Enabling socio-technical transitions – electric vehicles and high voltage electricity grids as focal points of low emission futures

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Title: **Enabling socio-technical transitions – electric vehicles and high voltage electricity grids as focal points of low emission futures**

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Abstract

Today humankind is facing numerous sustainability challenges that require us to question CO2 intensive practices like those present in the transport and energy sector. To meet those challenges, many countries have adopted ambitious climate targets. Achieving such targets requires an understanding of the wider socio-technical context in which, for example, renewable energy projects, transmission grids and electric vehicles are embedded. It is important to understand how such transitions and innovations can be enabled in society. The aim of this licentiate thesis is therefore to analyse such socio-technical transitions towards low-emission futures enabled by the electrification of passenger car transport and high voltage grid development in the energy sector.

The thesis consists of three papers. Paper I presents a study of the goals, policies and industry position regarding electric vehicle (EV) developments in Norway, Denmark, Sweden and Finland. Two scenarios, an incremental and a breakthrough EV scenario, are created by combining existing scenarios found in the literature. These are used to analyse climate impacts as well as potential future policy requirements for attaining climate targets. The analysis of governance measures showed that in terms of policy both a short term and long term approach would be needed in a breakthrough scenario. On top of that the actual technology development phase as well as the day to day life of potential electric vehicle adopters have to be taken into account.

Paper II is a comparative analysis of the planning procedures for high voltage transmission lines in Norway, the United Kingdom and Sweden, in order to study opportunities or challenges in the established grid development regime. The goal of the paper is to identify the institutional reasons for conflicts and how to address them, in order to create a more sustainable grid development regime. The paper also analyses historical trajectories and resulting technological setups of each case country's grid. One of the main results of the article when it comes to the planning procedures for grid development, is that a sole focus on economic efficiency in grid planning will most likely be unsuccessful and actually will lead to longer lead times due to citizen opposition. Instead, well spent time is necessary to ensure legitimacy and social sustainability of grid planning.

Paper III is deepening the initial document analysis of paper I with regards to innovation dynamics by conducting in-depth expert interviews in Denmark, Norway and Sweden. The paper employs a joined Multi-level Perspective and Technological Innovation System framework to better grasp dynamics within the technology niche but also the dynamics between the innovation, the established regime and the external environment. Analytically, this is called the landscape. The paper shows that strong initial technology legitimacy was needed to start substantial innovation dynamics. This could be further strengthened with a strong and broad coalition of actors around EVs. The legitimacy and quality of the coalition of actors led, among other factors, to a larger variety and better match of the policy instruments in Norway. This happened to a lesser extent in Sweden but not at all in Denmark.

Building on the results in paper II and paper III, one important aspect that can be highlighted is that there was a high need for legitimacy and political accountability across the case studies at hand. Another point of discussion is the question of which actors were a

major driving force. In both the grid development and the electric vehicle papers, the local and regional level played an important role. Also, in situations where the regime was not favourable towards supporting the niche from a national level, municipalities could compensate to some extent. An overarching question in all papers was how strongly the socio-technical regimes would actually be changed by upcoming sustainability issues, conflicts or niche developments.

Conclusions that can be drawn from the studies are that preconditions for transitions can be found between and within the niche, the established regime and the landscape. Between them favourable dynamics can eventually become motors that can sustain a development long term. That entails factors like legitimacy, strong and coordinated coalitions, established and concrete targets, preferably agreed upon in political consensus, and policy instruments that take into account the dynamics between niche, regime and landscape as well as the state of technology development.

As such this thesis has shown that transitions are not just about technology or policy instruments as such but about the dynamics and processes needed to enable them. The transition context (niche, regime, landscape), process (creating legitimacy, political pressure etc.) and dynamic (motors) are important components, just as much as the concrete policy solution. This can be relevant in other transitions that otherwise may underestimate the importance of these components.

Concrete policy advice, which can be drawn from this research, is that there is a need for both long term and short term policy environments that can spur innovation broadly as well as more selected. There is also a need for a larger focus on the day to day life quality of potential innovation adopters. The conflicts between local, regional and national levels of government have to be able to come forward in a constructive way. Any policy instruments put forward, should entail a mid to long term certainty in how long they would be valid for. Moreover, they should be part of a common agenda that wants to reach a measurable goal which in turn is guaranteed by a majority of the political parties.

Keywords: Socio-technical system, innovation system, transition, MLP, TIS, low emission future, electric vehicles, high voltage transmission grid, Sweden, Norway, Denmark, Finland, United Kingdom

Sammanfattning

Mänskligheten behöver bemöta flera hållbarhetsutmaningar som innebär ett behov av att ifrågasätta flera CO2 intensiva användningsområden som bland annat finns i transport- och energisektorn. För att möta utmaningarna har flera länder infört ambitiösa klimatmål. I syfte att kunna uppnå dessa behövs en bredare förståelse för det sociotekniska sammanhanget som t ex projekt inom förnyelsebar energi, elnät och elbilar är inbäddade i. Det är viktigt att skapa kunskap hur sådana omställningar och innovationer kan bli möjliggjorda i samhället. Målet med denna licentiatavhandling är därför att analysera hur sociotekniska omställningar mot lågemissionsframtider kan bli möjliggjorda genom elektrifiering av personbilstransport samt kraftnätsutveckling i energisektorn.

Licentiatavhandlingen består av två artiklar och ett bokkapitel. Artikel I är ett bokkapitel och undersöker mål, politisk inställning och industrins position angående elbilsutvecklingen i Norge, Danmark, Sverige och Finland. Två scenarier, ett med stegvis utveckling och en genombrytande, skapas genom att kombinera scenarier från befintlig litteratur. De används för att analysera klimatpåverkan av elbilar samt för att föreslå möjliga framtida politiska åtgärder som kan behövas för att uppnå klimatmål. Analysen av åtgärder visar att det behövs både kortsiktiga och långsiktiga politiska styrmedel för att uppnå ett genombrottscenario. Ovanpå detta behövs fokus på den individuella utvecklingsfasen av teknologin i fråga samt fokus på användarnas vardagsliv.

Artikel II är en artikel som jämför planeringsprocesser för högspänningsledningar i Norge, Storbritannien och Sverige, i syfte att undersöka möjligheter och utmaningar i den etablerade regimen för kraftnätsutvecklingen. Målet med artikeln är att identifiera institutionella orsaker till konflikt och hur man kan adressera dessa för att skapa en mer hållbar kraftnätsutvecklingsregim. Artikeln analyserar också historiska utvecklingsbanor samt teknikupplägg i varje lands kraftnät. Ett huvudresultat angående planeringsprocessen för kraftnätsutveckling är att ett strikt fokus på ekonomisk effektivitet inom kraftnätsplanering troligtvis inte kommer att vara framgångsrikt och dessutom kan leda till längre utvecklingstid på grund av motstånd från befolkningen. I stället är det nödvändigt att använda tiden väl för att skapa och säkerställa legitimitet och social hållbarhet av kraftnätsplanering.

Artikel III fokuserar på innovationsdynamik och fördjupar den första dokumentbaserade analysen i artikel I genom att fördjupade expertintervjuer i Danmark, Norge och Sverige. Artikeln använder sig av ett kombinerat ramverk av ”Multilevel Perspective” och ”Technological Innovation System” för att bättre kunna förstå dynamik inom den teknologiska nischen men också dynamikerna emellan nischer, den etablerade regimen och den externa omvärlden, som analytisk kallas för ”landscape”. Artikeln visar att en stark legitimitet för tekniken behövdes för att starta en stark innovationsdynamik. Detta kan senare styrkas med en kraftfull och bred koalition av aktörer kring elbilar. Legitimiteten och kvalitén på koalitionen av aktörer ledde, tillsammans med andra faktorer, till en större variation och bättre passning av politiska styrmedel i Norge. Så blev inte fallet i Danmark och bara i mindre omfattning i Sverige.

Baserat på resultaten i artiklarna II och III, är en viktig aspekt att det i alla fallen fanns ett stort behov av legitimitet och politiskt ansvarstagande. En annan diskussionspunkt berör

de aktörer som var viktiga drivkrafter i utvecklingen. I både kraftnätsartikeln och elbilsartikeln har den lokala och regionala nivån spelat en viktig roll. Detta var ännu viktigare i situationer där den etablerade regimen inte var positiv inställd att stödja en nisch från den nationella nivån. Städerna kunde då delvis kompensera detta. En övergripande fråga i alla uppsatser var också hur starkt den sociotekniska regimen egentligen kunde ändras på grund av kommande hållbarhetsproblem, konflikter och utvecklingar i nischer.

Slutsatser som kan dras från artiklarna är att förutsättningar för omställningar finns att söka emellan och inom nischer, den etablerade regimen och landskapet. Mellan dem kan fördelaktig dynamik skapas som så småningom kan bli motorer som kan bära en långsiktig utveckling. Detta är faktorer som legitimitet, starka och koordinerade koalitioner, etablerade och konkreta mål företrädesvis skapade i en politisk samstämmighet, och politiska instrument som beaktar dynamiker inom och mellan nischer, regimer och landskap samt den teknologiska utvecklingsfasen.

Avhandlingen visar att omställning är inte endast en fråga om teknologi eller politiska instrument utan om dynamik och processer som tillåter en sådan utveckling. Sammanhanget i en omställning (nischer, regimer, landskap), processer (skapa legitimitet, politiskt tryck etc.) och dynamik (motorer) är lika viktiga komponenter som den konkreta politiska lösningen angående politiska instrument. Detta kan vara relevant i andra omställningar som annars kan underskatta betydelsen av dessa faktorer.

Konkreta politiska råd som kan baseras på denna forskning är att det finns ett behov att samtidigt ha långsiktig och kortsiktig politik som kan driva fram innovation både brett och mera selektivt. Det finns också ett behov att fokusera mer på användarna och deras vardagsliv när en teknikomställning ska ske. Konflikter mellan lokala, regionala och nationella styrningsnivåer behöver också kunna hanteras på ett konstruktivt sätt. Politiska instrument som läggs fram behöver specificera hur långsiktiga de är, och med hur stor säkerhet. Dessutom bör de vara del av en agenda som strävar mot att uppnå mätbara mål som dessutom en majoritet av de politiska partierna står bakom.

