TØI report 1678/2018

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Decarbonising the Nordic transport system: A TIS analysis of transport innovations

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Front-page photography/illustration: Shutterstock

ISSN 2535-5104 Electronic
ISBN 978-82-480-2204-6 Electronic

Oslo, December 2018

Tittel:	Dekarbonisering av det nordiske transportsystemet	**Title:**	Decarbonising the Nordic transport system: A TIS analysis of transport innovations
Forfattere:	Ove Langeland (ed.) Magnus Andersson Tom Erik Julsrud Steven Sarasini Maria Schnurr Stefan Tongur	**Authors:**	Ove Langeland (ed.) Magnus Andersson Tom Erik Julsrud Steven Sarasini Maria Schnurr Stefan Tongur
Dato:	12.2018	**Date:**	12.2018
TØI-rapport:	1678/2018	**TØI Report:**	1678/2018
Sider:	73	**Pages:**	73
ISSN elektronisk:	2535-5104	**ISSN Electronic:**	2535-5104
ISBN elektronisk:	978-82-480-2204-6	**ISBN Electronic:**	978-82-480-2204-6
Finansieringskilde:	Nordisk energiforskning	**Financed by:**	Nordic Energy Research
Prosjekt:	4267 – SHIFT	**Project:**	4267 –SHIFT
Prosjektleder:	Julia Hansson, Svenska miljöinstitutet	**Project Manager:**	Julia Hansson, IVL
Kvalitetsansvarlig:	Marika Kolbenstvedt	**Quality Manager:**	Marika Kolbenstvedt
Fagfelt:	Regional utvikling og reiseliv	**Research Area:**	Regional Development and Tourism
Emneord:	Transportinnovasjon Avkarbonisere Drivstoff Kjøretøyteknologi Autonome kjøretøy Mobilitet som en tjeneste	**Keywords:**	Transport innovations Decarbonising transport Vehicle and fuel technologies Autonomous vehicles Mobility as a service

Sammendrag:

Omstilling av transportsystemet er en av de største utfordringene for energi og klima i Norden. Det har vært en sterk vekst i etterspørselen av transporttjenester for folk og gods i de seinere tiår og transportsektoren er svært avhengig av fossilt drivstoff. Flere tiltak for å avkarbonisere transportsektoren er introdusert i Europa og i Norden. Denne rapporten fokuserer særlig på nye teknologier knyttet til kjøretøy og drivstoff, men den omhandler også andre transportinnovasjoner som potensielt kan bidra til mer klimavennlige transportmåter, så som mobilitet som en tjeneste (MaaS).

Summary:

Transforming transport is one of the biggest energy challenges in the Nordic region. The past decades have seen a rapid increase in demand to move people and goods, and the transport sector relies heavily on fossil fuels. Several measures and initiatives to decarbonise transport have been introduced in Europe and in the Nordic countries. This report focuses particularly on new vehicle and fuel technologies but it also deals with other transport innovations which potentially can contribute to a shift to cleaner modes of transport, such as mobility as a service (MaaS).

Language of report: English

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Preface

This report is a result of a cooperative effort between researcher from RISE Viktoria and The Institute of Transport Economics (TOI). The report is part of the project Sustainable Horizons in Future Transport (SHIFT) financed by Nordic Energy Research which runs from 2015 - 2019. The SHIFT project analyses transport and energy transformations in the Nordics, and this report particularly focuses on transport innovations for decarbonising the Nordic transport system and it describes the the development of transport innovations by using a technological innovation system approach (TIS). The report mainly focuses on the development in Norway and Sweden. Denmark and Finland are mentioned more occasionally. Most of the work is done in 2017 and early 2018 and the report is not fully updated on all aspects of the rapid development of the different transport innovations.

The report is written by Magnus Anderson, Steven Sarasini, Maria Schnurr and Stefan Tongur from RISE Viktoria, and Tom Erik Julsrud and Ove Langeland (ed.) from The Institute of Transport Economics.

Oslo, December 2018

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Abbreviations

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
ASECAP	European Association of Operators of Toll Road Infrastructures
AV	Autonomous vehicle
AVGS	Automatic Vehicle Guidance System
BEV	Battery Electric Vehicle
CAGR	Compound Annual Growth Rate
C2C-CC	CAR 2 CAR Communication Consortium
C2X	Car-to-X
CITS	Cooperative Information and Technology Services
DAVI	The Dutch Automated Vehicle Initiative
DG	Directorate General (EU Commission)
DIV	Driverless Intelligent Vehicles
DOT	Department of Transportation
ECS	Electronic Components and Systems
EGVI	European Green Vehicles Initiative
EPoSS	European Technology Platform on Smart Systems Integration
ERTRAC	European Road Transport Research Advisory Council
EUCAR	European Council for Automotive Research
EV	Electric Vehicle
FAME	Fatty Acid Methyl Esters
FCV	Fuel Cell Vehicle
FOT	Field Operational Test
HEV	Hybrid Electric Vehicle
HVO	Hydrotreated Vegetable Oil
IEA	International Energy Association
IoT	Internet of Things
ITS	Intelligent Transportation Systems
JTI ECSEL	Joint Technology Initiative Electronic Components & Systems for European Leadership
KET	Key Enabling Technology
LDW	Lane Departure Warning
LKA	Lane Keeping Assist
LTA	The Land Transport Authority of Singapore
MIT	Massachusetts Institute of Technology
MLIT	Japanese Ministry of Land, Infrastructures, Transport and Tourism
NHTSA	National Highway Traffic Safety Administration
PHEV	Plug-in Hybrid Electric Vehicle
OEM	Original Equipment Manufacturer

SAE	Society of Automobile Engineers (USA)
TCO	total cost of ownership
TIS	Technological Innovation System
TNC	transportation network company
UNECE	United Nations Economic Commission for Europe
USP	Unique Selling Proposition
VDA	Verband der Automobilindustrie (German Association of the Automotive Industry)
VKM	vehicle kilometres traveled
VMT	Vehicle miles travelled
WHO	World Health Organization

Summary

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Oslo 2018 73 pages English language

Transforming transport is one of the biggest energy challenges in the Nordic region. The past decades have seen a rapid increase in demand to move people and goods, and the transport sector relies heavily on fossil fuels. Transport is the only major EU sector where emissions today are well above their 1990 levels. More than two thirds of transport-related greenhouse gas emissions are from road transport and this contributes to about 20% of the EU's total emissions of CO^2. The Nordic countries are also dominated by carbon-intensive means of transport and transport currently accounts for around 40% of CO^2 emissions from Nordic countries.

Several measures and initiatives to decarbonise transport have been introduced in Europe and in the Nordic countries. This report focuses particularly on new vehicle and fuel technologies but it also deals with other transport innovations which can contribute to a shift to cleaner modes of transport, such as mobility as a service (MaaS) and autonomous vehicles (AV). The analysis considers how policy has mobilised key resources for low-carbon transport innovations in the Nordic region and how the different technologies and fuels have developed.

A Technological Innovation System (TIS)-approach is applied in the analysis of transport innovations (technologies, fuels and services) and the first part of the report (chapter 2) presents the theoretical background and analytical framework used in an innovation system approach. The next part (chapter 3) which make up the main part of the report, presents and examines the different transport innovations for decarbonising road transport by using the TIS-approach, particularly focusing on functions in the innovation system. Six innovations comprising vehicle and fuel technologies and services are examined. For each innovation, relevant TIS functions are described. For some of the most developed technologies, such as electric vehicles and biofuels, all functions are examined. For less developed transport innovations, such as mobility as a service (MaaS) and autonomous vehicles, only some functions are examined.

The report mainly focuses on the development in Norway and Sweden, Denmark and Finland are mentioned more occasionally. Sweden differs from the other Nordic countries as the only country which currently hosts vehicle manufacturers, with Volvo Cars and National Electric Vehicle Sweden (NEVS) focusing on cars; and Volvo and Scania focusing on different types of heavy vehicles (buses, trucks, construction equipment).

Technological innovation system (TIS)

The Technological Innovation System (TIS) concept was developed to explain the nature and rate of technological change. It can be defined as a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology. It represents an analytical framework for examining a set of interlinking 'functions' that is thought to be key to the development and diffusion of a new technology.

The TIS analysis focuses on *system elements* and *system* functions. There are four types of system elements: *Actors* (individuals, organizations and networks, companies, government, NGOs, research institutions etc.); *institutions* (habits, routines, rules, norms and strategies); *interactions* (networks and individual contacts) and; *infrastructure* (physical, knowledge and financial). Functions in innovation systems refer to a set of key activities that are key to the development and diffusion of a given technology, see table below.

Table S.1: Key 'functions' or activities within innovation systems.

Technological IS (Hekkert et al., 2007)	**Technological IS (Bergek et al., 2008a)**	**National IS (Chaminade and Edquist, 2006)**
Knowledge development Knowledge diffusion through networks	Knowledge development and diffusion	Provision of R&D Competence building
Guidance of the search	Influence on the direction of search	Articulation of quality requirements from the demand side
Entrepreneurial activities	Entrepreneurial experimentation	Creating and changing organisations
Market formation	Market formation	Formation of new product markets
Creation of legitimacy/counteract resistance to change	Legitimation	Networking and interactive learning Creation/change of institutions
Resources mobilisation	Resource mobilisation	Incubating activities Financing of innovation processes Provision of consultancy services
	Development of positive externalities	

Development and diffusion of knowledge refer to knowledge creation through processes of learning e.g. learning by searching, learning by doing, to exchange of information and to learning by interacting and learning by using in networks. *Guidance of search* refers to activities that positively affect the visibility of wants of actors (users) and that may have an influence on further investments in the technology. *Entrepreneurial activities* refer to the presence of active entrepreneurs as a prime indication of the performance of an innovation system, and to activities to appropriate basic knowledge, to generate and realize business opportunities. *Market formation* is the process where new markets evolve in conjunction with new, innovative products or technologies. This may develop through several stages, niche markets, 'bridging' markets and mass markets. In order for new technologies to develop and diffuse, they must undergo a process of *legitimation*. This include activities that counteract resistance to change or contribute to taking a new technology for granted. Social and stakeholder acceptance for a new technology, and compliance with institutions is particularly important for the legitimation process. *Resource mobilisation* highlights the different types of resources that must be mobilised for technological innovations to develop and diffuse. These include competence and human capital, financial capital, complementary assets and, in some cases, physical infrastructures. *Development of positive externalities* refers to outcomes of investments or activities that cannot be fully appropriated by the investor, i.e. generation of positive external economies, such as pooled labour, knowledge spillovers, specialised intermediate goods, and complementary products, services and infrastructure.

If the dynamics of an innovation systems does not work well, it can be due to problems with either the system elements or the system functions. The development of a new technology can be slow or fail because important actors are absent or due to lack of competence or, because specific institutions are not in place or not able to support the new technology. It can also be due to interaction problems (lack of interactive learning, trust etc.) or to infrastructural problems (lack of resources). Identification of systemic problems can be helpful for politicians to formulate strategies and to use tools to remedy malfunctions in innovation systems.

The TIS-approach can also be used to analyse if and how technologies are related and interact, e.g. how synergies and conflicts can arise between technological systems. Technologies may compete in markets and for resources, they may complement one another or be neutral to one another. A new technology may also benefit from the existence of an older technology, sometimes at the expense of the older technology. Finally a new technology can be locked out via the existence of an older technology.

Technological and organisational innovations

Chapter 3 examines a number of technological innovation such as electric vehicles, electric road systems, biofuels, hydrogen and autonomous vehicles and one organisational innovation, mobility as a service (MaaS), in the Nordic countries. It highlights strengths and weaknesses in each of these technological and organisational systems.

Vehicle electrification

Vehicle electrification represents an important option for reaching global and national climate goals. Greenhouse Gases (GHG) emission and local pollution from well to wheel is much smaller from electric vehicles (EVs) than from vehicles propelled by internal combustion engines (ICEVs). An electric vehicle (EV) can be defined as a vehicle with at least one electric motor for propulsion. Broadly, there are two categories of EVs: all-electric vehicles and hybrid electric vehicles.

All-electric vehicles include battery-electric vehicles (BEVs) and fuel-cell electric vehicles (FCEVs). BEVs store the electricity in on-board batteries providing energy to the electric engine while diving. FCEVs have an on-board fuel-cell that produces electricity from hydrogen stored in a tank. These vehicles are zero-emission vehicles and BEVs are at least twice as energy-efficient as an ICEV. *Hybrid vehicles* (HEVs) combine an internal combustion engine with an electric engine. HEVs can drive on electricity generated when driving. Plug-in hybrid electric vehicles (PHEVs) can in addition charge their battery like BEVs, thus making more electric driving possible.

Main technological barriers related to vehicle electrification is on-board energy storage, range, battery technology and charging infrastructure. Other barriers are related to price, energy sources and raw materials for batteries.

The current interest in BEVs can be traced back to the late 1980s/early 1990s and was initially driven by new regulation, mainly in the US and partly in Europe. Globally, sales of EVs have undergone exponential growth since 2010, with over 1,2 million EVs in the current vehicle stock, which corresponds to around 1%. In absolute terms, China has the largest market for EVs, and in relative terms, Norway has the highest proportion. At the end of 2017 the market share for EVs in Norway was over 50% (20% BEVs, 20% PHEVs and 13% HEVs). In September 2018 Green electric vehicles, i.e. BEVs and PHEVs represented 27% and 20% of the new market sale and 5,9% and 3,0% respectively of the total vehicle stock. In the future one foresee more interactions between vehicle electrification and batteries that are used to balance intermittent energy sources.

Knowledge development and diffusion

Knowledge development and diffusion of EVs in Sweden has relied heavily on public funds, which have served to reinforce the technology when there was a lack of legitimacy. In the 1990s, Swedish government agencies provided funding for R&D projects on EV technologies alongside public procurement activities that sought to promote the vehicle demonstrations. During this period, Swedish carmakers focused on hybrid technologies, but made little headway in scaling up production due to an immature market. Until the mid-2000s, developments in Sweden focused mainly on the development of knowledge related to BEVs, HEVs and FCVs via R&D initiatives that were funded by both the automotive industry and public funds. Aside from some niche applications of HEV technologies, the main outcome was the development of concept vehicles and prototypes. In 2006, the Green Car R&D programme gave renewed impetus to R&D on HEVs. In 2007, the Swedish Hybrid Centre (SHC) was established to focus on collaborative R&D on HEVs. Generally, Swedish carmakers have relied heavily on knowledge developed by key suppliers such as Bosch. The Swedish heavy vehicle sector, by contrast, was more active in developing in-house knowledge, and field tests helped manufacturers develop knowledge regarding user perceptions of HEV technologies.

Influence on the direction of search

In the late 2000s, EU legislation was established to reduce vehicles' CO^2 emissions per kilometre and Nordic countries started to establish policy measures in the form of subsidies and tax reductions for the purchase of low-emission vehicles and fuels. The Swedish government has established the political goal of having a fossil-free vehicle fleet by 2030. In Norway, both the national government and municipalities have set several goals for decarbonization of the road transport system and for the dissemination of BEVs, reflected in their high and broad level of incentives. From 2025 the light vehicle market should only include zero emission vehicles and from 2030 the passenger fleet should be fossil-free. Finland has established a national climate target of an 80% reduction by 2050, but has not specified a specific target for the transport sector, instead relying on EU legislation to dictate national policy. Denmark has less ambitious climate targets, and tends to follow what is decided at the EU level. Denmark earlier had a more aggressive EV strategy with a target for the deployment of 200,000 EVs by 2020 offering a full rebate of car registration taxes. This was abolished in 2015.

Entrepreneurial experimentation

In Sweden, entrepreneurial experimentation has mainly occurred via tests and demonstrations of new vehicle configurations among the major automakers. On the heavy vehicle side, Volvo tested different types of HEV technologies in distribution trucks, wheel loaders, refuse trucks and inner-city buses during the 1990s. Scania has focused mainly on applying HEV technologies to buses, with tests and demonstrations. On the car side, Volvo experimented with series and power-split hybrids during the 1990s and with plug-in diesel hybrids and micro-hybrids in the late 2000s. Since 2010, car manufacturers have succeeded in commercialising HEVs. In 2012, Volvo Cars launched the V60 PHEV, and have scaled up their plug-in hybrid efforts to other vehicle models ever since. In 2015, Volvo Cars announced plans to electrify its entire vehicle portfolio, focusing on PHEVs and a full BEV by 2019.

Market formation

In Norway, the combined effect of fiscal and local incentives has contributed to a very strong growth in the Norwegian BEV- and PHEV-market. Economic incentives reduce the costs of buying BEVs and FCEVs, and local incentives make BEV travel cheaper and more convenient. Fiscal incentives are exemption from registration tax, VAT exemption, reduced annual vehicle license fees and, reduced company car tax. Local incentives are free or lower toll roads, reduced fares on ferries, free public parking, access to bus lanes and, free charging at public charging stations. The fiscal and local incentives will gradually be changed as the car fleet becomes more electrified. Denmark also created a strong set of incentives to support the market introduction of EVs and meet EV-specific targets, including exemptions from registration taxes and from the so called 'green ownership fee', a subsidy given to private individuals that own and drive EVs. However, in 2015, the Danish government decided to phase out these incentives, resulting in a dramatic decline in EV purchases from 2016. Finland has created tax exemptions for EV owners, but the overall level of subsidy is much lower than in other Nordic countries and the Finnish EV fleet consists of few vehicles. Sweden has the second largest EV market in the Nordics and subsidies focusing on green cars such as BEVs and FCEVs.

