany in 2019 nearly three percent of renewable electricity production was lost as a consequence of feed-in management. An amount which could have theoretically supplied more than 1,15 million EU-28 households[2].

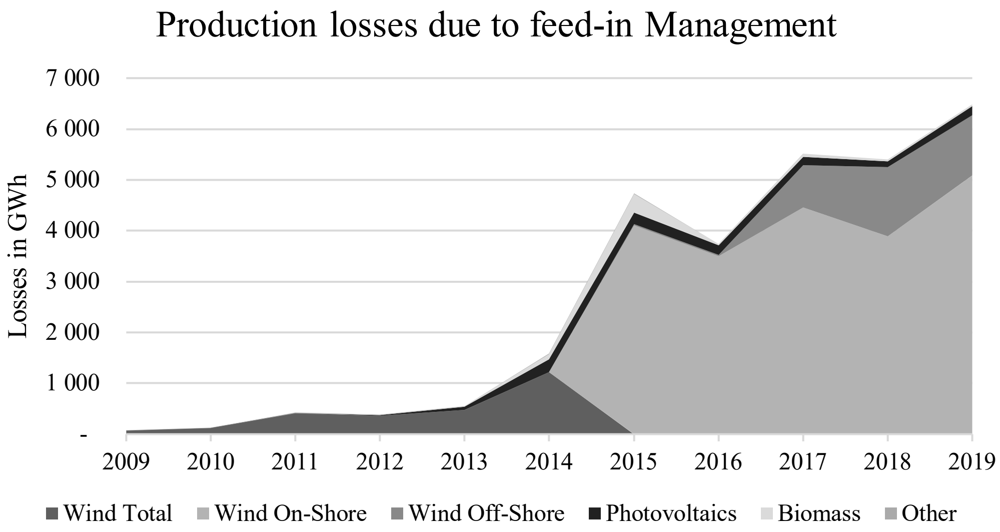

Figure 8: Production losses due to feed-in Management in Germany in 2019. Own illustration inspired by Bundesnetzagentur (2021).

The compensation payments to electricity producers by the grid operators amounted to 710 million euros in 2019 and are estimated to rise to 720 million euros for 2020 (Bundesnetzagentur 2021). Large increases over the last decade become apparent in Table 4 with wind power being the most affected renewable source (Bundesnetzagentur 2021).

[2] Given an average yearly consumption of 5.487 kWh (European Commission 2020b)

Table 4: Compensation payments by grid operators and most effected renewable source for feed-in Management. Own illustration based on data from Bundesnetzagentur (2021).

Year	**Production losses**	**Compensation Payments**	**Most affected**
2009	73,7 GWh	6,0 Mio. EUR	Wind (100 %)
2010	126,8 GWh	10,2 Mio. EUR	Wind (99 %)
2011	420,6 GWh	33,5 Mio. EUR	Wind (97 %)
⋮	⋮	⋮	⋮
2018	5.402,7 GWh	718,8 Mio. EUR	Wind (97 %)
2019	6.482,0 GWh	710,0 Mio. EUR	Wind (97 %)
2020*	6.368,0 GWh	772,0 Mio. EUR	Wind (97 %)

* Forward predictions/estimates based on data for Q1-Q3 2020

The trend in the development dynamics calls for smart grid solutions and better ways of storing excess electricity from renewables (Langendahl et al. 2019; Mah et al. 2017). One solution is a conversion of power (electricity) to gas. Especially the usage of hydrogen in this context is highlighted and its uptake and development is promoted by the European Hydrogen Energy Network as well as the European Clean Hydrogen Alliance, both initiated by the European Commission. Correspondingly the European Commission has adopted a strategy on hydrogen and biomethane in line with the European Green Deal in 2020 (European Commission 2020a). Several European countries have since then also published strategy papers on PtG, e.g. Spain, Sweden, Germany. As an example, the National Hydrogen Strategy presented by the German Federal Ministry for Economic Affairs and Energy Government has a budget of more than 12,5 billion euros (BMWi 2020). Next to several lighthouse projects such as Westküste100, eFarm, HyRostock or Lingen Green Hydrogen, various small-scale projects are being funded across Germany (DVGW 2020). In the Netherlands North2, in Denmark Energy Island, in Sweden HYBRIT or Green Hysland in Mallorca, Spain are further examples of PtG lighthouse projects across Europe.