Nyckelord: Sociotekniska system, innovationssystem, omställning, MLP, TIS, lågemissionsframtid, elbilar, kraftnät, Sverige, Norge, Danmark, Finland, Storbritannien

Zusammenfassung

Die Menschheit muss sich derzeit mit mehreren Nachhaltigkeitsherausforderungen beschäftigen, welche CO2 intensive Praktiken im Transport- und Energiesektor in Frage stellen. Daher haben viele Länder ambitionierte Klimaziele verabschiedet. Um diese Ziele zu erreichen, benötigt es ein Verständnis für den sozio-technischen Kontext in welchem sich Projekte in erneuerbaren Energien, Hochspannungsleitungen und Elektroautos bewegen. Es ist wichtig zu verstehen wie solche Umstellungen, „Wenden“ und Innovationen in der Gesellschaft ermöglicht werden können. Das Ziel dieses Lizentiats ist es deshalb, die sozio-technischen Umstellungen zu analysieren, welche eine emissionsarme Zukunft ermöglichen. Dies geschieht mit einem genaueren Blick auf die Elektrifizierung des autobasierten Personenverkehrs, sowie Hochspannungsleitungen im Energiesektor.

Das Lizentiat besteht aus drei Arbeiten. Arbeit I präsentiert eine Studie über die Ziele, Politikinhalte und die Industrieposition von Norwegen, Dänemark, Schweden und Finnland bzgl. Elektroautos. Durch die Kombination bestehender Szenarien zu diesem Thema wurden ein inkrementelles und ein Durchbruchsszenario entwickelt. Diese werden anschließend verwendet, um die Klimaauswirkungen von Elektroautos zu untersuchen sowie um potentielle, zukünftige politische Maßnahmen zur Erreichung von Klimazielen zu prüfen. Die Analyse der verschiedenen, möglichen politischen Inhalte zeigt, dass es sowohl einen kurzfristigen als auch einen langfristigen Politikansatz für ein Durchbruchsszenario braucht. Zusätzlich müssen die aktuelle Entwicklungsphase der jeweiligen Technologie und der Alltag von potentiellen Anwendern von Elektroautos berücksichtigt werden.

Arbeit II ist eine vergleichende Analyse des Planungsprozesses für Hochspannungsleitungen in Norwegen, Großbritannien und Schweden. Es werden die Chancen und Herausforderungen des etablierten Regimes zur Planung und Entwicklung von Hochspannungsleitungen studiert. Das Ziel der Arbeit ist die Identifizierung von institutionellen Konfliktursachen und wie man diese adressieren kann um ein nachhaltigeres Hochspannungsnetzentwicklungsregime zu entwickeln. Die Arbeit basiert dabei auch auf einer Analyse der historischen Entwicklungspfade, sowie der technologischen Zusammensetzung in den jeweiligen Fallstudien. Ein Hauptresultat ist, dass bei dem Planungsprozess für Hochspannungsleitungen ein einseitiger Fokus auf wirtschaftliche Effizienz sehr wahrscheinlich nicht erfolgreich ist und stattdessen zu Verzögerungen aufgrund von Opposition führt. Stattdessen ist es notwendig, genügend Zeit aufzuwenden um die Legitimität und die soziale Nachhaltigkeit von Stromnetzplanung zu gewährleisten.

Arbeit III vertieft die erste Analyse aus Arbeit I zum Thema Innovationsdynamik durch umfangreiche Experteninterviews in Dänemark, Norwegen und Schweden. Die Arbeit vereinigt dabei die „Multi-level Perspective“ und den Ansatz des „Technological Innovation System“ um die Dynamik ,welche sich in einer Technologienische, aber auch zwischen der Nische, dem etablierten Regime sowie der externen Umgebung (analytisch definiert als „Landschaft“) besser abbilden zu können. Die Arbeit zeigt dass es eine starke anfängliche Legitimität benötigt um die Innovationsdynamiken in Gang zu setzen. Die Dynamik konnte anschließend weiter gestärkt werden durch eine starke und breite Koalition von Akteuren mit Interesse an der Verbreitung von Elektroautos. Legitimität und die Qualität der Koalition waren notwendige Faktoren für die Etablierung einer größeren Vielfalt unter

den Politikinstrumenten sowie auch insgesamt passgenaueren Politikinstrumenten in Norwegen. Dies geschah nicht in Dänemark und nur zu einem geringeren Maß in Schweden.

Basierend auf diesen Resultaten werden unter anderen Aspekten die Notwendigkeit von Legitimität und politischer Verantwortlichkeit über alle Fallstudien hinweg diskutiert. Ein anderer Diskussionspunkt ist, welche Akteure eine wesentlich treibende Kraft in der Entwicklung waren. Sowohl in der Arbeit zu Hochspannungsleitungen, als auch in den Arbeiten zu Elektroautos spielen die lokale und regionale Ebene eine wichtige Rolle. In Situationen, in denen das etablierte Regime unvorteilhafte Bedingungen für eine Nische auf nationaler Ebene etabliert hat, konnten Städte und Kommunen dies teilweise kompensieren. Eine übergreifende Frage aller drei Arbeiten beschäftigt sich damit, wie stark die etablierten, soziotechnischen Regimes wirklich von den aufkommenden Nachhaltigkeitsproblemen, Konflikten oder Entwicklungen in einer Nische beeinflusst wurden.

Eine Schlussfolgerung die man übergreifend ziehen kann ist, dass die Vorbedingungen für Umstellungen bzw. „Wenden“ innerhalb der jeweiligen Nische und zwischen der Nische, dem Regime und der Landschaft zu finden und zu analysieren sind. Zwischen diesen Ebenen können Dynamiken mit der Zeit Motoren für Veränderung werden, welche eine Entwicklung langfristig in Gang halten können. Dies beinhaltet Faktoren wie Legitimität, starke und koordinierte Koalitionen, die Etablierung konkreter Ziele, welche vorzugsweise in einem politischen Konsensus entstanden sind, und Politikinstrumente welche die angesprochene Dynamik zwischen den Ebenen aber auch den Entwicklungszustand der Technologie mit einbeziehen.

Das Lizentiat hat gezeigt das eine „Wende“ nicht nur einseitig mit Technologie oder Politikinstrumente zu tun haben, sondern mit der Dynamik und den Prozessen welche diese erst ermöglichen. Der Kontext für solch eine Umstellung (Nische, Regime und Landschaft), der Prozess (Legitimierung, politischer Druck etc.) und die notwendige Dynamik (Motoren für Veränderung) sind genauso wichtige Komponenten wie die konkreten Politikinstrumente. Dies kann in anderen „Wenden“ relevant sein, in denen die Rolle der angesprochenen Komponenten nicht akkurat dargestellt wird.

Als konkrete Politikempfehlung kann darauf hingewiesen werden, dass sowohl langfristige als auch kurzfristige Politikumgebungen notwendig sind, um Innovationen breit aber auch selektiv zu fördern. Es besteht auch der Bedarf an verhaltensbasierten Politikinstrumenten, welche sich vermehrt auf die alltägliche Lebensqualität von möglichen Anwendern von Innovation einstellen. Auch die Konflikte zwischen der lokalen, regionalen und nationalen Regierungsebene müssen in einer konstruktiven Weise ihren Ausdruck finden können. Jedes Politikinstrument, welches vorgeschlagen wird, sollte auch eine mittel- bis langfristige Planungssicherheit beinhalten. Außerdem sollten Politikinstrumente Teil einer Agenda sein welche ein gemeinsames, messbares Ziel erreichen will. Eine Mehrheit der Parteien sollte hinter diesem Ziel stehen.

Schlüsselwörter: Sozio-technisches System, Innovationssystem, Umstellung, Wende, MLP, TIS, emissionsarme Zukunft, Elektroautos, Hochspannungsnetz, Schweden, Norwegen, Dänemark, Finnland, Großbritannien

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List of papers

Paper I Albrecht, M., Nilsson, M., & Åkerman, J. (2013). Electrification of vehicles – policy drivers and impacts in two scenarios. In Q. Wu (Ed.), *Grid Integration of Electric Vehicles in Open Electricity Markets*. West Sussex, United Kingdom: John Wiley & Sons, Ltd.

Paper II Sataøen, H. L., Brekke, O. A., Batel, S., & Albrecht, M. (2015). Towards a sustainable grid development regime? A comparison of British, Norwegian, and Swedish grid development. *Energy Research & Social Science, 9*, 178–187. https://doi.org/10.1016/j.erss.2015.08.011

Paper III Albrecht, M. (2017). System innovation dynamics around electric vehicles. The cases of Norway, Denmark and Sweden. *To Be Submitted*.

Comments about contributions in each paper

Paper I In paper I the introduction section was co-authored by me and Måns Nilsson. I was the author for the section "1.2 Policy Drivers, Policies and Targets" which was based on a document analysis. In section "1.3 Scenarios and Environmental Impact Assessment" I was responsible for selecting the scenarios that were the basis for the consequential LCA performed by Jonas Åkerman. I was also responsible for table 1.1 and figure 1.5 in that section. I was the author for the section "1.4 Future Policy Drivers for a BEV and PHEV Breakthrough". This section required another document analysis on my behalf with regards to previous research on policies for hybrids and EVs. The section also contains a rather compact theory section. The section 1.5 Results and Conclusion was co-authored by all authors depending on their previous parts in the paper.

Paper II I contributed to the papers' theory part through supplying material about large technical systems, socio-technical systems, socio-technical regimes, transition theory as well as administrative or historical traditions. I contributed to what later is defined as grid development regime. Furthermore, I was responsible for the Swedish case study in the paper which entailed document analysis in order to show the historical trajectory of the Swedish high voltage transmission grid, the Swedish planning system for new high voltage transmission lines, as well as their main drivers for grid extension. I also contributed to the discussion and conclusion, particularly when socio-technical regimes and lock-in or path dependencies were discussed.