Legitimation and resource mobilisation

In Norway, there has been a strong rise of interest groups and their lobby action related to the EV market formation. Particularly the Norwegian association for electric vehicles (*Norsk elbilforening*) with 70 000 members has been important for legitimation of EVs in Norway. Denmark and Sweden also have similar associations for promoting EVs. Industry support is another way of assessing legitimacy of EVs, and this was weak in Sweden in the 1990s and early 2000s but increased later because of climate change challenges. The Swedish EV system has also been relatively weak in terms of resource mobilisation during this period.

Electric Road Systems

Electric Road Systems (ERS) refers to dynamic power transfer from the road infrastructure to the vehicle while the vehicle is in motion. Such systems have existed for over a century in the form of trams, streetcars, and trolleybuses. In recent years, ERS has emerged as a plausible solution for achieving urgent policy goals related to sustainability and fossil fuel dependency with a special emphasis on heavy-duty trucks. ERS reduces the need for batteries and relies on well-established electricity infrastructure.

ERS has the following subsystems: the road, the truck (based on an ERS powertrain), power transfer technology and the power grid and stations. The roads would be accessible to both vehicles with ERS propulsion and conventional fossil-fuel vehicles. There are different ERS technologies with varying degrees of technological maturity. Currently, there are three main competing technological trajectories in the ERS TIS: overhead lines, in-road conduction, and in-road induction. Each technology has its advantages and disadvantages, and is developed, demonstrated and marketed by different firms. There are several ongoing pilots- and demonstration projects around the world to develop and evaluate the viability of ERS. So far ERS has not moved beyond the development phase yet and it remains to see if it will succeed into deployment on commercial markets.

Sweden is a highly active research actor, with some activity in Norway. Two ERS demonstration projects have been developed and co-funded in Sweden, one in Gävle (with Siemens over-head line technology) and in Arlanda (with Elways). Incorporating infrastructure design and maintenance, the ERS area is characterized by a wide set of heterogeneous actors. The most active players are vehicle manufacturers and transport authorities but there are also numerous research institutions involved in developing ERS.

Energy producers and power grid actors have thus far not been a driving factor in research and testing.

Entrepreneurial experimentation

Reflecting the early phase of the development of ERS, entrepreneurial experimentation is a major function. Rail solutions have been developed and tested at two sites in Sweden and the ERS technology has been tested on both specific test tracks and on public roads. Overhead-line solution has also been tested on public roads in Sweden. By comparison, the wireless trajectory has received relatively scarce attention in the Nordic countries, but some actors have been involved in some tests elsewhere. Swedish vehicle manufacturers (SCANIA, Volvo) and research institutions (KTH) are involved in a large EU project FABRIC, and The Norwegian road administration is financing SINTEF to perform the ELinGO study which will explore different ERS solution for the E39 coast road. This project is intended to be coordinated with Swedish demonstration projects.

Knowledge development and diffusion

Globally, there have been several R&D and demonstration activities in the ERS innovation system. Most of these projects have been initiated by policy makers and largely financed through public funding, and focusing on creating and developing new knowledge rather than on creating a commercial market. The early stage of ERS development explains this; it is necessary to increase the knowledge level of all ERS technologies before making decisions on any large-scale investments in this field. This also includes reaching a common understanding of how ERS technologies could be standardized on an international basis in order to avoid bad investments and technological lock-in.

Resource mobilisation

There have been many actors involved in the development of the ERS innovation system, particularly in Sweden. Sweden has two major truck OEMs that have an interest in developing technology that could reduce the environmental impact of their products. Likewise, many entrepreneurs from the electric equipment industry have created new innovations. However, it is public agencies that have supported and funded most of the ERS activities. Until now there has been low resource mobilization from the users, such as transport buyers or haulers.

Market Formation

There is currently no commercial market for ERS in the Nordic countries, neither for heavy duty trucks or passenger vehicle. So far, the ERS innovation system is engaged in pilots, demonstration and deployment projects. Upcoming deployment projects may be crucial for stimulating regions, suppliers, and users to deploy ERS and develop functioning business models that support a market diffusion of ERS to niche- and mass markets.

Guidance of search

The International Energy Agency (IEA) points at ERS as one of the most feasible technologies since it reduces the need for battery capacity which makes trucks heavy and bulky, and could utilize future developments of fuel cell technology as range extenders or increased capacity in biofuels as the alternative fuel. There are also strong economic incentives for hauliers and transport buyers in moving towards ERS due to lower operating costs. Hence, there are both environmental and economic aspects that supports the guidance of search towards ERS.

Legitimation

ERS has encountered several challenges regarding legitimacy. One is that the main focus has been on passenger cars and on air quality legislation for trucks rather than on CO^2 regulation. Furthermore, the current road transport is characterized by a decoupling of infrastructure and vehicles while ERS involves a stronger coupling between infrastructure and vehicles (as with the railway system). Either ERS will fundamentally change current responsibilities of societal actors in terms of infrastructure provision, or it must introduce a new organizational field of private actors supplying the new infrastructure. This fundamental shift in relationship between infrastructure and vehicles constitute an important barrier for the establishment of ERS. Governments seek to decrease the perceived risk of ERS development through research investments and international cooperation. New conferences have also been created the past years in order to increase the legitimacy concerning ERS questions.

Hydrogen vehicles and infrastructure

Hydrogen is an energy carrier that can be produced from almost any primary energy source. Compared with electricity, large amounts of hydrogen can be stored relatively easily. As a fuel in vehicles, hydrogen is typically used to produce electricity for an electric motor using a fuel cell.

Germany, Japan and the USA are at front for promoting hydrogen as an alternative fuel in transport. However, deployment is still at an early stage (R&D) and hydrogen vehicles are rare in most countries. The hydrogen infrastructure is also under-developed and a major shortage of refuelling stations in most countries makes it inconvenient to have a hydrogen car. Huge investments are required to develop a sufficient hydrogen infrastructure, and as long as the vehicle fleet is so small, fuel companies hesitate to invest. However, various incentive schemes and new infrastructure plans are under way in several countries.

The Nordic countries are at the forefront of hydrogen vehicle deployment. The Nordic countries also cooperates closely both on infrastructure development and vehicle introduction through the Scandinavian Hydrogen Highway Partnership. However, so far, the market for hydrogen vehicles in the Nordics is small or almost non-existing. There are isolated pilot tests and a burgeoning infrastructure but there was little or no diffusion of hydrogen vehicles in the period from 2008 – 2016. Although the improvements of the hydrogen infrastructure may enhance the use of hydrogen cars in the Nordics, there is no clear sign of up-scaling or significant market formation, the main hydrogen activities still relate to R&D, pilot projects and lobbying.

Knowledge development and diffusion of knowledge

Due to the vehicle manufacturing industry in Sweden, there has been substantial research into different kinds of fuel cell technology with Scania and Volvo Cars being the most active parties. There are also new entrants focusing on hydrogen production and purification and several research institutes working on hydrogen innovation activities. In Norway, there is a long tradition for research on hydrogen both related to industry and to transport. Most R&D activities in this field takes place at Norwegian University of Science and Technology (NTNU), in SINTEF and Institute for Energy Technology (IFE). Important research takes place in the project MoZEES which focuses on battery and hydrogen value chains, systems, and applications (Mozees.no). Different networking actors are also important for the diffusion of knowledge of hydrogen.

Guidance of the search

In Norway, national policies and regulations have been introduced to stimulate use of hydrogen in the transport sector. A national hydrogen strategy was introduced 2016 in order to stimulate research on H2 and to contribute with financial incentives for the development of a hydrogen infrastructure. The state agency ENOVA which was established in 2001 is a key instrument for stimulating a transition in use and production of energy, included hydrogen. As for EVs there are also a lot of financial and local incentives for hydrogen vehicles, such as exemption from registration tax, VAT exemption, reduced annual vehicle license fee and reduced company car tax. Local incentives include free toll roads, reduced fares on ferries, free public parking and access to bus lanes.

Legitimation

Of the organisation and lobbying group promoting hydrogen in Norway, the Norsk Hydrogenforum (NHF) is the most important. NHF has members from industry, research institutions, authorities and transport operators and environmental NGOs. Oslo Renewable Energy, Environment Cluster (OREEC) is a secretariat for NHF. OREEC is a network with businesses, research institutes, education and public actors within the field of renewable energy and environment in the Oslo region. The network cooperates closely with local governments and other public and private partners in order to enhance research and innovation in the hydrogen field. The environmental organization ZERO is also involved in projects and lobbying for promoting hydrogen as a green fuel alternative in the transport sector.

Barriers for hydrogen vehicles

The most important barriers for hydrogen vehicles, seems to be technological. The hydrogen fuel cell technology is not yet as mature as the battery technology. There are concerns related to on-board storage, safety and liability and to high production costs of fuel cell. The limited number of car models also limit the possibilities for potential users. Lack of infrastructure (refueling stations) also reduces the market potential for hydrogen fuel cell cars as do the strong growth of EVs. The EVs seems to have reached a critical mass whereas the hydrogen fuel cell car is still in a test phase and constitute a niche market. This may change in the coming years but so far, expensive production of fuel cells, small production volumes, high prices and lack of infrastructure form barriers for an up-take of hydrogen vehicles both internationally and in the Nordic countries.

Biofuels

Biofuels used in transport are typically bioethanol which is used as a petrol substitute and biodiesel which is used as a diesel substitute. Generally, there are four types of biofuels - biodiesel, biogas, ethanol and synthetic fuels. In 2016, conventional biofuels accounted for only around 4% of world road transport fuel. However, research on biofuels is on the increase and biofuel projects are announced in a growing number of countries. Sustainability criteria for biofuels within the EU heavily influence the research and development of biofuel. The European biofuel directive seeks to limit greenhouse gas emissions and prevent that feedstock is grown on converted land (wetlands, forests).

Technical maturity and cost-competitiveness are key elements for the success of biofuels but significant non-technical issues exist. Biofuels have been contested since their inception, mainly because of food competition. Biofuel policies and regulations suffer the same fate, being regarded as “backfiring”, “incoherent”, and “exacerbating long-standing problems". Biofuels stand out from other alternative drivetrains/fuels as they show significant regional specialisations. Due to the need for regional optimisation of land use and relevant policies the scope and types of biofuels used vary significantly between countries and regions. The market share and growth of biofuels is highly correlated to political mandates concerning biofuels.

In the Nordic countries, particularly Finland and Sweden have invested in biofuels as an important means for fulfilling ambitious CO^2 reduction targets. Forests are big natural resources in both countries and they also have a strong pulp and paper industry. In 2017 in Sweden biofuels accounted for 21% of all the fuels used for transportation. Finland also has an advanced biofuel strategy in which biomass play a central role in meeting the target of renewable energy sources for transport. Biofuels also play a major part in the renewable energy strategy of Denmark. The consumption of biofuel has also increased in Norway the past years but the production of biofuel is small. Despite having successfully integrated biofuels in the transport system, Sweden is currently going through a stagnation period regarding biofuels. Finland on the other hand, has the most abitious target in EU for renewable energy share in the transport system, production capacity is growing and tax policy support use of biofuel in transport system.

Knowledge development and diffusion

A wide range of organisations are involved in knowledge development (mainly players from the academic and private sector) and diffusion (mainly players from the public and NGO sector). Sweden is currently involved in several of ongoing H2020 projects on RDI through academic and private organisations, some focusing on innovation technology, whilst others look at improving sustainable supply chain management for biomass and bioenergy promoting biofuels for sustainable mobility. The Finish Biorefine Programme aimed to develop new technologies, products and services related to biomass, and activate SMEs on niche products and markets and commercialize new technologies. Biomass-based fuels for transport were a specific topic of the programme. The Swedish Energy Agency (SEA) has also invested a lot in research aiming to improve efficiency and cost effectiveness of biofuel production.

Influence on the direction of search

The development of biofuel has been stimulated by both financial incentives and policy regulations. Both Finland and Sweden have ambitious climate and energy plans and tax exemptions for promoting use of biofuel in order to decarbonise transport. The recent decision of the EU Commission to ban palm oil as feedstock, whilst allowing forestry by products, energy crops and tallol has been welcomed by the biofuel industry in Sweden and Finland.

Entrepreneurial experimentation

In Sweden 200 cleantech start-ups are currently listed of which 18 in the biofuel sector. The European Commission Eco-Innovation Observatory has noted the presence of publicly funded environmental technology clusters: Biofuel regions, Bioenergy in Småland, Sustainable Business Regions, Eco-design clusters. In Finland, there are a few demonstration projects.

Market formation

In Sweden, biodiesel and other biofuels use is expected to continue to rise in the future, however, this growth is expected to slow down after 2020. In Finland, Neste has just become the supplier of its renewable biodiesel for all public vehicles in the city of Espoo in its bid for carbon neutrality by 2030, joining a number of similar initiatives in the country. Governance arrangements on the European level influence the development in the Nordics. The biofuels distribution obligation (Act 1420/2010) requires that the share of biofuels in transport petrol and diesel consumption shall be 20% by 2020. However, on EU level, there is no certainty of consistent long-term policies in support of biofuels markets after 2020. This has led some of the main market and research actors to withdraw from biofuels and rather invest in less risky alternatives. Swedish biorefining operators have started to transfer their attention towards cellulosic products or green chemicals which promise to yield higher value.

Legitimation

The "food vs. fuel" controversy has followed biofuels since their inception. Historically, the support to the agricultural sector and energy security were the main drivers of biofuel, now combating greenhouse gas emissions has become an equally important goal for biofuel support in the EU and in Scandinavia. The largest biomass industry association in the Nordics is SveBio, with their platform BioDriv which promotes the use of biofuels. On the other side, many environmental and development organisations, mainly non-governmental, have lobbied against biofuels due to their harmful effects on food security and soil depletion. OEM-led lobbying efforts have been accused of preferring biofuels over electrification of the vehicle fleet as this obviously is more compatible with existing fuelling technology.

Resource mobilisation

Tax exemptions were introduced early in the 1990s and several governance arrangements have followed - reduction of fringe benefit tax for company cars, investment grants for biogas projects and so forth. Resource mobilisation is also indicated by the number of people working with biofuel innovations. For biofuels and biofuel-driven vehicles, this is hard to pin down as many statistics will merge biofuels and biomass; and at OEM level, it will be almost impossible to pin down the exact number of engineers working exclusively with biofuels. Market analyses will be even more general as their scope is as large as the "bioeconomy" which encompasses everything from agriculture, and forestry to paper milling.

Autonomous Driving

Autonomous driving and automated vehicle technologies are rapidly evolving as autonomous driving vehicles are tested on the road. Automated technologies have been incorporated into cars for a long time, and ICT is spurring their rapid deployment and integration. However, there exists considerable uncertainty regarding the technical feasibility and market diffusion of autonomous vehicles. While some analysts don't see full autonomous vehicles before 2040, many OEM have been stating they will have models ready as early as 2020. Autonomous driving will change the mobility sector significantly as new mobility services and routines are enabled, new stakeholders emerge and new demands are placed on policies. Conditions for adaptation will heavily depend on regulation and on road traffic conditions.

While the main motivation for vehicle automation is increased safety and comfort, and reduced costs, it may also contribute to decarbonisation in the transport sector by improving traffic flows and reducing energy use. This probably requires a paradigm shift of electrification, urban and transport planning and shared mobility patterns. The technology and market for AVs is barely unfolding and this is even more true for their decarbonisation potential which will not unfold until a certain market penetration is reached, not to speak of their blending into low-emission mobility service concepts.

Global research on AVs is vast and encompasses disciplines reaching way beyond conventional automotive engineering. Research areas for AVs reach all the way from software, electronics, vehicle concepts, simulation and testing to socio-economic disciplines working with policies, business models and environmental effects. A main part of the research on AVs consists of defining roadmaps for research as the field is not yet entirely mapped. The European Union has a long history of funding collaborative research projects contributing to the development of automated driving. Projects are mainly conducted in four different categories: a) Networking and Challenges, b) Connectivity and Communication, c) Driver Assistance Systems and d) Highly automated urban transport systems.

The logistics and servicing industry is poised to be the fastest adopter of driverless cars compared to private vehicles. This include urban deliveries and services; long-distance transport; warehouse and other indoor logistics and confined areas such as factory sites, mines, ports and logistics centres. More than any technological innovation in mobility, AV technology will change not only transportation with ever more diversified vehicles and services but also the automotive market landscape. Supply chains will be altered, business models revolutionized, and incumbents' competitive edge threatened by rising niche players. The development of AVs has sparked a vast number of new start-ups and niche companies and the main influx of new players comes from the IT side, and it creates a much more diversified and dynamic market landscape.

Sweden is at the forefront of AV activities as it has domestic OEMs. But there is also a lot of testing activity and policy/regulatory discussion going on in Norway and Finland, especially in relation to the countries' ambitious decarbonisation and mobility goals. Denmark is home to several suppliers which are quite active in research, along with academic research, but has no demos, pilots or test regulation changes announced yet. On the infrastructure side, all the Nordic countries are busy in developing smart and connected roads to be prepared for autonomous vehicles. In general, a lot of activity is happening within the goods logistics sector.

Knowledge Development and Diffusion

In the Nordic countries, mainly Finland and Sweden have initiated major research lines on AVs but all countries are participating in international research projects in this area. Sweden's strategic innovation program DriveSweden is a government-sponsored collaboration platform for designing the next generation mobility system, based on Connected, Automated and Shared vehicles. Finland and Norway are part of a cross-boundary project, the "Aurora Borealis Intelligent Corridor and Test Ecosystem for CAD". It includes a 38-km test track on the E8 between Finland and Norway and the SnowBox testing facility.

Two initiatives that have gained attention is Smart Feeder and E6 Borealis. Both initiatives involve some elements of research although the key focus are on technology testing, *Smart feeder* on automated shuttlebuses and *E6 Borealis* mainly addressing intelligent transport systems in the northern part of Norway. In Norway, the three city regions Oslo, Stavanger and Kongsberg also run pilots on self-driving buses. Denmark is home to a very visible and unique player in self-driving vehicles, namely vehicle operator "Autonomous Mobility". The company imports and operates self-driving mini buses from French and US operators and has been involved in demonstration projects also in Sweden.

Besides personal cars, there is massive research going on in the heavy vehicles (trucks and bus) segment. In Sweden, Volvo CE and Volvo Trucks both are developing autonomous heavy vehicle prototypes and concepts and are conducting real-world tests. Norway has a strong focus on AV applications in the freight, construction and maritime sector. It is place of the first demonstration project of an autonomous boat (SoUrCe).

Influence on the direction of search

Sweden's "National Transport Plan 2018–2029" defines that "connected, autonomous and electric vehicles combined with mobility services have the potential to radically transform road transport.". The same message is to be found in the Norwegian National Transport Plan. These priorities are reflected in the funds and efforts that are put into AV development in various public research programs in the Nordic countries. The automotive industry in Sweden also influence the development of AV and manufacturers and operators are part of the large research projects in Scandinavia, like DriveSweden or Aurora Borealis.

Entrepreneurial experimentation

Several pilots and demonstrations in the goods logistics area take place in the Nordics, particularly in Sweden, many of them initiated by Swedish companies. In 2017, the Ride-hailing company Uber ordered 24,000 SUVs from Volvo which Uber is planning to operate and deploy in a proprietary self-driving fleet in the US by 2019. This is the largest order ever placed on self-driving vehicles and has moved the Nordics ahead in the entrepreneurial landscape. Besides industrial trials there are several active players within IT and systems development related to AV development.

Legitimation

In 2017, Sweden changed its regulatory framework in a way that allows for pilots with AVs on public roads. This is supposed to spark AV piloting and testing around the country. Test regulation in Denmark also allows for tests with self-driving vehicles on public roads from the same year. In Norway's National Transport Plan for 2018-2029, the need for intensified development of vehicle technology, including ITS and AV open for trials and testing with automated vehicles. The three countries Norway, Finland and Sweden signed the EU joint statement on connected and automated mobility which includes a commitment to cross-border testing in Finland, Norway and Sweden.

Mobility as a Service

Mobility as a Service (MaaS) refers to a novel concept which aims to provide a valid and service-based alternative to private car ownership by combining different transport modes, both public and private. The MaaS concept has gained international recognition, with pilots and related R&I activities underway in Scotland, the Netherlands, Austria, Australia and Singapore. Several R&I projects in this field have received funding and international networks are created as useful channels for knowledge dissemination and networking.

Sweden was arguably the birthplace of the MaaS concept via two R&I projects that were conducted between 2011-2014. The first, entitled 'The Flexible Traveller', investigated business opportunities associated with MaaS (Boethius and Arby, 2011). The second project was a *VINNOVA*-funded action-research project in Gothenburg entitled Go:Smart, which comprised a field-operational test (pilot) of a mobility service that combined public transport, car- and bicycle-sharing services, car rentals and taxis in 2012-14. However, barriers to collaboration among partners have hindered the commercialisation of MaaS services. Recently new projects are coming up. Finland has run a set of tests and interest has spread to other Nordic countries. In Denmark, pilots are currently underway via the EC2B project, run by the Swedish consultancy *Trivector*. EC2B links Malmö and Copenhagen. In Norway, the public transport operator *Ruter* has recently started to discuss the MaaS developments in Oslo.

Knowledge development and diffusion

In Finland, a series of pilots were established in 2015 to trial the MaaS concept and create market opportunities. Sweden has recently established a R&I initiative entitled KOMPIS to supply funds for pilots and trials of MaaS services. In Denmark, a pilot entitled EC2B aims to trial MaaS in the *Öresund* region that links Malmö and Copenhagen. In Norway, discussions are underway regarding a MaaS pilot in Oslo. Despite the high level of interest in MaaS, several barriers remain to be resolved by R&I activities. One significant barrier is the set of perceived risks associated with collaboration in new networks and ecosystems. Another barrier relates to the lack of a validated business case for MaaS, and the concurrent development and validation of business models. There is also a lack of knowledge related to the sustainability impacts of MaaS, which is important can generate legitimacy for the concept among policymakers and government agencies. A further barrier relates to user perspectives, to motives for adoption, willingness to pay, and behavioural aspects of MaaS.

Influence on the direction of search

Two distinguishable sets of factors drive innovation in the MaaS field. The first is linked to sustainability, and is rooted in a set of generic, transport-related problems such as climate change, oil dependency, air pollution, traffic congestion, traffic safety, and the underutilisation of passenger and goods vehicles. Against this backdrop, mobility services are increasingly seen as a remedy to a more sustainable transport system, and are linked to better urban management; improvements in energy efficiency and urban air quality; greater use of renewable fuels; reduced congestion and improved accessibility.

The second set of factors related to different megatrends that are driving a set of radical innovations in the transport sector. The most important megatrends are *Urbanisation* related to congestion and land use; the *sharing economy* which is challenging dominant logics within the field of transport and *digitalisation*, which has emerged following technological developments in the fields of embedded systems, wireless networking and automation, and is currently unfolding in the drive towards connected and autonomous vehicles. Taken together, these pressures for change influence the entire transport system, and the emergence of MaaS is natural consequence of such pressures.

In Sweden, public transport authorities and operators have linked MaaS developments to the so-called “doubling goal”, which aims to double market share of public transport passengers. MaaS developments in Finland are supported by a stronger set of incentives than in Sweden, including the strong need for innovation given the consequences of the economic downturn and the decline of Nokia. In Denmark and Norway not much has happened regarding MaaS.

Entrepreneurial experimentation

Sweden and Finland are currently hosting a range of pilots and trials of MaaS services. In Sweden, the success of the Go:Smart project (Gothenburg) resulted in a start-up (UbiGo, later UbiGo Innovation) and also created interest for the MaaS concept within the public sector. Following the project, the public transport operator in Gotenburg (*Västtrafik*) has experimented with different means of procuring MaaS services, and other public transport authorities and operators have become interested in MaaS. Swedish public sector interest in MaaS is also channelled via the Smart Mobility Programme. In Finland, several start-ups have emerged following the MaaS Joint Programme. The most notable include MaaS

Global, Tuup, Sito and Ylläs Around. MaaS Global is the most renowned Finnish start-up, having established partnerships in Helsinki and in foreign locations such as the UK, the Netherlands and Singapore.

1 Introduction

Decarbonising the transport system is a major challenge in many countries, including the Nordic countries. Transport is the only major EU sector where emissions today are well above their 1990 levels. While greenhouse gas emissions from non-transport sectors fell 15% between 1990 and 2007, transport emissions increased by 33% over the same period. More than two thirds of transport-related greenhouse gas emissions are from road transport, which contributes to about 20% of the EU's total emissions of CO^2 (European Commission, 2016b). The Nordic countries are also dominated by carbon-intensive means of transport and transport currently accounts for around 40% of CO^2 emissions from Nordic countries.

Several measures and initiatives to decarbonise transport have been introduced in Europe and in the Nordic countries. This report focuses on road transport and particularly on new vehicle and fuel technologies but it also deals with other transport innovations which can contribute to a shift to cleaner modes of transport, such as mobility as a service (MaaS) and autonomies vehicles (AV). The analysis considers how policy has mobilised key resources for low-carbon transport innovations in the Nordic region and how the different technologies and fuels have developed.

A Technological innovation System-approach (TIS) is applied in the analysis. The first part of the report presents the theoretical background and analytical framework used in an innovation system approach. It outlines definitions of innovation systems and examines the structure and functions of such a system, and discusses the dynamics of the system. Finally, it describes the interactions between vehicle and fuel technologies in an innovation system perspective.

The next part which make up the main part of the report, presents and examines the different technologies and fuels for decarbonising road transport by using the TIS-approach, and focusing particularly on functions in innovation systems. Six different vehicle and fuel technologies/services are examined but not all functions are analysed for each technology, just the ones regarded to be most important. For some of the most developed technologies, such as electric vehicles and biofuels, all functions are examined. For less developed transport innovations, such as mobility as a service (MaaS) and autonomous cars, only some functions are examined. The function market formation, for instance, is less relevant for these technologies and services. The development of both combined mobility services and autonomous driving are primarily characterised by testing and experimenting, i.e. entrepreneurial activities, and not market formation.

The TIS-analysis follows a common structure; it first gives a short description of the global development for the technology or innovation, then follows an overview of the development in the Nordic countries, and finally, the analysis of the different functions for each technology or service is presented.

The report mainly focuses on the development in Norway and Sweden, Denmark and Finland are mentioned more occasionally. Sweden differs from the other Nordic countries as the only country which currently hosts vehicle manufacturers, with Volvo Cars and National Electric Vehicle Sweden (NEVS) focusing on cars; and Volvo and Scania focusing on different types of heavy vehicles (buses, trucks, construction equipment, etc.). The presence of these actors differentiates Sweden from the other Nordic countries, which do not host vehicle manufacturers of a similar size and global relevance. In fact, the four Nordic countries that form the basis of this study have each progressed along different technological trajectories and they vary by policy regulation and industrial profile, i.e.by factors which may influence their transport policy and innovations.

2 Theoretical background and analytical framework

This paper applies an innovation system approach. The concept innovation system was developed by Freeman (1987, 1995), Lundvall (1992) and Nelson (1993). It points out that the flow of knowledge, information and technology among actors (firms and organisations) is decisive for an innovation process. The systemic nature of innovation processes refers to the fact that organisations normally innovate through collaboration and interdependence with other organisations (Fagerberg 2005). These interactive micro-level processes appear as innovation on a macro level and, they are governed by both market and non-market forces (Soete et al 2009). The innovative behaviour of firms and organisations, therefore, is shaped by institutions (Edquist 2005, Lundvall 2005, 2007).

In his definition of an innovation system, Edquist (2005) underlines the following three aspects[1].

- Constituents: A system consists of *components* (organisations and institutions) and the relations (formal and informal) among them. The components and relations should form a coherent whole
- The system has a *function*, it should achieve something
- The system should have defined *boundaries* and be possible to separate from the rest of the world

Concerning the main constituents, Edquist (op. cit.:188) defines organisations as "formal structures that are consciously created and have an explicit purpose". Organisations are actors such as firms, universities and research institutions and public agencies. Institutions are defined as "sets of commons habits, norms, routines, established practices, rules or law that regulate the relations and interactions between individuals, groups, and organisation" (rules of the game).

In his definition of a national innovation system (NIS), Lundvall (1992) points out three building blocks of innovation systems:

- *Sources* of innovation – learning and search and exploration
- The *nature* of innovation – incremental and radical innovation
- Non-market *institutions* – user-producer interaction and institutions

Although a common definition of an innovation system is lacking, IS are generally understood to include "all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations" (Edquist, 1997). The main function of an innovation system is to pursue innovation processes, i.e. to "generate, diffuse and utilise technology" (Carlsson et al 2002, Lundvall 1992). Innovation processes requires different types of capabilities – selective/strategic capabilities (effectiveness), organisational (integrative or coordinating) capabilities, functional capability (efficiency) and learning/adaptive capability (Carlsson et al 2002). A

[1] Carlsson et al. (2002) proposes a similar definition as Edquist by focusing on components as operating parts of the system (actors), relationships and attributes (properties of components and relationships).

dynamic innovation system should be able both to generate change and to respond on changes in the environment.

One way to study innovation processes in a dynamic perspective, is to focus on what "happens" in the system, i.e. focus on essential activities or functions within the system (Edquist 2008). Key activities in innovation systems are *knowledge input* (R&D, competence building), *demand side activities* (formation of new product markets, quality requirements), *provision of constituents* of SI (entrepreneurship, networking, institutions) and *support services* for innovating firms (incubation, financing and consultancy services) (Edquist 2008: 10).

IS approaches are commonly divided into four fields: national, regional, sectoral and technological innovation systems. The first two approaches (national and regional IS) are not particularly relevant for the transport sector, as they tend to focus on all innovative activities within a particular region or national setting. Sectoral (SIS) and technological innovation systems (TIS) appear to be better suited to this task. However, a SIS-approach is much broader than a TIS-approach. Whereas the first one focuses on overall key economic sectors, the second one focuses mainly on activities of different actor groups related to specific technologies, for instance fuel technologies. A major shortcoming of the sectoral IS approach is also that it focuses exclusively on the supply side of innovations and neglects other key aspects (e.g. user-driven innovation, adoption and diffusion) (Geels, 2004). The application of SIS to the road transport sector would necessitate the inclusion of a global scale in order to capture key developments linked to new automobile technologies. Whilst such as study would likely elucidate useful insights, the technological IS approach is arguably a more robust means to examine both supply-side and demand-side dynamics.

2.1 Technological Innovation Systems (TIS)

The Technological innovation system (TIS) concept is developed to explain the nature and rate of technological change. TIS can be defined as a:

"...networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse and utilize technology. Technological systems are defined in terms of knowledge or competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks" (Carlsson and Stankiewicz, 1991, p. 111).

The TIS-approach may be applied to at least three levels of analysis: i) to a technology in the sense of a knowledge field (Carlsson et al. 2002), ii) to a product or an artefact; or iii) to a set of related products and artefacts aimed at satisfying a particular [societal] function. With respect to the latter, the approach has especially proven itself in explaining why and how sustainable (energy) technologies have developed and diffused into a society, or have failed to do so. The TIS definition, focusing on actors, networks and institutions has been expanded by Wieczorek and Hekkert (2012). They propose four types of system elements: actors, institutions, interactions and infrastructures. The main difference from the "Carlsson-approach" is that i) the system element networks are regarded as a type of actor, alongside individual actors; ii) interactions between actors are included as a system element, highlighting relationships; and iii) infrastructure is included as a system element. Institutions are similar in both approaches.

i) Actors:

For analysing TIS we delineate categories of actors (individuals, organizations and networks) based on their role in the economic activity: civil society, government, non-governmental organisations (NGOs), companies (start-ups, small and medium-sized enterprises (SMEs), multinationals, large firms), knowledge institutes (universities, technology institutes, research centres, schools), and other parties (legal organisations, financial organisations/banks, intermediaries, knowledge brokers, consultants). These different actors can all fulfil different roles (Wieczorek and Hekkert 2012).

ii) Interactions:

Since interaction is dynamic, it is difficult to consider it as a structural element (Wieczorek and Hekkert 2012). A 'network' has been used in some literature positions (Johansson and Johnson 2000) to describe the cooperative relationships and links between actors but a 'network' can also be a higher form of actors' organisation. However, interactions are not restricted to occurring within networks. In the early stages of the development of a system there are no networks, but bilateral interactions between actors can be traced. The focus here is on relationships and they can be analysed at the level of networks and of individual contacts (Wieczorek and Hekkert 2012).

iii) Institutions:

Institutions encompass a set of common habits, routines and shared concepts used by humans in repetitive situations (soft institutions) organised by rules, norms and strategies (hard institutions) (Crawford and Ostrom 1995). Institutional set-ups and capacities are determined by their spatial, socio-cultural and historical specificity (Lipsey et al. 2005) and are different from organizations (such as firms, universities, state bodies etc.) (Edquist 1997). Organisations of various kinds are considered in this paper as a type of actor (Wieczorek and Hekkert 2012).

iv) Infrastructures:

Infrastructure does not have a steady position as a structural element of innovation systems and there is no conclusive agreement in the key literature positions as to what the term infrastructure covers (Wieczorek and Hekkert 2012). This paper proposes to consider three categories of infrastructure as structural components of the innovation systems.

- The physical infrastructure encompasses: artefacts, instruments, machines, roads, buildings, telecom networks, bridges and harbours.
- The knowledge infrastructure includes: knowledge, expertise, know-how and strategic information.
- The financial infrastructure includes: subsidies, financial programs, grants etc.