Paper III I was the author of the paper. I was supported by my supervisors to achieve this.

Contents

Abbreviations

BEV	Battery only electric vehicle
CLCA	Consequential life cycle analysis/assessment
CO2	Carbon dioxide
DKK	Danish krone
EV	Electric vehicle (combining BEV, PHEV & REV)
EU	European Union
GDR	Grid development regime
GHG	Greenhouse gas
HEV	Hybrid electric vehicle (not included in “EV”)
ICE	Internal combustion engine
LCA	Life cycle analysis/assessment
MLP	Multi-level perspective
NOK	Norwegian krone
OEM	Original equipment manufacturer
PHEV	Plug-in hybrid electric vehicle
REV	Range extended electric vehicle
SEK	Swedish krona
TCO	Total cost of ownership
TIS	Technological Innovation System
VAT	Value added tax

1 Introduction

Today humankind is facing numerous sustainability challenges that require us to question CO2 intensive practices. If we don't stabilize the CO2 content in the atmosphere, several tipping points could be reached that can lead to even higher CO2 emission content (Hansen et al., 2008; T. M. Lenton et al., 2008; Timothy M. Lenton, 2011). In 2010 the transport sector alone stood for 23 percent of global energy related CO2 emissions (Sims et al., 2014). In the EU28, the transport sector stood for approximately 20 percent of total GHG emissions in 2014 (12 percent for cars) (EEA, 2016). What is also alarming is the fast pace at which globally fossil fuel intensive practices are continuously adopted when it comes to e.g. flying and passenger cars (Åkerman & Höjer, 2006; Sims et al., 2014). In fact transport related greenhouse gas emissions have by 2010 more than doubled globally since 1970 and have increased at a faster rate than any other energy end use sector (Sims et al., 2014). Around 80% of that increase has come from road transport. It has also been predicted that passenger car ownership will increase from 0.6 billion in 2005 to 2.9 billion by 2050 (Chamon, Mauro, & Okawa, 2008). In the EU28 in 2014, the emissions stemming from the fuel combustion in public electricity and heat production accounted for 24-25 percent depending on the inclusion of international aviation in the total greenhouse gas amount (EEA, 2016). The energy sector and the transport sector are also associated with health impairing emissions like particulate matter, nitrous oxides and sulphur dioxide (Sovacool, 2010). Additionally, there are challenges due to lock-in effects present in both the electricity supply and distribution industry, as well as the transport sector (Unruh, 2000).The transport sector has proven to be a particularly hard to change sector when it comes to greenhouse gas emissions, due to long lead times in car fleet renewal, high development costs for new vehicle platforms, user and consumer behaviour, and other lock in effects (Frank W. Geels, 2012; Kemp, 1994).

Renewable energy production, transmission of that renewable energy, and electrification of passenger car transport are strategies to not only reduce CO2 emissions, but also to increase security of energy supply and increase innovation (Cohen & Naor, 2013; European Climate Foundation, 2010; Kim, 2014; Transport & Environment, 2016; Vine, 2012). Particularly in North European countries, like Sweden or Norway, which have a minor fossil fuel input for electricity production on average, electrification of transport has been seen as a viable strategy. Overall in Europe and also in the case study countries present in the papers of this thesis, quite ambitious climate targets have been adopted in the described realms. One of these is the Swedish goal of achieving a fossil fuel independent transport fleet by 2030 (Swedish Government, 2009). In this case, the goal was criticised for not being well defined in detail, missing an action plan or of having no sufficiently strong enough policy strategies to achieve it (Gröna Bilister, 2011; IEA, 2013; Riksrevisionen, 2013). What can be said in general, is that most such goals would probably necessitate relatively fast deployment of suitable technologies with the corresponding adoption dynamics. Those dynamics require an understanding of the wider socio-technical context in which these technologies are embedded (Frank W. Geels, 2012; Tran, Banister, Bishop, & McCulloch, 2012).

The high voltage electricity grids are also an important focal point of several of the mentioned challenges and conflicts today. Since much of renewable energy is connected to the power grid, new high voltage transmission grids are often needed in order to transmit

that electricity from at times remote places to centres of electricity consumption. Furthermore, renewable energy projects sometimes require a modernisation of the grid around them. The closure of fossil fuel or nuclear power plants in some cases also removes a local power source that might be needed by local industry, which in turn increases the need for high voltage transmission lines. Security of supply, a common issue high up on the political agenda in many countries, may be increased through higher transmission capacity. Also the ambition to integrate Europe's regional electricity markets more and more into a joint European electricity market, necessitates high transfer capacity across borders to reduce bottlenecks in the system, which are after all the historic result of a national development for such systems (Entso-E, 2016b; Högselius & Kaijser, 2007). Entso-E, the association of electricity grid operators, estimates a need for grid investment in the realms of 150 billion Euros until 2030, or in another estimate 10-20 billion Euros each year until 2050 (e-Highway2050, 2015; Entso-E, 2016a; van Renssen, 2015). Despite the need for such projects, the reality is that one in three of such projects in Europe is delayed (Entso-E, 2012). This can be attributed to e.g. permitting procedures that are longer than expected, and local opposition against both the renewable energy projects as well as the following grid projects. It is basically a double opposition that is being offered despite the fact that in general citizens are in favour of renewable energy and necessary grid projects (Sataøen, Brekke, Batel, & Albrecht, 2015). This indicates a conflict between national level policies and local community interests.

Other authors have researched electricity grids as socio-technical systems in the past. Notably, Hughes, Kaijser and Högselius have studied the emergence of Western as well as North European Electricity grids and networks (Högselius & Kaijser, 2007; Hughes, 1983; Thue, 1995). Transformation oriented research in that area has for example focussed on the deregulation of the electricity sector as a result of changes in ideology and national politics (Högselius, 2009; Högselius & Kaijser, 2010). Högselius used in depth interviews to analyse the internal, entrepreneurial and institutional transformation the publicly owned Swedish utility Vattenfall went through in light of its internationalisation strategy. He showed how the business rationale grew more important than the national Swedish energy policy, partly through a generational shift. Högselius and Kaijser (2010) use the concept of business and political arenas to analyse actor and stakeholder strategies in the political process leading to deregulation of the electricity sector in Sweden. They demonstrate how such actors can have seemingly opposing strategies in those arenas and that stakeholders usually were wrong in their initial judgement of the consequences of deregulation. Other research has focussed on how the electricity grid can be an important part of transitions scenarios (Foxon, 2013; G. Verbong & Geels, 2007; G. P. J. Verbong & Geels, 2010).Foxon (2013), and Verbong and Geels (2010) developed so called pathways which each entail e.g. different framings and governance arrangements, which can ultimately inform the political debate about which energy futures are possible. Doing so, they broaden the scope by showing a way beyond pure economic modelling of future electricity systems and technological fixes. Several authors have argued that the transmission grid infrastructure should play a bigger role in studying transitions and innovation systems that concern for example different renewable energy technologies (Andersen, 2014; Flynn, 2016; Sataøen et al., 2015). Andersen underscores this in the case of high voltage direct current (HVDC) transmission grids in the context of the EU by using a technological innovation system (TIS) approach that conceptualizes a socio-technical sector as consisting of multiple TIS and technological fields. He describes infrastructure as

having a temporal duality that changes between long periods of stability and periods of dynamic change through institutional or technological innovation. Andersen sees Europe's transmission infrastructure in a new "transformative period" which entails the introduction of new technologies, institutions and organisations (Andersen, 2014, p. 91). There is also a large body of literature dealing with questions of justice, public response, acceptance and opposition when it comes to relationships between actors, groups, communities or interests during the implementation of energy and infrastructure projects (Aas, Devine-Wright, Tangeland, Batel, & Ruud, 2014; Batel, Devine-Wright, & Tangeland, 2013; Devine-Wright, 2011; Sovacool, 2009; Wüstenhagen, Wolsink, & Bürer, 2007). For example Batel et al. argue for the need to move beyond the top down notion of "acceptance" when discussing the social aspects of transitions on the level of local communities (Batel et al., 2013, p. 4) .

Electric vehicles have also been increasingly studied from a socio-technical systems perspective. Some studies highlight differently radical departures from the existing transport regime, where electric vehicles are included in some of the options (Dijk, Orsato, & Kemp, 2013; Nykvist & Whitmarsh, 2008; van Bree, Verbong, & Kramer, 2010). Nykvist and Whitmarsh (2008) analyse the potential for system innovation in the transport sector by looking at novel technologies (including battery only electric vehciles (BEVs)), a shift from products to services and mobility management (Nykvist & Whitmarsh, 2008). They point out that those niches could benefit from regime openings, but that there are also diverging trends impacting the niches. Dijk, Orsato and Kemp show the historic origins of BEV developments and see six future challenges for electric mobility to succeed, namely infrastructure, a shift to mobility services, smart grid technology, changes in the global car regime, changes in energy prices as well as climate policy and public opinion (Dijk et al., 2013). Similar to Nykvist and Whitmarsh (2008) they also see other forms of mobility as possible. Nykvist et al. have analysed electric vehicle adoption in Stockholm, by using a multi-level transition perspective on the city level (Nykvist & Nilsson, 2015). They see it as a paradox that one of the supposedly greenest cities in Europe has not scaled up electric vehicles EVs faster. Among other results they find only limited accounts of successful local EV initiatives and more specifically have encountered normative barriers to EV adoption and a barrier in the form of unpredictability of national EV policy support. (Nykvist & Nilsson, 2015, p. 40). In a recent publication, Figenbaum analyses the electric vehicle transition in Norway (Figenbaum, 2016). He uses a multi-level perspective approach (MLP) and uses four hypotheses that stipulate that the Norwegian adoption rates are the result of well-functioning niches, a weak national internal combustion engine regime, different windows of opportunity or a certain combination of governance mechanisms. He finds support for all these hypotheses although to a varying degree. A broad study of technical change from horse carriage to automobiles has been done by Geels (F. W. Geels, 2005). Geels demonstrates that this transition did not just occur as a simple switch from one technology to another, but rather involved the initial development of particular, quite separate niche applications for bicycles, electric vehicles, steam and gasoline automobiles, all of which were not a threat to the horse based urban transport regime at the beginning. Only steam based, as well as electric tram designs were in more direct competition to horse trams, and much later gasoline automobiles managed to capture increasing market shares. This represents a "widening up" and later "narrowing down" of technology options (F. W. Geels, 2005, p. 473). .Later Geels also showcased the usefulness of the multi-level perspective (MLP) in low carbon transitions in the transport sector in general (Frank W.