2.1.1 Functions in innovation systems

Generally, IS approaches are intended as a means to examine the determinants of innovation (Edquist, 2004), whereby the overarching aim of an innovation system is the development, diffusion and use of innovations (Edquist, 2005). As a means to examine such determinants, the TIS framework can be applied via the examination of a set of key activities, or 'functions' that are key to the development and diffusion of a given technology (Bergek et al., 2008a; Hekkert et al., 2007; see also Chaminade and Edquist, 2006), see table 2.1.

Table 2.1: Key 'functions' or activities within innovation systems.

Technological IS (Hekkert et al., 2007)	**Technological IS (Bergek et al., 2008a)**	**National IS (Chaminade and Edquist, 2006)**
Knowledge development Knowledge diffusion through networks	Knowledge development and diffusion	Provision of R&D Competence building
Guidance of the search	Influence on the direction of search	Articulation of quality requirements from the demand side
Entrepreneurial activities	Entrepreneurial experimentation	Creating and changing organisations
Market formation	Market formation	Formation of new product markets
Creation of legitimacy/counteract resistance to change	Legitimation	Networking and interactive learning Creation/change of institutions
Resources mobilisation	Resource mobilisation	Incubating activities Financing of innovation processes Provision of consultancy services
	Development of positive externalities	

Each of the three works cited in table 2.1 note the importance of activities linked to the *development and diffusion of knowledge*. This is linked to the notion of the knowledge-based economy (Leydesdorff, 2006) and, with regard to TIS, examines how local actors perform in relation to the global knowledge base associated with a particular technological field (Bergek et al., 2008a). It encompasses "different types of knowledge (e.g. scientific, technological, production, market, logistics and design knowledge)" (Bergek et al., 2008a), realised via activities that facilitate learning-by-doing, by-interacting, by-using and by-searching (Hekkert et al., 2007). R&D activities are typically carried out by private firms, within universities and other public research organisations (Chaminade and Edquist, 2006). These activities can be measured via indicators such as R&D investments and projects, patent and bibliometric analyses, analyses of learning curves, and R&D network analysis (Bergek et al., 2008a; Hekkert et al., 2007). Education and training activities that can deliver technical competence (human capital) are also included here (Chaminade and Edquist, 2006).

Another key 'function' refers to the presence of *factors that influence search heuristics* among TIS constituents. Such factors include: visions, expectations and success stories regarding technologies and their potential; landscape pressures; regulations and policies; market demands; and crises in business (Bergek et al. 2008; Hekkert et al. 2007). These factors serve to prioritise certain R&D activities over others (e.g. climate change as a historical driver of R&D in renewable energy technologies), as a selection mechanism (e.g. renewable energy policies and targets) and as a means to mobilize resources (Budde et al., 2015). The establishment of technical standards and the articulation of product criteria via public procurement activities is another means to influence search heuristics among innovating firms (Chaminade and Edquist, 2006).

Innovation system research place emphasis on *entrepreneurial activities*, which refers to tests and experimentation with new technology as a means to transform "the potential of new knowledge, networks, and markets into concrete actions to generate – and take advantage of – new business opportunities (Hekkert et al., 2007). Entrepreneurs may be new market entrants, or existing firms that seek to diversify their portfolios by appropriating and combining new technologies (Bergek et al., 2008a; Chaminade and Edquist, 2006; Hekkert et al., 2007). Entrepreneurial experimentation is a key learning process within TIS and serves to demonstrate the potential of new technology to a range of different stakeholders

(Hekkert et al., 2007). New entrants are also a means to introduce new capabilities, ideas, products and processes in an innovation system (Chaminade and Edquist, 2006).

Market formation is process where new markets evolve in conjunction with new, innovative products or technologies. The process consists of three phases (Bergek et al. 2008). At an early stage, a technology may be present within a limited 'nursing' or niche market that provides the opportunity for learning (see also Hekkert et al. 2007; Kemp et al. 1998). If a given technology proves to be a success, niche markets give way to 'bridging' markets, where new entrants and volumes increase (Bergek et al. 2008). The final phase occurs after several decades when a mass market emerges surrounding a given technology and its derivatives (Bergek et al. 2008). Again, public procurement can play an important role by creating demands for newly developed technological innovations (Chaminade and Edquist, 2006).

In order for new technologies to develop and diffuse, they must undergo a process of *legitimation*. Here TIS scholars place particular emphasis on social and stakeholder acceptance for a new technology, and compliance with institutions (Bergek et al. 2008; Hekkert et al. 2007). The latter include "IPR laws, technical standards, tax laws, environment and safety regulations, R&D investment routines, firm-specific rules and norms" that must in some cases be modified to accommodate new technological innovations (Chaminade and Edquist, 2006). Hence legitimation is a process whereby actors lobby for a new technology via, for instance, advocacy coalitions and interest groups as a means to establish a new techno-institutional regime (Hekkert et al. 2007). One other key element of the legitimation process is interactive learning, whereby new innovative networks serve to create interdependencies among and between innovators, the value chain and research organisations (Chaminade and Edquist, 2006). Incubators, science and technology parks and technology transfer offices are important facilitators of network creation. Interdependencies are also created via the co-location of firms, the emergence of pooled labour markets, the emergence of specialised suppliers, and the emergence of knowledge spillovers (Bergek et al. 2008).

Resource mobilisation highlights the different types of resources that must be mobilised for technological innovations to develop and diffuse. These include competence and human capital, financial capital, complementary assets and, in some cases, physical infrastructures (Bergek et al. 2008; Hekkert et al. 2007). Resources must be mobilised as a means to support other systemic 'functions' at different phases in the innovation cycle (e.g. R&D funding as a means to support knowledge development and diffusion) (Hekkert et al. 2007).

Development of positive externalities refers to outcomes of investments or activities that cannot be fully appropriated by the investor, i.e. generation of positive external economies, such as pooled labour, knowledge spillovers, specialised intermediate goods, and complementary products, services and infrastructure. Indicators are related to search for external economies as resolution of uncertainties, political power, combinatorial opportunities, pooled labour markets, etc.

In sum, technological IS represents an analytical framework for examining a fairly rigorous set of interlinking 'functions' that is thought to be key to the development and diffusion of a new technology (Bergek et al. 2008; Hekkert et al. 2007). These interlinkages have been described via the metaphor 'cumulative causation' (Jacobsson and Bergek, 2004). An overview of functions, definitions and indicators that can be used for assessing the TIS functions is presented in table 2.2:

Table 2.2: Overview of functions in innovation systems, definitions and indicators.

Function	Definition	Indicators to track the functions
Entrepreneurial activities (F1)	Presence of active entrepreneurs as a prime indication of the performance of an innovation system, activities to appropriate basic knowledge, to generate and realize business opportunities	Mapping the number of new entrants, number of diversification activities of incumbent actors, the number of experiments with the new technology
Knowledge development (F2)	Activities that lead to creation of knowledge through processes of learning e.g. learning by searching, learning by doing	Number of R&D projects, R&D investments or patents in a specific field
Knowl. diffusion through networks (F3)	Activities that lead to exchange of information but also learning by interacting and learning by using in networks	Number of workshops and conferences, network size and intensity
Guidance of the search (F4)	Refers to activities that positively affect the visibility of wants of actors (users) and that may have an influence on further investments in the technology	Targets set by governments or industries, number of press papers that raise expectations
Market formation (F5)	Involves activities that contribute to the creation of a demand or the provision of protected space for the new technology	Number of niche markets, specific tax regimes, environmental standards
Resource mobilization (F6)	Activities that are related to the allocation of basic inputs such as financial, material or human capital for all other developments in TIS	Detecting by interviews, whether or not inner-core actors perceive resource access as problematic
Creation of legitimacy (F7)	Activities that counteract resistance to change or contribute to taking a new technology for granted	Rise and growth of interest groups and their lobby actions
Development of positive externalities (F8)	Outcomes of investments or of activities that cannot be fully appropriated by the investor, free utilities that increase with number of entrants, emerge through firm co-location in TIS	Search for external economies as resolution of uncertainties, political power, combinatorial opportunities, pooled labour markets, etc.

(Source: Adapted from Bergek et al. 2008a; Hekkert et al. 2007).

2.1.2 The dynamics of a TIS - problems and instruments

Having explained the structural elements and functions of a TIS, as well as some of their interrelationships, the complete dynamics of a TIS can now be summarised by five main relationships (see figure 2.1): (1) the dynamics between structural entities; (2) the internal dynamics of the functions; (3) the influence of the structural entities on the functions; (4); the feedback from the functions to the structure and (5) the influence of exogenous factors on the functions. The mutual dynamic interaction between structural elements (1) and functions (2) as represented by the loop constituted by relationships (3) and (4) is captured through a coupled functional-structural analysis.

If the dynamics of a systems does not work well, it can be due to problems with either the system elements or the system functions (Carlsson et al 2002, Wieczorek and Hekkert 2012). System elements can be either missing or they may lack capabilities or capacity to fulfil their functions. The development of a new technology can be slow or fail to appears because important actors are absent or because lack of competence or, because specific institutions are not in place or not able to support the new technology. It can also be due to interaction problems, such as cognitive distance between actors, lack of trust and lack of interactive learning in the innovation system. Finally, infrastructural problems may hamper the development of a new technology because necessary resources (physical, knowledge, financial) are not sufficiently provided. To sum up; systemic problems can be defined as factors that negatively influence the direction and speed of innovation processes and hinder the development and functioning of innovation systems.

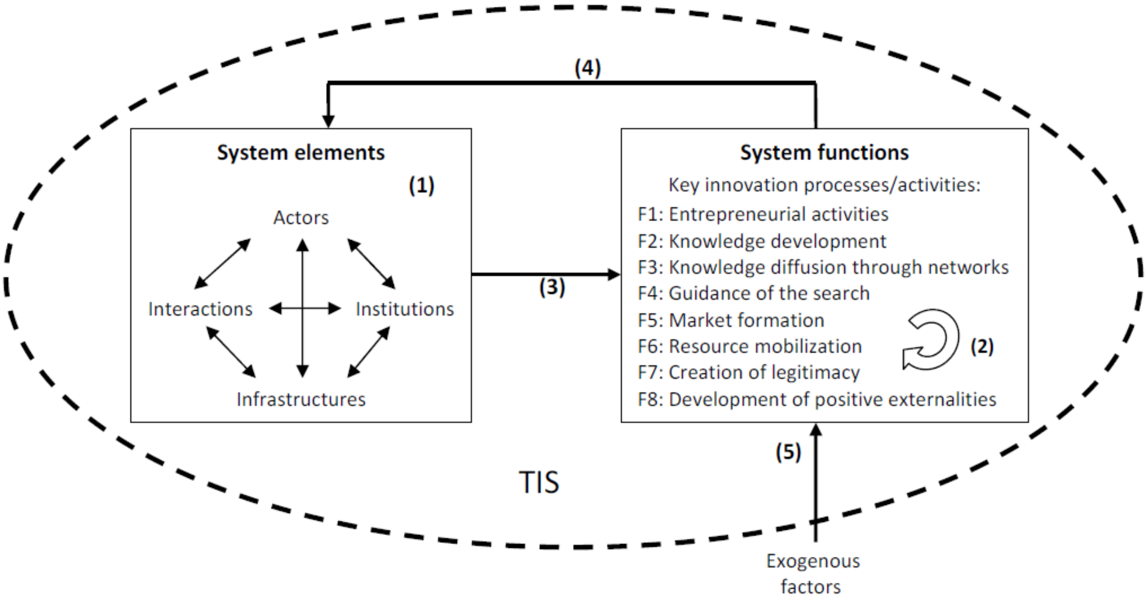

Figure 2.1: A schematic representation of the dynamics of technological innovation systems.

Source: Hellsmark (2010)

The identification of systemic problems will be helpful for politicians to formulate strategies and to use tools to remedy malfunctions in innovation systems. Wieczorek and Hekkert (2012) suggest to use the following systemic instruments for solving systemic problems in an innovation system, see table 2.3.

Table 2.3: Goals of systemic instruments per (type of) systemic problem.

Systemic problems	(Types of) systemic problems	Goal of systemic instruments
Actors problem	Presence?	Stimulate and organise the participation of relevant actors (1)
	Capabilities?	Create space for actor's capability development (2)
Interactions problem	Presence?	Stimulate occurrence of interactions (3)
	Intensity/quality?	Prevent too strong and too weak ties (4)
Institutional problem	Presence?	Secure presence of hard and soft institutions (5)
	Capacity/quality?	Prevent too weak and too stringent institutions (6)
Infrastructural problem	Presence?	Stimulate physical, financial and knowledge infrastructure (7)
	Capacity/quality?	Ensure adequate quality of infrastructure (8)

Source: Wieczorek and Hekkert (2012)

2.2 Interactions between technologies

The terms 'development of positive externalities', or 'spillovers', have been used to describe different types of positive interactions between technological systems. Spillovers are linked to the 'relatedness' of technological systems, that is, the extent to which they "share structural elements: actors and networks, technology or institutions" (Bergek et al., 2008b: 585). Spillovers are facilitated by, among other things, the entry of new types of firms into a given technological field with the effect that some of the functions listed above are strengthened (Bergek et al., 2008a). The entry of new firms can, for example, influence other actors' search functions, support market creation, improve technological legitimacy, and support the creation of pooled labour markets (Bergek et al., 2008a). Another type of spillovers is linked to the way in which different technological systems interact. The classification of solar photovoltaics and biofuels as renewable technologies, for instance, can boost their legitimacy in that they are both seen as constituents of a low-carbon energy future, despite the fact that they share little in common from a technical perspective (Bergek et al., 2008b). This type of spillovers can be useful for the advocacy of favourable policies by coalitions of like-minded actors.

Bergek et al. (2015) further explore different interactions between structural factors and technologies, noting that synergies *and* conflicts can arise between technological systems. They note, for instance, that photovoltaic cells enjoy synergistic interactions with battery technologies, but conflict with wind turbines. Value chain configurations are one source of interactions between technological systems, particularly when different technologies make up complex products. This can be problematic when upstream actors control critical resources or inputs. When these types of interactions, or 'structural couplings' occur, downstream actors may seek to collaborate along the value chain via joint ventures or strategic alliances in a manner that supports some of the TIS functions outlined above. Furthermore, technological systems can compete for inputs and resources (e.g. land for energy crops/food) and for institutional resources (e.g. financial resources distributed via government policies).

Sandén and Hillman (2011) elaborate on the different types of interactions that can arise between technological systems. By depicting technology as "bundles of value chains and…socio-technical systems extending in material, organisational and conceptual dimensions" (408), the authors reiterate the notion that interaction issues from value chain configurations. They outline six types of interaction between technologies, shown in table 2.4.

Table 2 .4: Interactions between two technologies (Sandén and Hillman, 2011).

Mode of interaction	Technology 1	Technology 2	Nature of interaction
Competition	–	–	Common resource or market is in short supply
Symbiosis	+	+	Interaction favourable to both
Neutralism	0	0	Neither technology affects the other
Parasitism	–	+	Technology 2 is benefited and 1 is inhibited
Commensalism	0	+	Technology 2 is benefited and 1 not affected
Amensalism	0	–	Technology 2 is inhibited and 1 not affected

Competition refers to the way technologies compete in markets and for resources. *Symbiosis* occurs between technologies that occupy different positions in the same value chain or between products that complement one another. *Neutralism* refers to technologies that do not influence one another, either because they utilise different resources and provide different services, or because they utilise commonly available resources. *Parasitism* occurs when a new technology benefits from the existence of an older technology, at the expense of that older technology. *Commensalism* occurs when non-exclusive resources associated by one technology can benefit another technology (e.g. non-patented knowledge). *Amensalism* occurs when a new technology is locked out via the existence of an older technology.

3 Innovations for decarbonising vehicle transport

This section examines developments in technologies and fuels including electric vehicles, electric road systems, biofuels, hydrogen and autonomous vehicles in each of the Nordic countries, highlighting strengths and weaknesses in each of the technological systems set up around these. These are all examples of innovations in vehicle and fuel technologies where a TIS-analysis should be appropriate. In addition to these technological innovations, the TIS framework is also applied on the development of Mobility as a service (MaaS). Although MaaS primarily is an example of organisational innovation, the study of functions using a TIS framework is also relevant here.

3.1 Vehicle electrification

Ambitious climate and environmental goals both internationally, nationally and locally make new technology and transition to fossil-free energy sources important for reducing emissions from motor-vehicle traffic. Greenhouse Gases (GHG) emission and local pollution are two to three times lower from electric vehicles than from vehicles driven by internal combustion engines. Vehicle electrification thus represents an important option for reaching global and national climate goals. In addition, it is much cheaper to use due to its higher energy efficiency. (Figenbaum and Kolbenstvedt 2015b).

It is also worth noticing that production of electric power is a part of the Emission Trading System (ETS) in EU. When an ICE vehicle is substituted by an all-electric vehicle the emissions will be included in the ETS system. Increased use of electric power for transport must then be compensated by reduced use in other sectors included in ETS (Fridstrøm and Alfsen 2014).

There are several types of EVs. To understand their effect one must differ between full electric vehicles and others using electric propulsion to different degrees. In the research literature at hand it is often not distinguished between these types, and the EV-concept is not precisely defined. Concrete figures for EVs which not define the type referred to, must thus be read with caution. Another challenge when reporting the status of vehicle electrification is that the technology's character as well as the diffusion process change so quickly that data often can be too old to illuminate the current situation.

Vehicle electrification also refers to the provision of electric vehicle charging infrastructure, in domestic or public locations, or as part of the road infrastructure.

The final report from the COMPETT project (Figenbaum and Kolbenstvedt 2015b) describe the different types like this:

- *Full electric battery vehic*le (BEVs) come in mini, small, compact and large vehicle sizes. BEVs are propelled exclusively by rechargeable batteries. Batteries can be charged by connecting vehicles to the electric grid whith stationary (at domestic or public charging points), or via electrified roads whilst in motion. The electricity is stored in the on-board batteries providing energy to the electric motor, which powers the wheels while driving. The regenerative braking system allows for one pedal driving, i.e. the vehicle brakes by running the motor as a generator when the foot is lifted off the accelerator pedal.

- *Plug in Hybrid Electric Vehicles (PHEVs)* have both an electric motor and one internal combustion engine. They can operate in a purely electric mode utilizing electricity recharged into the vehicles battery from grid power. They also have an extended range mode using the ICE fuelled by gasoline or diesel. Thus, owners will not experience range challenges. These vehicles generally come in the larger vehicle classes as the technical installation requires much space. The purely electric driving range is normally within 30-80 km to allow for most daily transport to be done in this mode. These vehicles can also operate as regular hybrid vehicles (HEVs) without recharging electricity from the grid.
- *Fuel cell electric vehicles (FCEV)* have an on-board fuel cell that produces electricity from hydrogen stored in the vehicle's hydrogen tank. It operates much like a battery electric vehicle. The difference is that rather than recharging the vehicle with electricity it is filled up with hydrogen at a filling station. The range between hydrogen fillings can be comparable to ICE vehicles. It only takes a few minutes to fill. Hydrogen can be produced from fossil and non-fossil energy sources, including electricity. The latter will however be less energy efficient than using the electricity in a BEV due to energy conversion losses.

A *Hybrid vehicles* (HEV) has two engines and is mainly driven by it's internal combustion engine (ICE). The ICE also generate power to a small battery for electric propulsion, Hybrid vehicles are classified as series, series-parallel, parallel and complex hybrids according to the configuration of the drivetrain.

Incentives for electrification or increased diffusion of green/environmental vehicles mostly concern BEVs and FCEVs and sometimes also PHEVs.

Main technological barriers related to vehicle electrification are related to on-board energy storage, battery production and charging infrastructure. In addition there are barriers related to market price, energy sources and scarce materials for battery production. Although lithium-ion batteries are currently the most popular choice, R&D has also been performed on lead-acid, nickel-iron, and zinc-air batteries at different stages in the past. At present, solid-state batteries, ultracapacitors and flywheels are at the experimental stage.

The BEV technology is under constant and rapid development. BEVs range has increased from 80 km in the 1990s to 160 km by 2010, to over 500 km for some models after 2013. Slow charging from domestic plugs was standard up to 2010, although some French BEVs produced in the period 1998-2003 could be fast charged at 20 kW power. Today 50 kW fast charging capability is standard on most BEVs, while Tesla BEVs can charge at 120 kW. From 2017 fast charging can be done in 6-9 minutes. (Figenbaum 2018).

3.1.1 Global developments in vehicle electrification

In the early 20th century, EVs were popular because of the ease of operation. Range limitations and the invention of the electric starter for internal combustion engine vehicles (ICE)made EV disappear. Progress in Li-Ion battery technology and increased environmental policy pressure led to the rebirth of EVs (Figenbaum and Kolbenstvedt 2015 a, Figenbaum 2017)).

The current interest in BEVs can be traced back to the late 1980s/early 1990s and was initially driven by new regulation, mainly in the US and partly in Europe. The Zero Emission Vehicle mandate was established by the California Air Resources Board in 1990, stating the 2% of new vehicles should be emission-free by 1998 (Kemp, 2005). This legislation coincided with the launch of the now infamous EV1 model from General Motors. In Europe, early BEV initiatives consisted of artisan projects within engineering schools, where Swiss, German and Danish engineers' exploits motivated politicians to promote the commercialization of EV technology via funding for RD&D and incentives for market deployment (Dijk and Orsato, 2013). During this period, a Norwegian start-up called *Think* also started to experiment with BEVs, and the French energy company EDF ordered 2000 BEVs (Hoogma et al., 2002). Similar experiments in the Swiss town of Mendriso succeeded in launching around 400 BEVs, supported by substantial subsidies, whose eventual cessation resulted in declining BEV interest (Dijk and Orsato, 2013).

Following this early interest in BEVs, attention shifted towards the development of FCV prototypes in the mid-1990s to mid-2000s, before receding again before 2010 (Geels, 2012; Romm, 2004). Since then numerous automakers have commercialized HEVs following the success of Toyota with the Prius and other hybrid models (Dijk and Orsato, 2013; Geels, 2012; Dijk and Yarime, 2010). During these cycles, the automotive sector has maintained its traditional focus on the internal combustion engine. This is reflected in the patents awarded to automakers between 1990-2005, of which 80% focused on ICE and only 20% on BEV/HEV technology (Oltra and Saint Jean, 2009). Toyota and also Honda are exceptions, having taken a global lead in hybrid R&D as reflected by patenting activities (Magnusson, 2011). More recently, the efforts of Tesla and other new market entrants, notably in China, has initiated a more serious yet gradual shift towards EVs among incumbent automakers. It even has been argued that new entrants like Tesla wait for an incumbent to finally hit the market with a so-called "Tesla killer" (meaning an EV that is competitive to Tesla's EVs) which would greatly increase acceptance for EVs – in the hopes to create a spill-over effect from incumbents to new entrants.

Globally, sales of EVs have undergone exponential growth since 2010, with over 1,2m EVs in the current vehicle stock, i.e. around 1% (IEA, 2016). In absolute terms, China has the largest market for EVs, and in relative terms, Norway has the highest proportion at 23% (IEA, 2016). The growth of EV market shares closely correlates to the level of public subsidy and the availability of recharging infrastructure (Li et al., 2015; Sierzchula et al., 2014). The further deployment of BEVs hinges largely on battery costs energy density, where there are encouraging signs – battery costs underwent a 73% decline in seven years and some automakers project costs below 100 USD/kWh by 2020 (IEA, 2016).

In the future, many foresee interactions between vehicle electrification and the energy system, where the commensurate roll-out of smart grids and renewable technologies will link with batteries that are used to balance intermittent energy sources (Dijk and Orsato, 2013; Spickermann et al., 2014). Further, EVs may be deployed by fleet operators, organised car sharing and intermodal mobility services, due to their low operating costs (Dijk and Orsato, 2013; Sarasini et al., 2016a, 2016b; Spickermann et al., 2014). The widespread deployment of EVs requires investments in infrastructures, such as battery swapping, recharging points, electrified roads and, depending on the technical configuration, hydrogen production/distribution. Battery swapping was pioneered by Better Place (see Budde Christensen et al., 2012), despite high expectations, the company reported bankruptcy in 2013. Several governments and private companies (notably Tesla) have invested in an infrastructure of recharging points for BEVs and HEVs (Dijk and Orsato, 2013). Countries such as Germany, Korea, the UK and Sweden have performed experiments and pilots for electrified road technology and are actively taking steps to commercialize the technology, see chapter 3.2 Hydrogen refuelling infrastructure is not yet at the same stage of development, though estimates suggest that the required investments are affordable, in the range of €200-300m for Europe (Köhler et al., 2010).

3.1.2 Developments in The Nordics

Since vehicle electrification concerns changes in vehicle technologies, Nordic countries cannot be compared with the same TIS functions. Sweden is the only country to host vehicle manufacturers, making functions F1-F6 relevant to base assessments. For the other countries functions F5 (market formation) and F7 (legitimation) can be especially relevant.

The diffusion of battery electric vehicles (BEV) in the Nordics in the past decade and has especially taken off in Norwaywhich is the leading BEV market in the world (Figenbaum and Kolbenstvedt 2015b and 2016, Figenbaum 2017 and 2018). There is a similar trend for chargeable hybrid vehicles (PHEVs) which also exhibit an exponential growth the past years. This is largely due to incentives created via public policies (F5), which offer a level of support that is not equalled in other Nordic countries, see table 3.1.

Table 3.1: Advantages of BEV incentives in Norway 2017 and future plans. (Figenbaum 2018).

Incentives	Introduction year	BEV buyers - relative advantage	Future plans (NTP 2017a, 2017b, Stortinget 2017, Lovdata 2018)
Fiscal incentives: Reduction of purchase price/yearly cost gives competitive prices			
Exemption from registration tax	1990/1996	The tax is based on ICEV emissions and weight. Example taxes: VW Up 3000 €. VW Golf: 6000-9000 €,	To be continued until 2020.
VAT exemption	2001	Vehicles competing with BEVs are levied a VAT of 25% on sales price minus registration tax.	To be continued until 2020.
Reduced annual vehicle license fee	1996/2004	BEVs and hydrogen vehicles 52 € (2014-figures). Diesel rate: 360-420 € with/without particulate filter.	To be continued indefinitely
Reduced company car tax	2000	The company-car tax is lower but BEVs are seldom company cars.	This incentive may be revised in 2018
Exemption from the re-registration tax	2018	A tax is levied on the change of ownership of ICEVs and PHEVs. 0-3 year old vehicles above 1200 kg: 610 Euros, 4-11 years 370 Euros. Older: 160 Euros. BEVs have an exemption.	Will be introduced from 2018
Direct subsidies to users: Reduction of variable costs and help solving range challenges			
Free toll roads	1997	In Oslo-area saved costs are 600-1 000 € per year. Some places exceed 2 500 €	Law revised so that rates for battery electric vehicles in toll roads and ferries will be decided by local governments, up to a maximum rate of 50% of the ICEV rate.
Reduced fares on ferries	2009	Similar to toll roads saving money for those using car ferries.	
Financial support for normal charging stations	2009	Reduce investors risk, reduce users range anxiety, expand usage.	A national plan for charging infrastructure shall be developed.
Financial support for fast charge stations	2011	More fast-charging stations influences BEV km driven & market shares.	ENOVA support programme to establish fast charging along major transport corridors. City fast charging is left to commercial actors.
User privileges: Reduction of time costs and providing users with relative advantages			
Access to bus lanes	2003/2005	BEV users save time driving to work in the bus lane during rush hours.	Local authorities have given the authority to introduce restrictions if BEVs delay buses.
Free parking	1999	Users get a parking space where these are scarce or expensive and save time looking for a space.	Local authorities will be given the authority to introduce rates up to 50% of the ICEV rate.
Free charging (some places)		Not regulated by national law, but often bundled wit	

EV developments in the Swedish automotive industry must be understood in a context where two of the four vehicle manufacturers changed ownership several times. In 1999, Volvo Cars was purchased by Ford, before being sold to the Chinese automaker Geely in 2010. Saab was acquired by GM in 2000, before being sold to Dutch automaker Spyker in 2010 and then filing for bankruptcy in 2011. In 2012, Chinese-owned NEVS acquired Saab assets, and has established a strategy that focuses on EVs and associated mobility services. Hence in the period during which key developments in EV technologies were taking place around the globe, Swedish car manufacturers shifted from Swedish to American to Chinese ownership.

The sale of electric vehicles dropped dramatically in Denmark from 2016 to 2017 due to the phasing out of tax breaks on EVs from 2016-2019. This new tax regime killed the market and clearly indicated that clean-energy vehicles still aren't attractive enough to compete without some form of subsidy (Bloomberg Markets). There is a lack of EV subsidies and charging stations in Denmark, the government seems to prioritise biofuel (since 2008, a national law has required fuel distributors to provide biofuels to the market) and interests between EVs and biofuels seem to conflict (Noel, L. (2017).

Finland is also lagging behind in electric car adaptation. Sweden has ten times more electric cars than Finland while Norway has over a hundred times more, thanks to the many incentives, cf. Table 3.1.

3.1.3 Knowledge development and diffusion

Knowledge development and diffusion in Sweden has relied heavily on public funds, which have served to reinforce the technology at times where there was a lack of legitimacy (Magnusson, 2011). In the 1990s, Swedish government agencies provided funding for R&D projects on EV technologies alongside public procurement activities that sought to promote the vehicle demonstrations. During this period, Swedish carmakers focused on hybrid technologies, but made little headway in scaling up production due to an immature market (Sundh, 2017). In 1992, for example, Volvo developed a hybrid concept called the Environmental Concept Car which was never commercialised. In total, government funding resulted in 279 vehicle demonstrations in major cities (Magnusson, 2011). Demonstrations of cars focused primarily on BEVs, whereas heavy vehicle demonstrations were focused on hybrid technologies, with Volvo buses the main beneficiary of government funds (Hedman et al., 2000; Rader-Olsson, 2000). Several Swedish suppliers also received funds to develop microturbine technologies that would feature in Volvo's hybrid bus concepts (Andersson and Björler, 2000). However, similar to applications within cars, these technologies were never commercialised. However, during this period, Scania developed six hybrid buses for the Stockholm public transport operator, in collaboration with Danish subsidiary DAB (Magnusson, 2011).

In the mid-1990s, following the Kyoto Protocol, Japanese automakers (primarily Toyota) took the lead in HEV technology. From the start of the 2000s, US companies Ford and GM started to reorient their patenting strategies as part of a centralised strategy that is not reflected in Volvo Cars and Saab patent records. Volvo Cars discontinued efforts to develop HEV concepts and prototypes following the Ford acquisition. In the early 2000s, most European carmakers started to prioritise fuel efficient diesel engines. Volvo Cars, like many other automakers, committed instead to FCVs (Magnusson, 2011). The Swedish state created a new funding programme for automotive research that focused on both HEVs and FCVs, with the former receiving roughly twice the level of funds. During this period, the Swedish heavy vehicle sector continued to focus on different hybrid configurations for bus and truck concepts and prototypes, with limited success in commercialisation

(Magnusson, 2011). Hence until the mid-2000s, developments in Sweden focused mainly on the development of knowledge related to BEVs, HEVs and FCVs via R&D initiatives that were funded by both the automotive industry and public funds. Aside from some niche applications of HEV technologies, the main outcome was the development of concept vehicles and prototypes.

In 2006, the Green Car R&D Programme, which operated as a collaboration between the Swedish government and the four Swedish major automakers, gave renewed impetus to RD&D on HEVs. In 2007, the Swedish Hybrid Centre (SHC) was established to focus on collaborative R&D on HEVs. During this period Swedish heavy vehicle manufacturers performed field trials of hybrid technologies in different types of trucks and buses, and in 2010 Volvo commercialised a hybrid bus, receiving 200 orders within one year (Magnusson, 2011). Swedish car manufacturers continued to develop hybrid concepts and initiated field trials, but did not succeed in commercialising HEVs (with the exception of Volvo Cars' inclusion of microturbine technology in three vehicle models in the late 2000s) (Magnusson, 2011). In the late 2000s, and early 2010s, Volvo Cars experimented with flywheel systems that could be fitted to the rear axle of some models, allowing for reductions of fuel consumption Yet despite successful tests and experiments, Volvo has not yet included the technology in its product line.

Generally, Swedish carmakers have relied heavily on knowledge developed by key suppliers such as Bosch. The Swedish heavy vehicle sector, by contrast, was more active in developing in-house knowledge, and field tests helped manufacturers develop knowledge regarding user perceptions of HEV technologies. Research related to EVs has according to Stier et al. (2018) focused technology and charging infrastructure and less on potential users needs and attitudes.

In Norway the diffusion process has been followed by yearly surveys among real users of BEVs, PHEVs. This has furnished authorities, producers and sellers with knowledge of different user's needs and preferences. The fact that diffusion is moving faster in Norway, is quite obviously related to the extent of the incentives offered for BEVs. The incentives existing in Norway for 20 -30 years, show the motor -vehicle industry that the authorities are focusing on electromobility. Thus, the incentives contribute to new BEV models arriving early in Norway, as necessary but not sufficient measures. Without a range of BEV models to choose from and an infrastructure facilitating the use of BEV, the incentives will not have a large effect (Figenbaum and Kolbenstvedt 2015a, Figenbaum 2017, Kolbenstvedt and Assum 2018).

Moreover, the diffusion process has its own dynamics, where early users affect the next-generation of users. In this process, friends, family, colleagues and social networks as well as BEV owners' organizations perform a "sales role". Nine out of ten Norwegians know someone who has a BEV. In 2018, BEV buyers have affected more friends to buy electric cars. Information from other sources than the car dealers, is particularly important in the first phase of the sales process as well as after the sales when buyers need support for the practical use of the BEVs (Kolbentvedt and Assum 2018).