Geels, 2012). Previously, different strategies for developing alternative automobile trajectories have been looked at, using the Netherlands and California as case studies (Schot, Hoogma, & Elzen, 1994).

Overall, the need to reduce greenhouse gas emissions in both the energy and transport sector, point to the need to analyse both high voltage grid development and the electrification of passenger car transport, not just as technologies but from a socio-technical perspective (Kemp, 1994; Thiel, Perujo, & Mercier, 2010; Williams et al., 2012). Therefore, it is important to understand how such transitions and innovations can be enabled and disabled in society. Nykvist and Nilsson also call for more comparative Nordic EV related research to better understand the differences between Denmark, Sweden and Norway (Nykvist & Nilsson, 2015). That way empirical evidence can be put into context to previous pathway literature about electric mobility or on the different transition patterns observed in other contexts.

The papers presented in this licentiate thesis contribute to the understanding of socio-technical transitions. It adds to previous research by combining at times rather separate lines of research, for example the MLP, the TIS framework, large technical system theory and institutional theory.

2 Aim of the licentiate thesis

The aim of this licentiate thesis is to analyse socio-technical transitions towards low-emission futures enabled by the electrification of the transport and grid development in the energy sector. As such it is a future oriented perspective which looks at how normative long term goals, like achieving a reduced greenhouse gas output, can be reached using a socio-technical transition framework. Case study analysis and scenarios are used to come up with policy recommendations as well as an understanding of how transition dynamics can limit policy options and ultimately an innovations' success.

On a more detailed level, the aim of paper I is to analyse what a fast rollout of electric vehicles would mean in terms of policy and what the consequences could be for achieving climate targets.

The aim in paper II is to analyse opportunities and challenges for creating sustainable energy infrastructure, through a comparison of the British, Norwegian and Swedish grid development regimes. The aim is also to compare how historical trajectories, grid planning procedures and needs definitions influence environmental, economic and social sustainability in high voltage transmission grid development in the different cases.

In paper III the main research aim is to identify barriers, drivers, dynamics and counter dynamics for the increased use of electric vehicles in Norway, Denmark and Sweden. A sub aim is also to understand such dominant dynamics taking place between the niche – regime – landscape and how such dynamics can enable or disable the establishment of the niche in the regime.

In paper I scenarios are linked to concrete transition policy suggestions as well as a consequential life cycle assessment. In paper II high voltage electricity grid regimes are

analysed using a combination of known transition theories with institutional theory as well as public response literature that is more rooted in psychology and behavioural sciences. Paper III combines the TIS and MLP theories and focuses on the process or dynamics within and between niche, regime and landscape levels. This is partially similar to Figenbaum (2016) who used the MLP to study the case of Norway. Paper III is however different because it has focus on the dynamics, the combination of multiple theories and the comparative analysis of several countries at once. All three papers also add to previous research through using a comparative approach. This can provide valuable lessons that otherwise would not be available since multiple countries are analysed using the same methods and frameworks.

3 Background

3.1 Theoretical starting points / underpinning

All three publications are in one way or the other concerned with socio-technical change. While paper II is about the conceptual development of a "sustainable grid development regime", paper I is about the possible environmental benefits of a future partially electrified car fleet as well as the policy instruments to get there. Paper III is concerned with how dynamics around electric vehicles (EVs) as a technological niche, can move closer or further away from an established regime.

A relevant theoretical basis for all the three publications is the research branch of "large technical systems" (LTS) and socio-technical systems. One of the main contributors to this research was initially Thomas Hughes who focused his work on the development of the western electricity networks (Hughes, 1983). He was one of the first scholars to use the term socio-technical systems. Hughes' starting point was the biography of Thomas Edison. He describes him as a "system builder" who mixed matters such as economics, technology and science in his business approach. Hughes describes those connections as a "seamless web" (Hughes, 1986, p. 285). Hughes also conceptualises the notion of the "development phase" of a system which would necessitate different measures (Hughes, 1983, p. 14, 1986, p. 290). Hughes also coins critical problems or difficult complex situations in the development of a socio-technical system as "reverse salients" (Hughes, 1983, pp. 14, 79). He further elaborates that manufacturing firms, research laboratories, university departments, utilities, banks and other organizations are often fully integrated components in a system in which physical artefacts are also components (Hughes, 1986). He thinks they are "a system because they fall under a central control and interact functionally to fulfil a system goal, or to contribute to a system output" (Hughes, 1986, p. 287). He proposes that technical, scientific, economic, political and social matters should be seen as overlapping categories (Hughes, 1986). He also argues that it is very difficult to change a dominant large socio-technical system and that any attempt to reform a technology without taking into account the shaping context as well as the other parts of the system will, in his words, be "futile" (Hughes, 1983, p. 465).

This is similar to the notion of what Unruh later refers to as path dependency (Unruh, 2000). Unruh understands socio-technical systems as developing along paths that get incrementally improved over time. At the same time such path dependencies can work as

barriers that hinder change processes and can lead to the lock in of existing regime structures.

After Hughes original work, the socio-technical system ideas branched out considerably. Another important research stream for the thesis is the work by Frank Geels and other Dutch scholars like Rip and Kemp which developed into the multi-level perspective (MLP) (Rip & Kemp, 1998).

Building partially on Hughes, but also many other authors, Geels describes socio-technical systems as a cluster of elements (technology, regulation, user practices, markets, cultural meaning, infrastructure, maintenance networks, supply networks) (Frank W. Geels, 2004). System innovation as another concept used, which he defines as the change from one socio-technical system to another, and which is achieved by: technological substitution, co-evolution, emergence of new functionalities (Frank W. Geels, 2004). Geels points to the importance of taking into account different phases in system innovations (Frank W. Geels, 2004). A second aspect that Geels identifies, is the importance to distinguish different levels of analysis (Frank W. Geels, 2004). For the purposes of his framework integration, Geels points to the three level multi-level framework which was developed by Kemp and others as a starting point (Frank W. Geels, 2004).

Building on that, Geels develops what he calls a "socio-technical regime" on the meso level of the MLP framework (Frank W. Geels, 2004, p. 33). The regime term has similarities to the socio-technical system but instead of just acknowledging the interactions, it focusses on the coordination, alignment and orientation that a semi-coherent set of rules brings to the activities of these actor groups (Frank W. Geels, 2004). In the author's eyes, the socio-technical regime is the reason for stability in socio-technical systems (Frank W. Geels, 2004). Geels mentions that this stability is still dynamic but usually only in an incremental way (Frank W. Geels, 2004). The regime in Geels original version is comprised of technology, scientific knowledge, markets/user preferences, infrastructure, culture/symbolic meaning, industry networks and sectoral policy/institutions (Frank W. Geels, 2004). While there usually is stability, these elements can also become misaligned or unstable (Frank W. Geels, 2004).

On the macro level Geels introduces the socio-technical landscape. This is the external context for actors in niches and regimes over which they have little direct influence (F. W. Geels, 2005; Frank W. Geels, 2004). In a general sense it consists of deep structural trends. More specific it contains "a set of heterogeneous, slow-changing factors" such as cultural and normative values, broad political coalition, ideologies, long-term economic developments, accumulating environmental problems growth, emigration etc. (Frank W. Geels, 2004, p. 34). Apart from the slow changing aspects it also contains shocks and surprises (Frank W. Geels, 2004).

On the micro level Geels uses the concept of niches that are somewhat protected from the normal market selection (Frank W. Geels, 2004). They are an incubation room for radical novelties. Important elements of niches are learning processes (technical, user preferences, regulations, symbolic meanings etc.), experimentation and the building up of social networks (Frank W. Geels, 2004). According to the author niches are geared towards problems in the existing regime (Frank W. Geels, 2004).

When it comes to timing for change, Geels notes that for a radical innovation to break free, the external circumstances and internal drivers have to be right. It is the linkages between developments at multiple levels that are important as well as the timing (Frank W. Geels, 2004). From the perspective of the niche that means that there are processes at the regime and landscape level that create a window of opportunity (Frank W. Geels, 2004). On the regime level this means that the activities of the social groups can be misaligned, for which there could be multiple reasons. The misalignment on regime level could be created due to technical problems, diminishing returns, changing user-preferences, strategic games by firms etc. (Frank W. Geels, 2004). Another possibility is that externalities caused by the regime are problematized more. Landscape level development can come as beneficial or unfavourable shocks and surprises.

Apart from the external circumstances, also the internal dynamic has to fit through increased momentum and linkages in the niche (Frank W. Geels, 2004). When the radical innovation enters the mass-market it will be in direct competition with the regime.