3.1.4 Influence on the direction of search

As noted in the above section, Swedish manufacturers in the light and heavy vehicle sectors were fairly active in developing hybrid concept vehicles, with the exception of the period 2000-2005. The success of Japanese competitors signalled that there are significant commercial opportunities in the HEV field, particularly after 2005. In addition, soaring oil prices after the mid-2000s signalled that fuel economy gains were well motivated. In 2005, the Swedish government established regulations which stipulated that 50% of the cars procured by public authorities must be 'environmental cars'.

In the late 2000s, EU legislation was established to reduce vehicles' CO^2 emissions per kilometre. As a result, Nordic countries started to establish policy measures in the form of subsidies and tax reductions for the purchase of low-emission vehicles and fuels (Kivimaa and Virkamäki, 2014). The Nordic countries have each outlined national political goals for decarbonisation and fossil-fuel independence. The Swedish government has established the political goal of having a fossil-free vehicle fleet by 2030. The goal is technologically neutral (Börjesson et al., 2014), such that some actors have called for EV-specific goals in order to reach climate targets (Sundh, 2017). Forecasts suggest that EVs will make up 26% of new vehicle registrations in 2020 (Trafikanalys, 2017). In Norway, both the national government and municipalities have set several goals for decarbonization of the road transport system (Meld. St. 33 2016-2017, Prop. 195/16). Oslo city, for example, aims to gradually phase out fossil fuel-based vehicles by 2030 and replace these with zero-emissions vehicles based on electricity or hydrogen. Several local incentives and regulations are used to promote a transition to fossil-free transport, On the national level there is political agreement that only zero-emission vehicles should be on the market from 2025 and the state have implanted many fiscal/economic incentives in order to promote fossil-free transport, see section on market formation further information. Finland has established a national climate target of an 80% reduction by 2050, but has not specified a specific target for the transport sector, instead relying on EU legislation to dictate national policy. In Finland, two research programmes (The Electric Vehicle Systems Programme, 2011-2015) and the ongoing TransEco Programme investigate ways in which EVs can contribute to decarbonisation via new business models, services and demonstration projects (Kivimaa and Virkamäki, 2014). The Danish government has set a target for the transport sector to be wholly reliant on renewable fuels by 2050. Similar to Finland, Denmark has less ambitious climate targets, and instead tends to follow that which is decided at the EU level. However, Denmark has a more aggressive EV strategy having created a target for the deployment of 200,000 EVs by 2020 (a target also established in Norway), offering a full rebate of car registration taxes, which reflects one of the highest levels of incentives for EVs in the world (Sprei et al., 2013).

In sum, these measures create signalling effects towards the automotive industry regarding the functionalities of vehicles vis-à-vis climate emissions, also influencing market formation (see section 3.1.6).

3.1.5 Entrepreneurial experimentation

In Sweden, entrepreneurial experimentation has mainly occurred via tests and demonstrations of new vehicle configurations among the major automakers. On the heavy vehicle side, Volvo tested different types of HEV technologies in distribution trucks, wheel loaders, refuse trucks and inner-city buses during the 1990s. During this period, Scania focused mainly on applying HEV technologies to buses, with tests and demonstrations of over 30 hybrid buses since the 1980s. On the car side, Volvo experimented with series and power-split hybrids during the 1990s and with plug-in diesel hybrids and micro-hybrids in the late 2000s. State-funded R&D programmes have played a key role in enabling these activities (Magnusson, 2011).

Since 2010, car manufacturers have succeeded in commercialising HEVs. In 2012, Volvo Cars launched the V60 PHEV, and have scaled up their plug-in hybrid efforts to other vehicle models ever since (at the time of writing, six Volvo models are available as PHEVs). In 2015, Volvo Cars announced plans to electrify its entire vehicle portfolio, focusing on PHEVs and a full BEV by 2019, with the expectation that 2018, 10 % of sales will be electrified cars by 2018 (Shelton, 2015). Elsewhere in Sweden, NEVS (New Electric Vehicle Sweden) acquired Saab's assets following its bankruptcy, and has signed a deal with Panda New Energy in China to deliver 150,000 BEVs by 2020.

In Norway entrepreneurial experimentation with Think, a small BEV, in the 1990-s was the starting point for establishing incentives for electrification. The purpose was support for industrial development and made Norway well prepared for actions when the climate challenges became an important political agenda (Figenbaum 2017).

3.1.6 Market formation

In Sweden, during the 1990s, public agencies made funds available for municipalities to procure BEVs and HEVs. However, the discontinuous focus on EV technology within Volvo and Saab (influenced by changes in ownership) meant that municipalities purchased from foreign automakers. EU vehicle emission standards and national subsidies/tax incentives established towards the end of the 2000s actually played a more important role in market creation for HEVs. Subsidies for EVs were introduced for private individuals in 2007, and were increased in 2011 as the government introduced subsidies for 'super-environmental cars', targeting newly purchased BEVs and HEVs (Magnusson, 2011). In 2017 BEVs represented 1,1% of the vehicle market (BIL Sweden 2018, referred to in Stier mf el 2018).

Norway has, together with Denmark the highest tax on vehicles in Europe, making it very expensive to buy and use a car (Sprei et al., 2013). However, fiscal incentives can make it cheaper to buy a BEV than an ICE vehicle. As shown in table 3.1, Norway, has several fiscal incentives that reduce the purchase price of a BEV, and local incentives that make EV travel more convenient (Figenbaum and Kolbenstvedt 2016). In addition the electric propulsion is much more energy efficient which significantly reduce the user costs (Figenbaum 2018). The most important fiscal incentives are exemption from registration tax, introduced in 1990 to be continued until 2020 and VAT exemption, introduced in 2001 and to be unchanged until 2022. Other incentives are reduced annual vehicle license fees, introduced in 1996/2004 and reduced to half rate of ICE vehicles from 2018 and full rate from 2020 and; reduced company car tax (50 %) which may be removed in 2018, se table 3.1.

The most important local incentives in Norway are free toll roads, introduced in 1997; reduced fares on ferries from 2009; free public parking from 1999; access to bus lanes from 2003/2005 and; free charging at public charging stations. The combined effect of fiscal and local incentives have contributed to a very strong growth in the Norwegian EV-market. Norway had the highest market proportion of EVs in the world at the end of 2017 (Figenbaum 2018). The market shares for BEVs, PHEVs and HEVs in 2017 respectively was 20%, 20% and 13% in 2017 (Figenbaum 2018).

As shown in figure 3.1 the growth did not take off until there were more vehicles from different brands in the market (Figenbaum and Kolbenstvedt 2015a, 2016). Although, the BEVs still represent a niche market the massive growth the past years is predicted to continue and, this rapid up-scaling should then pave the way for a what Bergek (et al 2008) call a "bridging market".

At the end of 2016 Norway had 97 532 BEVs in the passenger vehicle fleet. The fleet increased to roughly 140 000 BEVs by the end of December 2017, as seen in figure 3.1. This represents 5.1% of the total fleet. About 1 500 four-wheel electric motorcycles are also in the fleet. 67 577 PHEVs were in the fleet at the end of 2017, a share of 2,6% out of the total fleet of 2.71 million passenger vehicles. The growth of BEVs has continued in 2018 and the market share was 27% in September. The PHEVs kept the same share as in 2017 – 20% (OFV 2018). The share of the total vehicle stock at this time was 5,9% for BEVs and 3,0% for PHEVs.

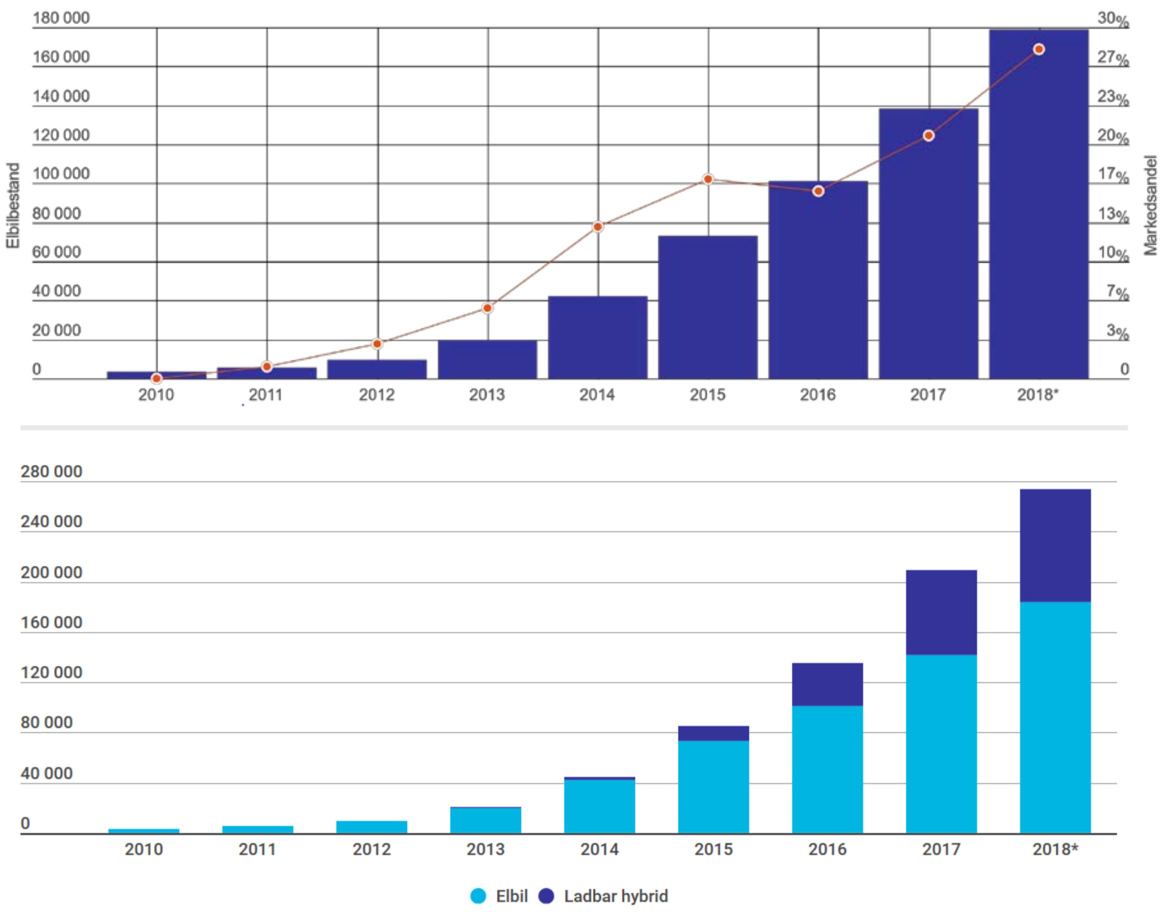

Figure 3.1: Total number of registered BEVs and PHEVs in the new market in Norway and share of fleet for BEVs. Passenger BEV(on top) and PEVs and PHEV (at bottom) from 1997-September 2018. Source:; Norwegian EV Organisation based on OFV AS (2018).

Denmark had also created a strong set of incentives to support the market introduction of EVs and meet EV-specific targets, including exemptions from registration taxes and from the so-called 'green ownership fee', which is a form of subsidy given to private individuals that own and drive EVs (Sprei et al., 2013). However, in 2015, the Danish government decided to phase out these incentives, resulting in a dramatic decline in EV purchases from 2016.

Finland has created tax exemptions for EV owners, but the overall level of subsidy is much lower than in other Nordic countries, such that the entire Finnish EV fleet consists of around 1000 vehicles (Albrecht et al., 2013). The government has, however, set up a working group to discuss the introduction of a target of introducing 250,000 EVs by 2025.

By contrast, the Swedish EV car fleet stands at approximately 35,000 vehicles (Powercircle, 2017), and the Norwegian BEV and PHEV fleets made up over 200,000 vehicles in 2017. Denmark currently has around 20,000 EV cars in the vehicle fleet (http://www.eafo.eu/europe, Figenbaum 2018,OFV).

Public charging points in Sweden have almost quadrupled between 2015 and 2017 (from ca. 900 to 3500 charging points at around 1000 charging stations). However, almost a quarter of these are located in Sweden's two largest cities, Stockholm and Gothenburg, such that many Swedish towns still lack charging points (Powercircle, 2017).

By comparison, Norway had ca 7500 normal charging stations with 9000 charging points in 2017, most of which are publicly available (http://info.nobil.no/). In addition ca 1 000 fast chargers were available. In September 2018 the numbers were increased to 10.400 and 1 500 respectively. However, Figenbaum (2018) still concludes that charging infrastructure is lagging behind the fleet increase.

Both in Norway and Sweden, BEVs are more common in cities and urban areas than in the countryside (Figenbaum and Kolbenstvedt 2016). This geographical distribution of EVs is likely due to a more developed charging infrastructure in urban areas, stronger local incentives and sociodemographic characteristics of EV owners. Figenbaum (2017 and 2018) has shown how BEVs are now spreading radially from the cities to larger geographic zones all over the country.t

Denmark currently boasts more charging stations than petrol stations, a large proportion of which are operated by the energy company E.On, which has made aggressive inroads into the Danish EV market. By contrast, and in accordance with its weak prioritisation of EV adoption, Finland has only 800 charging points at present.

3.1.7 Legitimation

Magnusson (2011) assesses the legitimacy of EV technology in Sweden by examining factors that influence: 1) the ability to justify industry spending on R&D activities; 2) the ability to justify investments in taking concepts and prototypes to the market; and 3) the existence of suppliers of EV technology. This rather narrow view of the concept of legitimacy refers nonetheless to the level of industry support for EV technology. In Sweden, Magnusson (2011) shows that industry support was weak during the 1990s and early 2000s, due to weak incentives and stable fuel prices. State funding was thus a key factor in driving R&D. However, towards the late 2000s, raised oil prices, the success of Japanese HEV exploits and the debate on climate change combined to put fuel economy on the automotive corporate agenda, resulting in increased support for EV developments in the Swedish automotive industry.

Another way to examine legitimacy is to focus on organisational platforms, interest groups and project groups that seek to create support and lobby for EVs, and to share knowledge and experiences. The most important lobby organisation for EVs in Norway is The Norwegian association for electric vehicles (*Norsk elbilforening*). The organisation was founded in the 1990s and has over 70,000 members from 2018. The organisation works for the diffusion of EVs on different levels and through many channels (e.g. policy and technology debates, news). A special trait characterizing the Norwegian EV-diffusion is a broad cooperation between stakeholders. The electromobility association arrange work shops together with the Automomobile organization and the Environmental organizations. This strategy probably make their common voice stronger in the political process (Figenbaum and Kolbenstvedt 2015a).

Norsk elbilforening is also in charge of NOBIL (www.nobil.no), a non-proprietary software tools, which includes practical and technical information, accessibility for users, type of connectors and charging capacity, map coordinates, and pictures. The data are available for the general public. NOBIL is a collaboration between Norsk elbilforening and the state agency ENOVA (www.enova.no), which finance NOBIL, and the purpose is to provide information to EV customers in order to promote the adoption of EVs. Electric Mobility Norway (EMN) is a another public-private partnership that functions as an innovation and knowledge arena (www.electricmobility.no). EMN is an industry cluster of Norwegian companies that cooperate and explore business opportunities within the electric vehicle market.

Denmark established the Centre for Green Transport and Copenhagen Electric to share knowledge experiences of EVs among different municipalities, companies and private individuals, and to campaign for EVs (Van Der Steen et al., 2015).In Sweden, the Network of Swedish clean vehicle cities and the Green Highway initiative lobby for policy that supports the adoption of EVs and charging infrastructure, also a platform for EV information campaigns. The vehicle strategic R&I (*FFI*) programme provides a basis for collaborative research on EV technologies.

3.1.8 Resource mobilisation

Magnusson (2011) assesses resource mobilisation by examining the level of technology specific competence required to support Swedish innovation in the EV field during different stages of its development. Until the mid-2000s, a large number of EV competent engineers was not necessary given the limited efforts of Swedish automakers. After this point, however, the need for human resources in electronics and electric systems escalated rapidly, and automakers sought to face this challenge by collaborating with foreign partners, international engineering consultants and academic researchers from technical universities (primarily CTH and KTH). In addition, the absence of key suppliers during this period means that the Swedish EV system can be regarded as weak in terms of resource mobilisation, despite efforts such as the establishment of a team to focus on energy storage and battery technology. Governmental R&D programmes played a role in supporting the development of key competences, though these were largely uncoordinated until the establishment of the SHC in the mid-2000s (Magnusson, 2011). More and more countries are investing in R&D for electric vehicles and using financial incentives and local policy instruments for promoting the use of "green cars". Vehicle electrification is regarded as important to contribute to the mitigation of GHG emissions, reduce local pollution and to more efficient use of energy (Catenacci et al 2013).

Norway's total R&D expenditure accounted for 1.65 per cent of gross domestic product (GDP) in 2014, a level that has remained stable over the past 20 years. Thus Norway lags considerably behind the average for the Nordic countries and the average for the OECD countries. There has been a decrease in R&D in the area of renewable energy, particularly in the business sector where the level is nearly half of what it was in 2009 (Nås 2015). However, Norway is at the very top when it comes to public R&D expenditure. This puts Norway in a unique position, as most countries are cutting research funding from public administrations. Research on EV diffusion and environmental and economic effects of electrification has been supported by EUs FPs, the Norwegian Research Council (Programmes on Climate, Energy and Transport 2025 as well as research programmes headed by the Norwegian Public Road Administration.

3.2 Electric Road Systems

Electric Road Systems (ERS) refers to dynamic power transfer from the road infrastructure to the vehicle while the vehicle is in motion. Such systems are not new and have existed for over a century in the form of trams, streetcars, and trolleybuses. In recent years, ERS has emerged as a plausible solution for achieve the urgent policy goals related to sustainability and fossil fuel dependency with a special emphasis on heavy-duty trucks (Tongur, 2018). The freight sector is often neglected in sustainability policy debate as most focus has been on passenger cars. Nevertheless, the freight transport is projected to increase and is considered one of the most difficult sectors to decarbonise. Alternative technologies to replace diesel engine (e.g. batteries and fuel-cell technologies) are considered commercially unviable and the availability of alternative fuels (e.g., biofuels) for this sector is uncertain (e.g. IEA, 2007). Compared with other alternative technologies, ERS reduces the need for batteries, relies on well-established electricity infrastructure, and could preserve flexibility in the freight sector (den Boer et al., 2013; Chen et al., 2015).

ERS has the following subsystems: the road, the truck (based on an ERS powertrain), power transfer technology and the power grid and stations. The basic principle is to power an electric engine within the vehicle from an external power source built into the road infrastructure. The electrical power is transmitted while the vehicle is in motion through a pick-up attached to the vehicle, as on a trolleybus. The roads would be accessible to both vehicles with ERS propulsion and conventional fossil-fuel vehicles. Furthermore, the ERS vehicles would be equipped with a small battery and a potentially smaller diesel engine (or fuel cell) to allow a flexible system in which vehicles could drive outside the electric road network on conventional roads. (Tongur, 2018)

There are different ERS technologies, with varying degrees of technological maturity, with the most advanced initiatives at TRL 7 (Sundelin, Gustavsson, & Tongur, 2016). From a conceptual point of view and a system perspective, the challenges of developing and commercializing ERS are similar, regardless of what ERS technology that will be implemented. For example, ERS challenges the interfaces between the established subsystems, for example, between the vehicles and pick-up, pick-up and electric road, and electric road and electricity transmission network, which would require standardization of key components. This allows new actors to enter and requires new ways of financing infrastructure and business models for vehicles and fuel (that must be more integrated compared with the diesel based transportation system). Currently, there are various ongoing research, pilot, and demonstration projects around the world to develop and evaluate the viability of ERS (cf. Tongur and Sundelin, 2016). However, ERS has not moved beyond the development phase yet and it remains to see if it will succeed into deployment on commercial markets.

3.2.1 Global developments in Electric Road Systems

During the past ten years, activities within the ERS TIS has evolved rapidly. There have been ongoing pilot and demonstration project in several countries and projects that explore the possibility to deploy and commercialize ERS on large scale markets. Currently, there are three main competing technological trajectories in the ERS TIS: overhead lines, in-road conduction, and in-road induction. Each technology has its advantages and disadvantages, and is developed, demonstrated and marketed by different firms.

An overhead-line solution uses an overhead line above the vehicle to provide the energy. The energy is transferred to the vehicle by means of a robotic arm following the overhead line and installed on top of the vehicle. However, due to vehicle form factors and the obvious impracticalities of attaching an oversized current collector to a car, the overhead concept is exclusively aimed at heavy vehicles. The system has a well-established technology interface and could be open for use by various actors. The pantograph is the subsystem that is the most immature and critical in the overhead line solution. Siemens is the main actor that has developed this technology, with pantographs that could autodetect the overhead-lines whilst the hybrid trucks are in motion. In 2012, Siemens presented a pilot project close to Berlin in Germany that consisted of about 2 km electric road in a closed research environment. Two demonstration projects with approximately 2 km electric roads each, one in LA, USA, and one in Gävle, Sweden, have demonstrated that the technology works on public road. In addition, three demonstration projects with catenary ERS are planned in Germany for in total 15 km electric road, the first to be built in Hessen in 2018. The costs of implementing catenary ERS solutions are uncertain but are estimated to be SEK 10–30 million per km (cf. den Boer et al., 2013).

In-road conduction utilizes a conductive rail installed in the road surface to provide the needed energy. The energy is transferred to the vehicle via a robotic arm installed beneath the vehicle, which follows the rail. The rail is connected to the electric grid and power stations along the roadside. The rail is segmented and is only powered when a vehicle is above it. If the vehicle is standing still or running at low speed, the system will remain turned off. The pick-up is designed to automatically detect and follow the rail despite vehicle movements. The technology could potentially be used for both light and heavy vehicles. The concept has gained interest in recent years and there are several ongoing efforts around the globe. Some of the more noteworthy nations are Sweden, Germany, and the US, where manufacturers and public authorities collaborate in various field trials and pilots. Rail concepts are theoretically possible to use with cars, thus broadening the market potential. This technology has been developed by Alstom and Elways. Elways has estimated the costs of electrification to be SEK 4 million per km in both directions.

An inductive wireless solution uses a magnetic field to provide the energy. The electric current in a primary coil installed in the road creates a magnetic field, which induces a current in a secondary coil installed beneath the vehicle. The wireless concept is theoretically possible to use with cars. Among the established global players, Korea has been developing the area for some time. Since 2013 the commercial company OLEV operates a bus route traversed by 2 buses (Ahn, Suh, & Cho, 2013). Bombardier has been conducting research for over five years into dynamic inductive power transfer as an evolution of its Primove commercial static solution. Furthermore, the inductive technology has been investigated and demonstration in project in the USA, Italy, and France. The downside of the technology is that its investment cost is high. For example, the costs of electrifying both directions have been estimated to be SEK 26–50 million per km (Olsson, 2013).

3.2.2 Nordic developments in Electric Road Systems

Sweden is a highly active research actor, with some activity in Norway. Initially the idea of ERS was debated in the Swedish public discussion in 2009, with start-up called Svenska Elvägar AB proposing to electrify the main highways as a more effective way to mitigate CO^2 emissions instead of investing in a high-speed rail solution. While Svenska Elvägar argued that overhead-line solution would be most appropriate, another start-up called Elways, argued that a rail solution would be more appropriate for ERS considering that it could be useful for both passenger cars and trucks. Scania and Volvo thereafter collaborated in a research project called Slide-In to investigate the feasibility of ERS together with Bombardier (inductive technology) and Alstom (conductive inroad technology). To further develop the ERS TIS, the road authorities initiated a precommercial procurement, in which two ERS demonstration projects were developed and co-funded, one in Gävle (with Siemens over-head line technology) and in Arlanda (with Elways). In June, the Swedish government presented a plan to create an ERS pilot project for 20-30 km, with up to 300 MSEK cofounding (matching 300 private funding).

The government stated that the ERS pilot project should be in operation already 2021 (Government, 2018).

Incorporating infrastructure design and maintenance, the area is characterized by a wide set of heterogeneous actors. The most active players are vehicle manufacturers (Volvo, Scania and Volvo cars), and Energy transmission (SIEMENS, ALSTOM, Elways, Qualcomm). Authorities including Swedish Trafikverket and Transportstyrelsen have been involved in various degrees. There are a number of organizations involved in research including research institutes in Sweden (RISE, VTI) and Norway (TÖI, SINTEF) Universities (Chalmers, KTH, Lund University), and consultancy firms (e.g. WSP). There are no formal education targeting ERS and the only relation to education is a channelling of master students to research projects involved in ERS. There is some involvement from infrastructure contractors (e.g. NCC and Elways collaboration), while municipalities, regions and others associated with public infrastructure have played relatively modest roles. Transport firms have been involved to a limited degree (small haulers involved in tests). 3rd party logistics players or transport costumers have not been actively involved yet. The energy producers, traders and power grid actors (e.g. EON, Fortum, Vattenfall and numerous local government run operations) have thus far not been a driving factor in research and testing. Currently, there are no dedicated networks promoting the technology in the Nordic countries.

3.2.3 Entrepreneurial experimentation

Reflecting a phase of development of ERS, the entrepreneurial experimentation function is centre stage. There are three major competing technological trajectories in the area, all with some Nordic involvement. These are: overhead lines, conductive rails, and wireless solutions, each with unique pros and cons and associated firms pursuing development and marketing.

Rail solutions have been developed by three suppliers and tested at two sites. The startup company Elways has tested its technology on a 350 m test track outside Arlanda, Sweden (Asplund & Rehman, 2014). Vehicle installation and the technology for switching between rail segments have not yet been publicly demonstrated, but will be developed as part of the ongoing pre-commercial procurement of electric roads in Sweden. In a second part of this project slated for 2017, the solution will be tested on a 2 km public road with the solution fully integrated on a DAF truck using E-Traction and a ZF powertrain. Alstom has conducted testing together with AB Volvo on a 400m test track at the Volvo test site in Hällered, Sweden. The vehicle integration was part of the Slide-in research project, completed in mid 2016 (Olsson, 2013). The Swedish Energy Agency is currently funding a research project that will demonstrate a rail solution in 2017 based on the technology of the company Elonroad[2]. The main difference from the Elways and Alstom solutions is that Elonroad intends to install the rail on the surface of the road instead of embedding it in the road.

An overhead-line solution has been tested on Siemens' 2 km test track east of Berlin, Germany. Full vehicle integration has been conducted jointly with Scania and integration for a Mack truck is ongoing. The solution has been tested on public roads in Sweden and the USA. The Swedish test was conducted on a 2 km stretch of the E16 highway outside Gävle, as part of the ongoing pre-commercial procurement of electric roads. The US is being performed on a 1 mile urban road in City of Carson in the vicinity of Los Angeles, and is led by the South Coast Air Quality Management District (SCAQMD) (M. Birkner &

[2] http://elonroad.com

M. Lehmann, 2015; Siemens, 2017). Germany's Federal Ministry for the Environment (BMUB) has issued a call to fund the demonstration of overhead-line solutions[3]. After some delay, German public road tests are now expected to take place during 2019 (Siemens, 2017).

By comparison, the wireless trajectory has received relatively scarce attention in the Nordic countries, but some actors have been involved in some tests elsewhere. Bombardier's Primove system has been integrated into a Scania truck and tested on an 80 m closed test track in Mannheim, Germany, as part of the Slide-in project (Olsson, 2013). The large EU project FABRIC has demonstrated dynamic inductive power transferring Sweden [4] and SCANIA, Volvo and KTH is involved in the project. The Norwegian road administration is financing SINTEF to perform the ELinGO study which will explore different ERS solution for the E39 coast road. This project is intended to be coordinated with Swedish demonstration projects [5].

3.2.4 Knowledge development and diffusion

As mentioned earlier, there have been several R&D and demonstration activities that have been ongoing globally in the ERS TIS. Most of these projects have been initiated by policy makers and largely financed through public funding. The focus of such activities has been on creating and developing new knowledge rather than on creating a commercial market. Since the different technologies have had different maturity levels, the different activities have focused oni improving knowledge about each technology before any large-scale investments are made. For example, the two precommercial procurement programs in Sweden (one resulted in the Arlanda and Gävle ERS projects whilst the second procurement program is ongoing) has been to raise the knowledge level of all ERS technologies and enhance more informed decision making. Another example is the Research and Innovation platform for ERS which gathers all relevant actors (excluding the power transfer technology firms) to conduct and share research done within the ERS field.

Public authorities run a risk in choosing a certain ERS solution that might become obsolete in the future if other technologies become more feasible or other countries decide for other solutions. Hence, creating an understanding of how ERS technologies could be standardized on an international basis is important. One key element creating a common understanding for ERS on a global level is the collaboration project between Sweden and Germany on ERS (CollERS) which stands for a main part of the knowledge diffusion within the ERS TIS. CollERS is a result of an innovation partnership agreement that was announced in January 2017 by the Swedish Prime Minister Stefan Löfven and German Chancellor Angela Merker. One point of the partnership is to strengthen cooperation between the countries by giving them access to each other's demonstration projects. Furthermore, the two countries announced that they would jointly study the potential deployment of ERS in a highway corridor linking Sweden and Germany. There is also a discussion between Sweden and France to create a similar partnership (Government, 2017).

3.2.5 Resource mobilisation

There have been many actors involved from in the ERS TIS, particularly in Sweden. One reason for this is that Sweden has two large truck OEMs that have an interest in developing technology that could reduce the environmental impact of their products.

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[3] http://www.erneuerbar-mobil.de/de/foerderprogramm/erneuerbar-mobil-foerderbekanntmachung-2015

[4] http://www.fabricproject.eu/index.php?option=com_k2&view=itemlist&layout=category&task=category&id=45&Itemid=259

[5] https://www.sintef.no/projectweb/elingo/

Similarly, there have been many entrepreneurs that come from the electric equipment industry (e.g. Elways, Svenska Elvägar) that created new innovations. However, the main reason for the resource mobilization in Sweden is that public agencies have supported and funded such activities. In Fig 3.2, resource mobilization is measured by identifying the number of ERS project that have been funded over the past decade. This shows that the resource mobilization has steadily increased and will probably increase more with the upcoming pre-commercial procurement program (about 200 MSEK in total funding) and pilot project (600 MSEK in total funding). However, until the now there has been low resource mobilization from the users, that is actors that will pay for using the ERS, for example transport buyers or haulers.

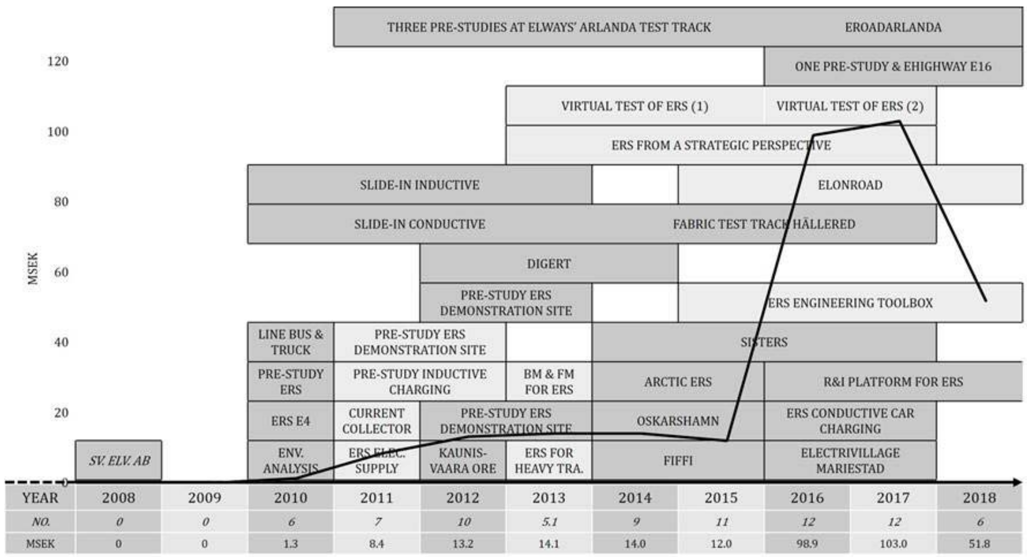

Figure 3.2: Number of initiated ERS projects in Sweden and the amount of (public) funding over the past decade (Berlin, 2018).

3.2.6 Market Formation

One important aspect of analysing the functionality of a TIS is to assess the market share for the new technology and what the potential market could be. This is difficult to assess for ERS since there currently is no commercial market for ERS in the Nordic countries, neither for heavy duty trucks or passenger vehicle (although there are functioning trolley buses, e.g. one line in Bergen, Norway and one in Landskrona, Sweden). The ERS TIS has mostly been engaged in the pilot, demonstration and deployment projects. While such activities have not yet resulted in commercial diffusion yet, Fig 3.3 shows that these activities have prepared ERS for potential takeoff. (Tongur, 2018) While there are rationales for adopting ERS coupled to "greening" legitimization and cost reductions for e.g. haulers and operators, currently there are no established business models for delivering that potential value sustainably. The upcoming deployment project that is being planned through the Swedish government national plan for infrastructure investment (Government, 2018) and the Transports administrations roadmap for ERS (Trafikverket, 2017) will be crucial for stimulating regions, suppliers, and users to deploy ERS and thereby developing functioning business models that support a market diffusion of ERS to niche markets and mass markets.

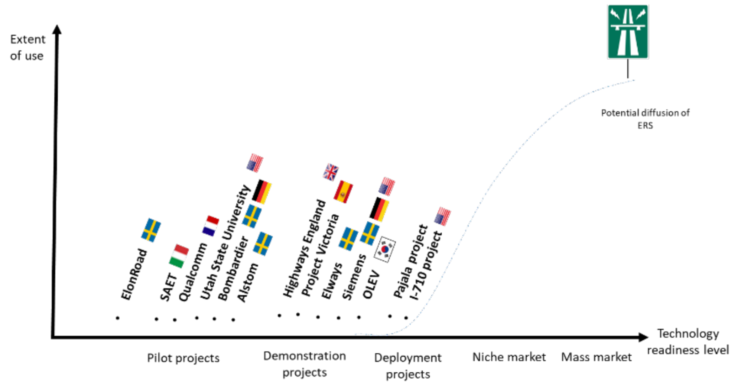

Figure 3.3: ERS activities preparing for commercial take-off (Tongur, 2018).