When it comes to the development of radical innovation over time Geels sees four main phases of development. The first phase is the emergence of the novelty in an existing context (Frank W. Geels, 2004). It is confined to technological niches and small market niches and heavily influenced by the existing regime in terms of concepts and rules (Frank W. Geels, 2004). A possible mechanism in this phase is technological add-on and hybridization when novelties link up with existing technologies (Frank W. Geels, 2004). The second phase, Geels calls technical specialization in market niches and exploration of new functionalities (Frank W. Geels, 2004). This is achieved through the increase of niche-actor interaction, socialization, institutionalization, professionalization etc. Learning experiences increase and a trajectory of its own is developed. Users test out new functionalities with the product. Overall the niche becomes more stable internally in that phase. The third phase is about wider diffusion, the breakthrough of the new technology and competition with the established regime (Frank W. Geels, 2004). For this to occur external opportunities have to present itself but also internal improvement have to be made, like e.g. price/performance improvements. Wider diffusion also creates higher visibility. If enough momentum is established economies of scale, network externalities and similar effects can be possible. The fourth and last phase is about the gradual replacement of the established regime (Frank W. Geels, 2004). This is often a gradual process as it takes time to improve the cost/performance ratio, establish all relevant components (new infrastructure, new user practices, new policies, new organizations etc.) and to conquer all markets in the system. Also the incumbents will defend themselves. While those phases are theoretical descriptions of how a niche might develop, Geels later conceptualised other forms of transitions as development or transition pathways (Frank W. Geels & Schot, 2007; G. P. J. Verbong & Geels, 2010). They refer to different kind of possible transitions with different kind of timing and interactions. These are particularly relevant when discussing a variety of transition directions.

Concluding, Geels stresses again that a look at promising novelties is not enough but that a look at processes in the regime and landscape is also needed (Frank W. Geels, 2004). But he sees the regime not just as a barrier, but also as an opportunity for novelties to link up with the regime. He also sees that system innovation can happen through the alignment or linking of multiple technologies (F. W. Geels, 2005).

While the MLP approach is useful for the analysis of socio-technical change overall, also because it takes into account hierarchical levels, it is not as strong in gaining a closer understanding of internal niche dynamics.

A framework that takes a closer look at a particular system around technologies or innovations is the technological innovation system. A TIS is a system focused on the development, diffusion and use of a particular technology (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Carlsson & Stankiewicz, 1991, p. 111; Jacobsson & Johnson, 2000). Inherent to the TIS concept is the functional dynamics approach which makes it possible to better identify key processes and interaction (Bergek et al., 2008; Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007). One of the main TIS goals is the systematic identification of policy problems (Bergek et al., 2008).

In terms of its system structure, a TIS is made up of three elements: *actors, networks and institutions* (Bergek et al., 2008). *Actors* can be firms, public agencies, research institutions or other organisations such as interest associations. *Networks* are particularly relevant for the transfer of tacit and explicit knowledge (e.g. standardisation networks, technology platform networks, policy networks, industry academia networks etc.) (Bergek et al., 2008). If an actor is integrated in a network, it greatly increases the knowledge and information base and such networks may also guide the perceptions around future desirable or possible courses of action. On the other side, networks can also be limiting technology choice. *Institutions* are the norms, rules, laws, regulation, routines and culture that guide the actor's actions in their interaction (Bergek et al., 2008). As such institutions have a large impact on the path that a technology will develop on.

However the structure of an innovation system in terms of its elements (*actors, institutions and networks)* is not enough to explain the system's performance which is why a look at functions is needed (Bergek et al., 2008; Hekkert et al., 2007). These functions are in effect sub systems of the overall system and are characterised by a particular set of activities essential to the development and performance of the TIS. Several such functions are relevant to the performance of a TIS (Bergek et al., 2008). The grouping used by Bergek et al. is entrepreneurial activities, knowledge development & diffusion, influence on the direction of the search, market formation, legitimation, resource mobilization and the development of positive externalities (Bergek et al., 2008). Some of these interactive functions need to be addressed by e.g. policy makers simultaneously in order to allow reinforcement, feedback mechanisms or complementary actions. If one of the mentioned system functions is missing it is possible that the innovation system ceases to function. Also, if feedback mechanisms between functions are neglected or overseen in the national policies, technology development can lead to unintended outcomes or no outcomes at all. Hence, those functions are both potentially inducing as well as constraining if they are missing or being neglected in an innovation system.

Similar to the MLP, also TIS acknowledges different development phases. The first phase is termed the formative phase. In that phase one usually finds competing designs, small markets, many entrants and a relatively high uncertainty around technology, markets and regulation (Bergek et al., 2008). Beyond that, certain factors are important that to some degree resemble the system functions mentioned before. Among those are early market formation (e.g. incentives for niche markets/protected spaces as well as demonstration

projects and experimentation in a variety of technology designs), the entry of firms and organisations, institutional change or alignment (e.g. redirection of science and technology policy and funding, market regulation and standards) and the formation of technology specific advocacy coalitions (e.g. needed to engage in political debates and influence institutions in the technology's favour) (Bergek et al., 2008). After the formative period, eventually a market expansion period is needed that further develops the TIS through virtuous circles and cumulative causation (Bergek et al., 2008).

It is also recommended as an additional analytical step to identify and understand blocking mechanisms or constraining factors e.g. if institutions fail to align to the new technology, niche markets are not formed, a lack of new actors on the markets prevails and networks fail to help the TIS due to poor connectivity (Bergek et al., 2008). These can differ depending on the development phase the system is in. These constraining factors can then be addressed through specifying key policy issues to help policy makers.

Both the MLP framework and the TIS framework have merit, but they also have their individual limitations. This is why it has been suggested several times to combine both approaches (Markard & Truffer, 2008). The TIS framework can profit from a deeper understanding of niche-regime interdynamics which is not conceptualised as strongly in the original TIS framework. MLP can profit from a deeper understanding of how a niche can develop internally.

In line with theories used in paper II, the MLP framework can be extended in its *regime* definition by considering also how a regime developed historically, e.g. how an electricity grid developed over time. This will influence some of the heuristics of how an established regime operates and hence can lead to path dependencies. Concretely, these can be defined as administrative traditions which can explain the behaviour and structure of public bureaucracies. In line with normative institutionalism these can be a historically based set of values, structures and relationships with other institutions and society (B. Guy Peters, 2008). Each individual country can have its own interpretation of that tradition and hence patterns can emerge that provide the means to understanding and interpreting public administration. This approach also shares parallels with historical institutionalism, in the sense that there is a persistent behaviour that influences administration over a time period (B. Guy Peters, 2008). Peters points out that these traditions have contemporary relevance, continue to influence the behaviour of public administrations and will privilege some types of reforms while they will reduce the probabilities of others. Peters argues that this notion of tradition includes political and administrative elites and their thinking of how administration should work, institutional features and the relationship between state and society in administrating public policies (B. Guy Peters, 2008). For example a very state centric position of administration would influence the success of citizen focused reforms (B. Guy Peters, 2008). He says the relationship between society and the state is important as that defines the role that societal actors and societal interests can legitimately play "in implementing and making public policy" (B. Guy Peters, 2008, pp. 126–128). Also the question whether the main approach to administration is by the rule of law or by managing is being referred to (B. Guy Peters, 2008). Similarly Pollitt and Bouckaert identify historic patterns in politico-administrative behaviour (Pollitt & Bouckaert, 2011). They identify a consensualist, a public interest as well as a corporatist state tradition.

3.2 Explorative and normative scenarios

As part of paper I we are exploring two possible future scenarios when it comes to an incremental battery only electric vehicle (BEV)/ plug-in hybrid electric vehicle (PHEV) uptake or a breakthrough scenario for BEV/PHEV uptake. Exploring those two scenarios can be seen as part of the future studies research field. Future studies can be used to develop and explore different images of the future and hence open up for reflection on more than just one limited solution (Wästfelt et al., 2012). Another very important point of departure for future studies is the notion of uncertainty (Bell & Olick, 1989; Wästfelt et al., 2012). Usually uncertainty means that there is more than one way to understand a certain situation or at least no complete understanding of the same. In futures studies usually predictive, normative and explorative scenarios can be distinguished (Börjeson, Höjer, Dreborg, Ekvall, & Finnveden, 2006).

The question of what will happen is answered by predictive scenarios that in turn consist of forecasts and what-if answers to specified events that might happen (Börjeson et al., 2006). As such predictive scenarios are often based on probability and likelihood. Hence they can only be valid in a short term timeframe (e.g. weather forecast). They are often based on the assumption that the current system structure persists and are often looking at past events to predict the future.

The question of what can happen in the future is the realm of explorative scenarios (Börjeson et al., 2006). Here external or strategic scenarios can be distinguished depending on the kind of change focus coming from outside the unit of interest (external) or on the strategic consequences of one's actions (Börjeson et al., 2006, p. 727). Explorative scenarios are often used in order to be prepared for a variety of events and to develop robust strategies.

Normative scenarios are different as they set out to reach a certain normative target. This is done through either a more conservative lens that assumes no radical system structure change, namely preserving scenarios, or a scenario type that assumes the necessity to system change to reach a normative target and can hence be called transforming scenarios (Börjeson et al., 2006). Preserving scenarios often use economic reasoning through cost optimisation modelling in different system like the energy, electricity or water sector. However, such scenarios are internally vulnerable to short term thinking, the assumption of optimal functioning market economies, rational and informed agents and are lacking an understanding for actors and institutions. As such modelling has often been criticised for reinforcing path dependencies and as being too far removed from real day to day dynamics (Sebitosi & Okou, 2010). Transforming scenarios start with the premise that larger system changes are needed to reach a normative target and hence typically work their way backwards through e.g. backcasting. Backcasting analyses certain images of the future and looks upon which implication such a future has for the present situation or system (Börjeson et al., 2006; Dreborg, 1996).

In paper I, through the consequential LCA methodology as well as the policy scenario analysis two future images have been explored (an incremental and a breakthrough scenario). Normative targets such as a fossil fuel independent transport sector in Sweden by 2030, can be seen as the premise for those scenarios. Using a transition theory approach for the other parts of the research, however, stresses the need for a closer look at

the actors, institutions, system functions and dynamics between and within niche, regime and landscape. Combining existing future studies methods, both quantitative and qualitative future studies methods, with theories and methods used in transition research can give a more complete picture of how to actually reach a certain target or what in more detail different explorative scenarios might entail. Developments in this area can already be seen in the transition study literature (Foxon, 2013; Frank W. Geels & Schot, 2007; G. P. J. Verbong & Geels, 2010)

4 Method

4.1 Case studies

Case studies are important to my research as they allow studying a specific object in the context of specific system boundaries. This is helpful because transition or innovation studies (e.g. TIS and MLP) often investigate a large number of factors that otherwise would be difficult to grasp and compare (Frank W. Geels, 2004; Jacobsson & Johnson, 2000). For the researcher it is easier to get that detailed knowledge of the innovation system if the boundaries are limited to e.g. a city or region or country. By interviewing, the innovation researcher will get to know the dynamics that lead to innovation in the system as well as the interactions between the actors, networks and institutions or the interactions between or within the niche, regime and landscape.

One of the perceived problems with case studies is that results from such studies are not generalizable. The argument against this critique is that well-chosen case studies can also contribute to accumulating knowledge and that in social sciences all research is somewhat context dependent (Flyvbjerg, 2006). Case studies are also interesting tools to falsify or to establish hypothesises. From a comparative perspective one can purposefully choose “similar” cases to identify what they do not have in common or choose very “different or extreme” cases to identify what they perhaps do have in common. It is also suggested to choose “critical” cases that possibly allow a certain predictive value with regards to other cases. For example in the case of Norway and electric vehicle development a uniquely successful and hence critical case was included.

The case studies in the present research have a comparative perspective as it is valuable to share good practices in the Nordic countries. One such comparison is the focus on the institutional environment around high voltage grid lines.

4.2 Data collection

4.2.1 Document analysis

In all papers presented, document analysis has been used for data collection. The documents used have been public sector documents, private sector documents, if relevant to the topic, different mass media outputs and digital documents such as websites. Bryman argues that one has to be aware that documents are created with “distinctive purposes in mind, and not as simply reflecting reality” (Bryman, 2016, p. 561).

4.2.2 Interviews

Interviews represent an important method in all social science research and are also of high relevance for research in socio-technical systems. Interviews have been used

particularly in paper III. Kvale defines interviews as an interaction between an interviewer and an interviewee where knowledge is constructed and hence is labelled a knowledge "construction site" (Kvale, 2007, pp. 1, 7–8). As a general dichotomy interviews are often described as either having no structure or a closed, detailed structure. However, in reality this dichotomy often is more like a continuum and hence interviews can be understood as somewhat between more or less structured (Brinkmann, 2013). In overly structured interviews there is a risk for missing out on important knowledge by not being able to account for meaning or interpretative frames (Brinkmann, 2013). Also they do not take advantage of the dialogical nature of an interview (Brinkmann, 2013). On the other hand, it is also not possible to have a completely unstructured interview as simply by asking one single question a certain direction or conversational norm will be given (Brinkmann, 2013). One of the issues one needs to be aware of while interviewing is the cultural, educational, ideological and social background of the participants in an interview (Kvale & Brinkmann, 2009). One should also be aware of the fact that one usually interprets what is being said on the backdrop of these factors. That means that interviews easily can become an interpretation of an interpretation etc. This makes it important to follow up during the interview, validate the results of an interview and to triangulate the findings.

In paper III semi-structured expert interviews were used as the main method to conduct the research. Compared to open interviews or closed, standardised surveys, this type of interview studies has the advantage of being able to follow up certain lines of thought by the interviewee. In order to craft the initial interview questionnaire, extensive literature study was done on transition theories like the MLP and TIS research frameworks. These frameworks provided basic categories which could then be explored further in the interviews e.g. in the market formation of EVs. Basic question could be "What was driving developments in this area?" or "What was hindering them?". From an MLP perspective another question was "Where was resistance coming from?".

For paper III a total of 27 interviews were conducted in Norway, Denmark and Sweden. In Norway and Denmark the interviews were conducted in English and in Sweden in Swedish. All interviews were recorded using a recording device. All interviews were then transcribed word by word for further analysis later on.

The data was first organised according to country and according to basic categories like drivers and barriers. In a second step, the data was further divided into niche, regime and landscape. In a third step, connected narratives or dynamics were outlined.

A way to identify possible interview actors was on the one hand through looking for public events, gatherings or presentations about the topic. That way a list of actors developed and by searching for their names in search engines often more events with potential interview partners could be identified. If the same experts appeared several times in such events they were earmarked as highly relevant for an interview. Other times interview partners were chosen directly because they represent an important organisation for the topic, such as car manufacturer companies (e.g. Think and Buddy in Norway, Volvo in Sweden). Once contact was established and an interview agreed upon, these experts were also asked whether they could recommend other experts in the area. Overall it was also tried to balance political views, as well as private/economic interests vs. public interests. All in all, interview partners worked for car manufacturers, energy companies, industry umbrella

organisations, mobility service providers, NGOs, Think Tanks, research institutes, government agencies on local, regional and national level and the respective national parliaments. On the whole 11 interviews were performed in Denmark, 8 were performed in Norway and 8 were performed in Sweden.

4.3 Data analysis

In paper I and III the TIS and MLP frameworks (Bergek et al., 2008; F. W. Geels, 2005; Frank W. Geels, 2004; Hekkert et al., 2007) were used as a way to first codify and then analyse the data collected in the interviews.

5 Summary of results

5.1 Paper I

Paper I presents a study of the goals, policies and industry position regarding electric vehicle developments in Norway, Denmark, Sweden and Finland in late 2012. Two scenarios, an incremental and a breakthrough EV scenario, are created by combining existing scenarios found in literature. These are used to analyse the climate impacts as well as potential future policy requirements for attaining climate targets.

The review of the EV developments showed that as of 2012 Norway and Denmark have been driving developments the most. They had stronger policies and also new business models that were enabling EV developments. At the time, Finland had also already some industry production experiences. Norway had a full range of different governance mechanisms (economic, regulatory and cognitive/normative) and long term guarantees for them that made these developments possible. Denmark and Sweden were less broad in their policy approach while Finland did not prioritise such developments politically.

The two scenarios created were chosen from a range of studies and reports which had a very large spread in terms of potential market uptake as well as share of car fleet until 2030. This shows that these studies used different sets of assumptions. The most important assumption in this regard is about the future developments in battery technology, also in comparison to the developments in ICE technology. In the paper an incremental scenario (18% EV share of car fleet in 2030) and a breakthrough scenario (33% EV share of car fleet in 2030) were used. We argued that the breakthrough scenario was conditional to beneficial developments in battery development, coordination and time horizon in policy support, public acceptance for EVs.

The scenarios input variables were then used as an input for a consequential life-cycle analysis. This analysis shows that EVs could reduce GHGs emissions up to 15% compared to no adoption of EVs by 2030. This however also illustrates that EVs can only be seen as part of a larger package of solutions to reduce emissions from transport.

In order to explore what a stronger support of EVs as part of a breakthrough scenario could imply, a literature review resulted in a number of possible policy instruments. This required adopting a somewhat entrepreneurial approach to policy on behalf of the government both in the short term and long term with the corresponding policy instruments. This entrepreneurial governance approach can be described as a policy environment where the government takes the role of an investor that actively tries to

support technologies that can help achieving its climate goals. For the choice and collection of possible policy instruments, theoretical underpinning from TIS and others were used, particularly when it comes to different development phases of technologies in a socio-technical system and the different system function of a TIS described earlier. In the analysis, policy instruments that do not just take into account the purchasing decision but also day to day life of EV users were included.

As a concluding proposal that wants to achieve a long term and stable innovation environment an ambitious feebate system was put forward as a viable solution. Such a system penalises buyers of high emitting cars and uses that money to subsidise adopters of low emission vehicles. To accelerate developments and fleet renewal even further also scrappage schemes could be an option with different trade in possibilities.

5.2 Paper II

Paper II compares the British, Norwegian, and the Swedish grid development regimes (GDR) in order to analyse their opportunities and challenges for creating a sustainable energy infrastructure. The paper deals with the paradoxical situation that even though large parts of Europe's population are in favour of renewable energy, concrete renewable energy projects often struggle with a local double citizen opposition. This includes the opposition against the concrete renewable energy projects themselves but also against the large high voltage transmission projects necessary to make the generated electricity available over larger distances. One reason for this situation is the fact that in many countries renewable energy projects are planned and implemented completely separate from the needed high voltage transmission grid to transport that electricity.

Paper II includes a comparative analysis of the planning procedures for high voltage transmission lines. Official regulations and regulatory guidelines, policy documents, white papers and green papers from all three countries, and interviews with key informants at the governmental level and grid companies were analysed. The analysis demonstrates that there are significant differences between the countries when it comes to their socio-technical grid development regime. This becomes apparent in their historical trajectories and resulting technological setups. For example, while Sweden and the United Kingdom had a strong need to establish a central grid to consumption centres for geographic reasons, Norway had a much more decentral history of grid development due to abundant water resources throughout the whole country. This resulted historically in less need for a fast development of a central and standardised high voltage transmission grid. Later on however, the different implementation approaches when it comes to market liberalisation of the electricity market, also lead to different, country specific need arguments and drivers for high voltage grid projects. Depending on that approach, this was driven by experts, the government, other levels of government or other stakeholders.

One of the main results of the article, when it comes to the planning procedures for grid development, is that a sole focus on economic efficiency in grid planning will most likely be unsuccessful and actually will lead to longer lead times due to citizen opposition. Instead, well spent time is necessary to ensure legitimacy and social sustainability of grid planning. One conclusion from the study is that the possibility to participate substantially in consultations early on in the process, as well as transparent and politically accountable decisions during the different stages of grid planning, clearly indicate higher chances for

timely implemented grid projects. The process is a way to reconcile the different and conflicting demands emanating from the national and regional governance level as well as concerns from conservationist, environmental, social or economic viewpoints. Another conclusion is that a strict division of a solely national expert driven concession process and a national politically needs defined starting point will be counterproductive as it reduces the legitimacy of grid projects and likely leads to later appeals in the courts.

5.3 Paper III

Paper III is deepening the initial document analysis of paper I with regards to innovation dynamics by conducting in-depth expert interviews in Denmark, Norway and Sweden. The paper employs a joined MLP-TIS framework to better grasp dynamics within the technology niche but also the dynamics between the innovation, the established regime and the external environment which analytically is called the landscape.

The paper shows that strong initial technology legitimacy was needed in both Denmark and Norway to start the innovation dynamics. This was provided in both those cases by industrial start-ups that made an EV industry vision appear achievable. In Sweden such an industry vision did not form as a legitimate cause in itself. What was however essential in Norway is that a strong and broad coalition of actors formed around EVs. The same quality of coalition network could not be reached in either Denmark or Sweden. This also impacted the variety and scope of the policy instruments in the three case studies. In Norway more and more policy instruments were added over time. These took into account different technology development phases and the usage of the EV. This did not happen in Denmark and only to a lesser extent in Sweden. Also the Norwegian policy instruments were backed by a long term commitment until a goal was reached.

There was also a clear difference in niche-regime dynamics. While in Norway the niche quickly made its way closer to the regime, there were clear barriers in Denmark as well as in Sweden although to a lesser extent.

Particularly noteworthy is that in the face of a stagnating EV innovation system, municipalities often picked up the slack and at least kept the niche alive over a longer period. This role holds also true for some electricity companies which could finance EV developments even if they were not profitable initially. Overall, the combined dynamics can be characterized in the three countries as a system motor in Norway, a municipal motor in Denmark and a somewhat weaker system motor in Sweden.

6 Discussion

The papers in this thesis have somewhat different focal points. While paper II is concerned with an established infrastructure which is the historical result of the (re) development of the current dominant socio-technical electricity regime the other two papers on EVs have the perspective of an innovation or a niche challenging the established regime. However in all three papers it could be shown that niche-regime interaction and regime openness is significantly influenced by legitimacy and institutional design. These allow or discourage conflict or dynamics to take place.

In paper II, as a result of their historical development (historical grid development and politico-administrative tradition) but also the recent market liberalisation, the socio-technical electricity regimes in the three case countries have individually produced different and partially locked in development pathways. This led to the formation of a varying ability to handle pressure from different societal or niche developments that entail social, economic or environmental sustainability issues. For example in Norway the grid development process was not able to include opposition against grid projects into the initial stages of grid development. Rather such opposition had to appeal at a very late stage of grid development to get their voices heard.

In Norway, due to the depoliticization and centralisation of the grid development and an increased focus on an expert driven needs assessment, fewer possibilities were given for new actors or other interested stakeholders to participate in grid development. As a result, authorities (national, regional or local) often play a very minor role in the grid planning process and are merely recipients of the experts' assessment. In that sense Norway has left parts of their former more consensual Scandinavian tradition of a politico-administrative regime. Also it has to some extent left its local level historical heritage of dealing with electricity systems. In Sweden, despite the market liberalization, more elements of the corporatist and consensualist politico-administrative regime have been maintained. This has led to higher political accountability of the existing grid development and also to more extensive consultation processes on the local level in Sweden. Allowing the participation of multiple interests early in the planning processes made it possible for the regime in Sweden to let the pressure for change enfold in a somewhat controlled manner. This also allows the regime to integrate the pressure in its established development pathway. In Britain, the public interest tradition, where the market and private actors played a more dominant role, led to a focus on efficiency, centralized decisions and a streamlined planning process. This centralized process reduced the ability of stakeholders from the local level to influence decision making. On several instances this led to conflict potential in the British grid development as it did in Norway although under different preconditions.

Paper II shows how the grid concession process can give voice to many different interests and is hence a concrete example of a somewhat formalised relationship between niche, regime, landscape but also different government levels as well as other societal interests and needs. This formalised relationship can be, but does not have to be, at odds or in conflict with goals at other government levels or even within the regime. One concluding remark is that a national government interest in renewable energy is not enough to ensure a sustainable grid development on all levels of society. Instead, sensible and sound strategies for developing the grid are needed as well as adequate legitimacy and political accountability on the different government levels. The criticism by for example Entso-E that the grid development processes take too much time is not entirely valid. We argue that the question really comes down to how to most effectively ensure the future sustainability of grid development. While the design of the process can be changed, time is needed to ensure especially social sustainability, accountability and legitimacy. Time can be saved by including lengthy and serious consultations before the formal application is filed instead of having to deal with appeals at a later stage.

In Paper III it becomes apparent that it was essential to initially have an industry vision, or the prospect of a potential EV industry, to politically secure the first powerful EV

incentives. Without these industry prospects it would have been difficult to justify special tax exemptions for EVs. Those *entrepreneurial activities* hence secured *legitimacy* of the technology, *guidance* in form of a common vision and provided a way forward to how the niche could move closer to the regime. As such there was a process or dynamic before the policy instruments were implemented that was more important for the long term success of the niche than the policy instruments as such. The implications of this insight can be that it is not just a matter of transferring policy instruments across countries, but that there needs to be a legitimacy that carries such changes also in the face of resistance. This is perhaps somewhat of a difference compared to paper II where the legitimacy of new high voltage grid projects often was not sufficient because not all actors impacted by the national decisions were convinced of that vision or cause for action. In paper III it was also shown that Sweden with its established car industry regime did not succeed in implementing as aggressive policies. This supports the notion that the legitimacy of the technology was not sufficient enough to cause a more immediate response.

The *entrepreneurial activities* in Norway were supported by a closely coordinated, varied and strong *coalition of actors* in Norway, whereas this was not the case in Denmark or Sweden in such a broad and coordinated fashion. Over a long time frame of 25 years the Norwegian coalition established themselves partially in the regime through continuous strategic work. This can be shown by the fact that in almost all Norwegian political parties there are members of parliament that support EVs. This holds even truer for the smaller left wing and right wing parties that are needed for coalition governments. In Denmark EVs are mostly a politically left wing issue and to some extent this is also true for Sweden.

There was also a difference in the receptiveness of the established regimes for new industrial ideas. Apart from the industry potential that motivated in Norway it can be noted that there was no existing regime lobby or no lobby that cared enough to intervene at that point against the upcoming niche. In Norway the oil industry did not have EVs on their radar, and this gave the niche more time to develop. There was also no substantial pre-existing car industry which meant that no established car player would try to hinder the niche's development either. In Sweden the regime was still heavily influenced by past experiences of pushing ethanol fuel that by many is not perceived as a success story. Second of all, the country also has a recent history in favouring technology neutral policy approaches, making it harder for new niches to receive a policy treatment according to their actual development stage. Also, Sweden already had an established car industry which meant that there was a higher interest to first receive a return of investment for established vehicle platforms, technologies, skills etc. In Denmark the regimes' receptiveness changed over time, also in light of the failures of the initial industry start-ups and later Better Place. Once the micro car regime that favoured and subsidised small, fuel efficient fossil fuel cars was more and more established, it became much harder for the niche to influence as EVs could not compete economically.

As in paper II, also in paper III, the local and regional level played an important role. In almost all municipalities environmental targets were a major driving force when it comes to EVs. It seems clear that many of the practical benefits that municipalities could offer early adopters, were crucial to compensate for the worse price/performance ratio of EVs compared to the established ICE cars. These were absolutely key in Norway as the national incentives probably would not have sufficed to convince early adopters of the early EV

models. But depending on the country, municipalities may be limited in their competences in the transport area. Particularly in Denmark and Sweden, where a private market was missing or still is missing, public procurement and joint public procurement among municipalities and interested actors was a very potent mechanism for attracting EV models at an early stage of EV development. The often clear set driving patterns in municipal services, combined with TCO fleet analysis, often made the case for EVs. As such municipalities played an important role to keep niche dynamics alive, particularly in Denmark, where the regime was not favourable towards supporting the niche from a national level. This is interesting as paper II and paper III demonstrate how the national policy goals can be out of balance with the local or regional policy goals. In paper II, the national political level often pushed for time efficient solutions that frequently favoured a strong national role in the electricity system. In paper III, municipalities to a certain degree kept EV developments alive where the national political level was inactive or unable to act. In the case of Norway it can be seen how powerful innovation dynamics can be created if the local, regional and national level work together as in the case of EVs. The Norway case even showed how the Norwegian example can become a landscape factor in other countries around the world to show that individual transport with EVs is possible.

Paper I looked into what a fast rollout of EVs would mean in terms of policy. It becomes apparent that this can only be achieved through a somewhat entrepreneurial governance approach to policies on behalf of the government in which niches are actively supported. While doing so, not just incumbent actors should be supported by for example government funded research and demonstration projects but also start-ups and entrepreneurs. The policy arsenal itself needs a long term perspective (e.g. feebate systems) but also a short term perspective that takes into account the different development phases of a TIS as well as the short time frames to reach the set climate goals. Of importance is also to give a long term and clear perspective in order to provide potential investors a useful time horizon for their decisions (Arentsen, Kemp, & Luiten, 2002). Another possibility as a policy focus is to not just consider the purchase decision itself but also focus policies on the day to day life or the life quality of potential adopters.

Paper III has shown that such approaches can work in practice. Especially Norway focused not only on the EV itself but also on the usage of the car in daily life through its policy instruments. Paper III has also shown that for a more lasting dynamic, demonstration and pilot projects need to be embedded into a larger functioning policy framework that includes economic support for purchasing and using the new technology. In the case of early stage BEV technology it became apparent that the price level needed to be at least at the same level as their ICE functional equivalents to achieve stronger dynamics. This meant for example in Norway that EVs at the beginning had to be able to compete with second household cars but now with improving technology also vice versa the existing first household car. On top of that, additional measures were needed to compensate for the risk taken by the early adopters. If the economic case becomes too narrow compared to the established ICE usage, many actors choose not to make the new and perhaps difficult or inconvenient choice. This can be seen as a reduction of transaction cost that compensates for inconveniences when adopting a new technology.

A further problem that was encountered in paper III, was the lack of political commitment over longer periods of time than the next budget decision or upcoming election. This led to

a large uncertainty whether the implemented policy instruments would continue or not which in turn led to many stakeholders stopping their investments completely. Norway showcased how this could be prevented by finding a political majority that first of all focused on an agreed policy target until which certain instruments would be guaranteed. Only thereafter possible changes in the framework would be enacted. This long term *goal focussed* policy approach instead of short term policy instrument focus allows for taking into account the current development state of the technology in question and also for spurring up dynamics if need be. This in turn will also lead to guidance for investors and other stakeholders. All in all a broad range of incentives can be used that are guaranteed until certain milestones are reached which allows that the technology development can be tracked both from the perspective of industry or market. One can argue that a lack of long term goal coordination also played a role in paper II where renewable energy projects were planned separately from the corresponding grid needs.

Overall it can be seen in paper III that the right mixture of policy instruments is essential but that at the same time they need to be backed up by a varied and strong coalition of actors including members of parliament of the whole political spectrum that put continued pressure on decision makers to achieve the established goals. They can also counter flawed arguments in the media debate or even destabilise the current regime by showcasing the disadvantages of the current dominant technology e.g. the uncertain diesel emission values.

As paper I demonstrated, the EV niche can potentially contribute up to 15% GHG emission reductions until 2030 compared to no adoption of EVs. This of course depends on the assumptions used in the LCA analysis as well as the assumptions inherent in the scenarios that served as an input. For timeframes until 2030 these uncertainties can be considerable. However what seems reasonable to assume is that EVs as one particular technological innovation can only be one part of a larger package of solutions to achieve sustainable transport systems. Such solutions could be a higher share for cycling and (electrified) public transport.

In all three papers, there was also the presence of different landscape factors that had enabling and discouraging qualities. In paper I and paper III the directives put forward by the European commission spurred car makers to innovate and reduce their emissions and also guaranteed that municipalities felt a different kind of pressure altogether, namely to reduce local emissions due to possible penalties. In paper II, the overarching goal of achieving a unified European electricity market led to a strong push to invest in high voltage electricity lines across Europe without taking into consideration other solutions or futures. In paper III it also became apparent how important the global development of lithium-ion battery technology was for the emerging electric car industry, as this allowed for a better performance of EVs. Also companies like Tesla Motors and Nissan which are global players played a big role of what electric cars in the eyes of many could stand for. However the landscape factors were not isolated from the niche-regime dynamics present in the case countries.

An overarching question in all papers was how strongly the socio-technical regimes would actually be changed by upcoming sustainability issues, conflicts, misalignments or niche developments. While paper III showcases that an individual passenger transport sector

without the internal combustion engine as its regime focus is possible, it also shows that the business model of selling cars did not change to a large degree. One could even argue that in that sense the system is still "locked-in" in that regard. Of course large behavioural changes on the side of the users were needed for EV adoption, but most of the "sale" success came when EVs felt more like "real cars" or even better cars to potential adopters. As such the development path did not alter that much. Rather it is more a form of hybridisation or technological add-on to the existing car regime, although new vehicle platforms were needed in some cases. As such this showcases how a niche has the potential of "getting stuck into the existing regime without a radical transformation" (Rob, 2007, p. 2399).

There were of course counterexamples and completely new actors, new actor networks or partnerships that have not existed before. Even actors from other regimes like the electricity sector started playing at least a temporarily large role in the car transport regime. However somewhat more radical ideas like the one showcased by Better Place in Denmark were not successful for reasons inherent in the Danish passenger car regime, but also because of internal business mistakes made. Other smaller development pathways slowly emerged like BEV shared car pools or car pools in general. These however remain smaller alternative development pathways and the dominating development pathway of owning a car is not yet substantially put into question. This is somewhat in line with Nykvist et al in which it was argued that the more radical niches may have the downside for the moment (Nykvist & Whitmarsh, 2008). On top of that they even hindered each other as in the case of Better Place in Denmark or the repercussions of the use of bio-fuels in Sweden. However, given upcoming learning rates in battery development, ICT and autonomous driving newer forms of mobility may gain in relevance. The niche looked upon could therefore be seen as temporarily contributing to aspects of the existing regime, although parts of the infrastructure, competences and capabilities the internal combustion regime is using are being made less relevant. There are even more radical development pathways possible in which the car, and in the case of this licentiate the electric car, is not at the centre of an electrified transport future. Especially in an urban context there are signs that less and less people see the need to use cars provided there are alternatives. More and more cities are also looking for ways to ban cars from certain parts of the city. Looking at the discussion by Geels made on the exact shape of the development pathways encountered in Sweden, Denmark and Norway it can be argued that BEVs, at least in Norway, shows first signs of "narrowing down" after initially different technologies were considered in all three countries (F. W. Geels, 2005).

The case of paper II shows the need to see infrastructure not just as socio-technical systems, but also in combination with the technological fields the infrastructure is or may be attached to, as well as which development paths those combinations represent. These development pathways can lead to conflict and misalignment with the current regime. The preconceived need for large high voltage transmission infrastructure as the dominating development pathway was put into question. This is often based on modelling that does not take into account the full extent of transition dynamics on multiple levels of governance (G. P. J. Verbong & Geels, 2010). It has been criticised in other places that Entso-E, which carries a lot of weight, often only sees the solution of building more high voltage grids without taking into account alternative solutions that consider decentral storage and demand side response (van Renssen, 2015). In previous research it has also

been shown that other development pathways increasingly take shapes that favour other constellations of energy and infrastructure ownership (G. P. J. Verbong & Geels, 2010). Here, locally owned renewable energy transmitted through locally owned smart micro grids comes to mind. In the last decade there have been instances where ownership was transferred back from a national level to a local level (Becker, Beveridge, & Naumann, 2015; Hall, Lobina, & Terhorst, 2013; Moss, Becker, & Naumann, 2015). As such the conflict between local, regional and national needs in sustainable grid development that emerged in paper II can also be seen as more than just as opposition against the lack of political accountability or lack of legitimacy of the high voltage transmission grid projects. It can perhaps be seen as a questioning of the whole suggested development pathway of high voltage grid development that is at the base of such a vision.

Overall the discussion of development pathways shows that there are multiple answers possible as to what is a sustainable energy or transport future with different constellations of ownership and interests.

When it comes to the definition of a *regime* and what it entails, it is apparent that it has been used somewhat differently in paper II and paper III. The reason for that is partly that the concept “regime” means different things in different research fields. In paper II the regime definition centres on a socio-technical understanding of high voltage transmission grid development with the nation states as system boundaries. The focus was not on the whole electricity system but on the high voltage transmission infrastructure as this infrastructure interacts with other technologies and transitions (Andersen, 2014). Apart from the socio-technical understanding of a regime as outlined by Hughes as well as the MLP framework, also institutional theory was included in the regime definition, including norms, rules, needs definitions, historical trajectories, administrative traditions and patterns in politico-administrative behaviour. The focus on the formal grid development process functions as a focal point for those research inputs and it is also the formalised procedure that defines how much change is possible in the regime. Paper III on the other hand has used a broader regime definition but the system boundaries have also been the nation states that were compared. The regime definition centres mostly on the national internal combustion engine based passenger car transport. Also, the aim of the paper is to analyse how electric car adoption took place in different countries. Hence, the system boundaries were also the reason why it was decided in the case of e.g. Ford Motors in Norway to see them mainly as an external influence from a macro, landscape level and not necessarily as a central part of the Norwegian established regime. This might have been different if Ford had been present for a longer time in Norway or if Ford would have been a national car manufacturer as Volvo in Sweden.

The landscape level as it was used in paper III also focuses on the nation state as system boundaries and on the question if the niche or regime actors can substantially influence those developments (F. W. Geels, 2005). As such it has been chosen in that paper to see Ford or the directives passed by the EU as landscape influences and not part of the regime. The reason for that is that for e.g. some of the actors in the nation state e.g. city governments cannot influence EU legislation directly but are nonetheless influenced by it.

Despite the regime definitions chosen here other regime definitions and system boundaries could have been used. In paper III, it could have been argued to have a wider focus on the

general automobile regime that focusses on selling cars. In paper II, also the wider electricity system regime could have been the focus.

7 Concluding discussion

System innovation in the sense that a societal function is fulfilled by new or different means has not taken place in the most radical sense in these cases. However it has been shown that provided certain preconditions are met, considerable transitions as well as reaching climate targets and spurring innovation can be achieved.

The preconditions for transitions can be found between and within the niche, regime and landscape. Between them favourable dynamics can eventually become motors that can sustain a development long term. That entails factors like legitimacy, strong and coordinated coalitions, established and concrete targets, preferably agreed upon in political consensus, and policy instruments that take into account the dynamics between niche, regime and landscape as well as the state of technology development.

As such it has been shown that transitions are not just about technology or policy instruments as such but about the dynamics and processes needed to enable them. The transition context (niche, regime, landscape), process (creating legitimacy, coalitions, guidance, political pressure etc.) and dynamic (motors) are as important components as the concrete policy solution. This can be relevant in other transitions that may misrepresent the former components.

Concrete policy advice that can be drawn from this research is the need for both long term and short term policy environments that can spur innovation broadly as well as more selected. There is also a need for a larger focus on the day to day life quality of potential innovation adopters. The conflicts between local, regional and national levels of government have to be able to come forward in a constructive way. If possible, policy instruments should entail a certainty in how long they would be valid as indicated by relying on common goals that are guaranteed by a majority of the political parties.

Moreover, and this is a topic not often researched in the transition literature, it would be useful to analyse the socio-economic consequences of a niches' success or a particular niche development path success. As this type of "creative destruction" can unravel not just e.g. transport practices but also jobs in for example the traditional car OEM industry. Some industry clusters will fare better in such change processes than others and hence some countries will profit or loose politically as well.

Although this research was a meaningful endeavour to investigate socio-technical transitions in low emission technology, many questions remain to be answered. One such question is how legitimacy, which has been highlighted several times as one of the essential stepping blocks, can be anchored more effectively. In the case of EVs industry, prospects have helped in the past, but the equivalent, but less visible role OEM suppliers could play, could not successfully be included as a legitimating factor in the case studies. Hence it would be interesting to see how legitimacy can be brought about in other ways. One such route would be a closer analysis of the landscape influence one case country has on other countries and for the development of the niche globally.

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