3.2.7 Guidance of search

There are limited technological options for heavy road transport to transform into a CO^2 free system, giving ERS a clear potential and it is the most actively researched option for this transport sector in the Nordic countries. In their report on the future of trucks, the International Energy Agency (IEA) (2017) argued that there were three main alternatives for reducing future energy demand and emissions growth (Fig. 3.4). The first is systemic improvement, for example, by using digital technologies in the freight logistics sector to improve truck utilization and reduce road activity. The second alternative is improving vehicle efficiency, for example, by deploying technologies in trucks that could reduce the amount of energy used and improve fuel economy. The third alternative is to switch from oil-based fuels to alternative fuels such as natural gas, biofuels, electricity, and hydrogen. Among these alternatives, ERS is lifted as one of most feasible one as it reduces the need for battery capacity which makes trucks heavy and bulky, and could utilize future developments of fuel cell technology as range extenders or increased capacity in biofuels as the alternative fuel.

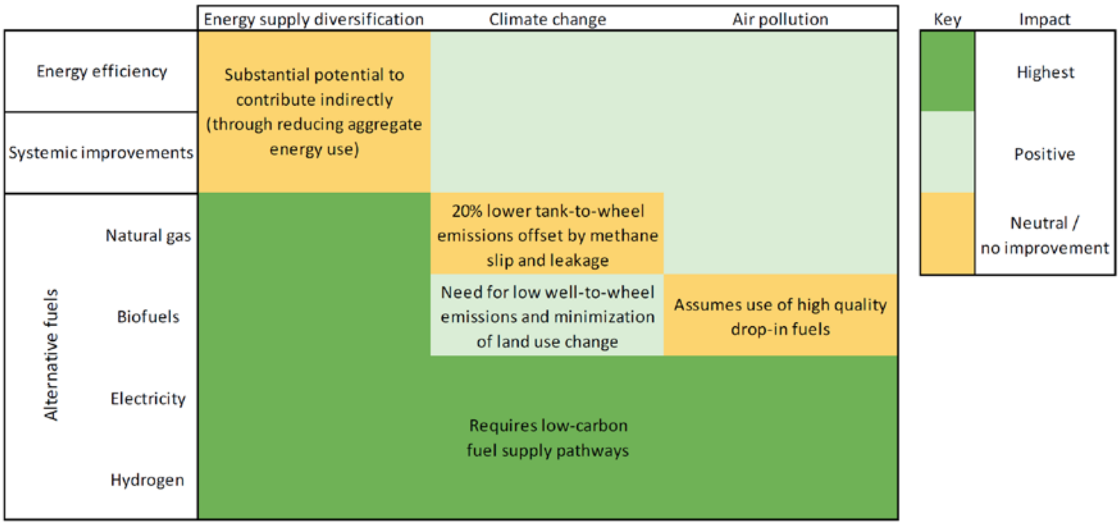

Figure 3.4: Summary of the impact of various alternatives on policy goals (EIA, 2017).

In addition to environmental impacts, there are strong economic incentives for hauliers and transport buyers in moving towards ERS due to lower operating costs. Electric engines are more energy efficient that combustion engines while electricity most often is cheaper than diesel. Furthermore, by using hybrid technology the vehicles could drive outside the electric road, potentially using biofuel or fuel cell, retaining the flexibility of the road transport system. Lastly, hybrid vehicles could offer lower costs in maintenance and an improved total cost of ownership compared to conventional vehicles. While electric and hybrid trucks typically have a higher purchase price, there have been policy measures to make such vehicles more attractive. For example in Germany the government has dropped highway tolls for electric trucks and also created a subsidy scheme to make the purchasing of such vehicles more commercially attractive (electrive.com, 2018a,b). Hence, there are both environmental and economic aspects that supports the guidance of search towards ERS.

3.2.8 Legitimation

ERS is one of few the options available to transform current road transport systems to CO^2 free operation but it has met several challenges regarding legitimacy. One reason is that the main focus has been on passenger cars and on air quality legislation for trucks rather than on CO^2 regulation (e.g. Euro VI requirement for diesel engines). Furthermore, the current road transport is characterized by a decoupling of infrastructure and vehicles while ERS involves a stronger coupling between infrastructure and vehicles (as with the railway system). Either ERS will fundamentally change current responsibilities of societal actors in terms of infrastructure provision, or it must introduce a new organizational field of private actors supplying the new infrastructure. This fundamental shift in relationship between infrastructure and vehicles constitute an important barrier for the establishment of ERS.

Governments are seeking to decrease the perceived risk through research investments and international cooperation in order to legitimise continued development efforts. As an example, the Swedish Transport Administration has investigated and reported a roadmap for whether electric roads could eventually become part of the national road network in Sweden and how this could happen. The Transport Administration will also manage the part of the Sweden-Germany innovation partnership dealing with electric roads. The aim is to support the development of a variety of technical solutions for electric roads (Trafikverket, 2017). There are also discussions to include France in such a collaboration (Government, 2018).

New conferences have also been created over the past years that increase the legitimacy concerning ERS questions and that have gathered the main actors from academia, public authorities and industry together. The second Electric road system conference (ERSC) took place on June 2018 in Arlanda, Sweden[6], while the third ERSC is planned to take place in may in Frankfurt, Germany. Also the third addition of the conference on electric roads and vehicles (CERV) took place on April 2018, in Park City, USA.

3.3 Hydrogen vehicles and infrastructure

Hydrogen is an energy carrier that can be produced from almost any primary energy source. Compared with electricity, hydrogen can be stored relatively easily in substantial quantities. As a fuel in vehicles, hydrogen is typically used to produce electricity for an electric motor using a device called a fuel cell.

[6] http://www.electricroads.org/

3.3.1 Global development

Germany, Japan and the USA are at the forefront of promoting hydrogen as an alternative fuel in transport. However, deployment is still at an early stage (R&D) and hydrogen vehicles are rare in most countries. Only 600 hydrogen cars were sold in Europe in the period 2013 – 2016. Several research and demonstration projects have been/are being carried out in European countries, such as the EU HyFLEET:CUTE project, which operated 47 hydrogen powered buses in regular public transport service in 10 cities on three continents (http://chic-project.eu/wp-content/uploads/2015/04/HyFLEETCUTE_Brochure_Web.pdf).

Hydrogen infrastructure is also under-developed; the lack of refueling stations in most countries makes it inconvenient to have a hydrogen car. Huge investments are required to develop a sufficient hydrogen infrastructure, and as long as the vehicle fleet is so small, fuel companies hesitate to invest. However, various incentive schemes and new infrastructure plans are under way. There are plans in Germany to build 400 hydrogen refueling stations by 2023; in Japan there are about 90 stations and plans for 160 by 2020; in South Korea there are plans to build 100 stations by 2020; and in the USA, mainly in California, there are approximately 70 stations and plans to increasing the number to 100 stations.

3.3.2 Developments in The Nordics

The Nordic countries are at the forefront of hydrogen vehicle deployment. In 2016, 23 hydrogen vehicles were sold in Norway, 20 in Denmark and 19 in Sweden. These were all passenger cars and it make up 40 per cent of the sale of hydrogen passenger cars in Europe that year. The Nordic countries also cooperate closely both on infrastructure development and vehicle introduction through the Scandinavian Hydrogen Highway Partnership (www.scandinavianhydrogen.org). As of today there are about 11 hydrogen refuelling stations in Denmark, which has the highest density of stations per capita in the world. Sweden has four stations, but has plans for an additional eight within 2020. In Norway, there are currently five stations and plans for additional six by 2020. The expansion of hydrogen refuelling infrastructure may increase the stock of hydrogen cars in the Nordic countries.

Compared with the recent growth of the EVs, the market for hydrogen vehicles in the Nordics is small or almost non-existing. There are isolated pilot tests and a burgeoning infrastructure. Sale figures for hydrogen cars in Norway were 23 in 1916 and 57 in 2017. Today there are about 100 hydrogen cars registered in Norway, most of them are in the Oslo region. This is partly due to the access to refueling stations. Other than some testing of hydrogen buses in public transport and hydrogen trucks for good delivery, there has been little or no diffusion of hydrogen vehicles in Norway during the period 2008 – 2016. Despite the low share of hydrogen vehicles, Norway is looked upon as a pioneer for market introduction of zero emission vehicles. Several of the world's leading manufacturers of hydrogen vehicles use Norway as a demonstration arena for their new vehicles.

Although improvements of the hydrogen infrastructure may enhance the use of hydrogen cars in Norway, there is no clear sign to up-scaling and significant market formation. The main hydrogen activities still relate to R&D (including pilot projects) and lobbying. Therefore, following the TIS framework, knowledge development and diffusion (F2, F3) together with guidance of search (F4) and legitimation (F5) seems to be the most relevant function for analysing the development of hydrogen vehicles in Norway and the other Nordic countries.

3.3.3 Knowledge development and diffusion of knowledge

According to a recent study, there are about 100 organisations active within the sector in Sweden. Owing to the vehicle manufacturing industry in Sweden, there has been substantial research into fuel cell technology with Scania and Volvo Cars being the most active parties. Besides the automotive sector, AGA, Sandvik, SSAB, Vattenfall are all interested in pursuing research and development. There are also innovative tech firms exporting knowhow and components, such as PowerCell and Cell Impact. There are new entrants focusing on hydrogen production and purification (e.g. Metacon, Cortus and EcoBioFuel). There are several institutes, consultancy firms and universities that are active and internationally competitive. The background to the current level of the Swedish hydrogen TIS can be found in a substantial public research program that provided long-term financial support to research for about two decades. This proactive stance has been replaced with a more modest technology watch strategy (Wallmark et al. 2016).

In Norway, there is a long tradition of research on hydrogen related to both industry and to transport. Most R&D activities in this field takes place at the Norwegian University of Science and Technology (NTNU) and SINTEF, one of Europe's largest independent research organisations, which is closely related to NTNU. SINTEF has been working with fuel cell technology since the 1980s and is currently working on several such projects. The Research Council of Norway (RCN) also administers a research programme, EnergiX, for the period 2013 – 2022 in which the use of hydrogen in the transport sector and fuel cell technology development is a significant topic (www.forskningsradet.no).

Networking actors such as the Norsk Hydrogenforum (NHF) and Oslo Renewable Energy, Environment Cluster (OREEC) and the environmental organization ZERO are important for the diffusion of knowledge on hydrogen, and for the legitimation of hydrogen as a zero-emission fuel (see legitimation below).

3.3.4 Guidance of search

In Norway, national policies and regulations have been introduced to stimulate use of hydrogen in the transport sector. In 2016 the Government presented a national hydrogen strategy in which it promised to stimulate research on hydrogen fuel and to contribute with financial incentives for the development of a related infrastructure. The state agency ENOVA, which was established in 2001 is a key instrument for stimulating a transition in use and production of energy, including hydrogen. From 2008 to 2015, transport issues were dealt with by a special state agency, Transnova (Nilsen et al 2010), which was created to promote sustainable transport, but this agency was integrated into ENOVA in 2015.

ENOVA contributes with financial and advisory support to projects and enterprises to promote energy and climate friendly solutions in industry, transport and buildings (www.enova.no). The agency has financially supported several transport projects related to hydrogen, including infrastructure like hydrogen refueling stations and the development of hydrogen-based vehicles for public transport and freight transport. As with EVs, there are also many financial and local incentives for hydrogen vehicles, such as exemption from registration tax, VAT exemption, reduced annual vehicle license fee and reduced company car tax. Local incentives include free toll roads, reduced fares on ferries, free public parking and access to bus lanes.

3.3.5 Legitimation

Stakeholder acceptance is important for the diffusion and use of hydrogen technology in transport. Of the organisations and lobbying groups promoting hydrogen in Norway, the

Norsk Hydrogenforum (NHF) is the most important. The NHF was established in 1996 and is a non-profit organisation that seeks to promote hydrogen as an energy carrier. NHF has members from industry, research institutions, public authorities and transport operators, and environmental NGOs. Diffusion on knowledge on hydrogen through seminars, workshops, websites, newsletters and other activities that can encourage research and innovation on hydrogen related technology is the primary task for the organization. The Oslo Renewable Energy, Environment Cluster (OREEC) is a secretariat for NHF. OREEC is a network with businesses, research institutes, education and public actors within the field of renewable energy and environment in the Oslo region (http://oreec.no/about/). The network cooperates closely with local governments and other public and private partners in order to enhance research and innovation in the hydrogen field. The environmental organization ZERO is also involved in projects and the promotion of hydrogen as a green fuel alternative in the transport sector. The Swedish landscape is similarly configured, with the interest organisation Vätgas Sverige acting as the main forum.

3.3.6 Barriers for hydrogen vehicles

There are probably several explanations for the missing market formation of hydrogen vehicles in Norway and in other Nordic countries as well as in the rest of the world. There are obvious technological barriers but also political obstacles to up-scaling and diffusion of H2 cars. Despite the long hydrogen R&D tradition in Norway, the lack of a national strategy for hydrogen as a transport fuel has been cited as making the country less attractive as a market for hydrogen vehicles (Tomasgard 2016, Moland 2017). The most important barriers, however, seem to be technological. Hydrogen fuel cell technology is not yet so mature as the battery technology. There are concerns related to on-board storage, safety and liability and to high production costs of fuel cells. The limited number of car models also limits the possibilities for potential users, although several new models will be introduced on the market in the next 2-3 years. In addition, lack of infrastructure (refueling stations) also reduces the market potential for hydrogen fuel cell cars as do the strong growth of EVs (Moland 2017). The EVs seems to have reached a critical mass whereas the hydrogen fuel cell car is still in a test phase and constitute a niche market. This may change in the coming years as (1) a larger range of models will be introduced on the market, (2) production costs are reduced, (3) infrastructure develops, and (4) financial, economic and local incentives for hydrogen vehicles are maintained. So far, however, high production costs of fuel cells, small production volumes, high prices and lack of infrastructure make up the main barriers for an up-take of hydrogen vehicles both internationally and in the Nordic countries (Hagman et al 2017).

3.4 Biofuels

Biofuels used in transport are typically bioethanol which is used as a petrol substitute and biodiesel which is used as a diesel substitute. Generally, there are four types of biofuels: biodiesel, biogas, ethanol and synthetic fuels, see below. These four types of biofuels are produced by using first, second, third or fourth-generation biofuel production procedures and they can be distinguished according to their value chains. The production process for each type of biofuel is crudely described as follows (Hillman 2011):

Biodiesel is sourced from vegetable/animal oils and fats (e.g. FAME from soybean, sunflower, rapeseed and palm oil), and is transformed via transesterification and hydrogenation processes.

Biogas is sourced from organic/animal wastes, sewage and grasses and is transformed via digestion processes.

Ethanol is sourced from sugar- or starch-containing crops (e.g. sugar cane, corn, grain and sugar beets) and is transformed via fermentation processes.

Synthetic fuels are sourced from cellulosic materials and is transformed via gasification processes.

3.4.1 Global developments

In 2016, conventional biofuels accounted for only around 4% of world road transport fuel. However, research on biofuels is on the increase and biofuel projects has have been announced in a growing number of countries the past decades (IEA 2017). By 2016, FP7 had funded 20 projects with EUR 70m (European Commission, 2016a; Su et al., 2017). The European Algae Biomass Association which represents research and industry in the field of algae technologies has 79 institutional members. However, the largest sponsor of algae biofuel projects remains the US government (Su et al., 2017). The European Biofuels Technology Platform currently lists 12 different EU supported programs which provide biofuel R&D funding (European Biofuels Technology Platform, n.d.). Horizon 2020 contains five separate calls related to biofuel development, covering all three generations of biofuels. Complementing technology research, the EC is financing research on non-technological barriers through the Intelligent Energy Europe Programme, stimulating cooperation in biotechnology through the European Biofuels Technology Platform[7].

Sustainability criteria for biofuels within the EU have heavily influenced the direction of search (Lazarevic and Martin, 2016). Aiming to increase the share of biofuels in the transport sector to 10% by 2020, the European biofuel directive only allows for biofuels that achieve greenhouse gas savings of at least 50% compared to fossil fuels. From 2018, 60% savings are required. Other criteria are that the feedstock cannot be grown on converted land (wetlands, forests) that had a high CO^2 absorption capacity nor on land with high biodiversity (European Parliament, 2009).

It is expected that second- and third generation biofuels gradually will offer progressively larger CO^2 reductions at lower costs than first-generation biofuels (Edwards et al., 2011). The commercialisation of biofuels from algae is the biggest obstacle to scaling it up, especially since the cultivation and harvesting consumes up to 70% of the energy produced, and the processing can consume another 30% (Su et al., 2017). Second-generation biofuels minimize food-fuel competition, while third-generation biofuels eliminate it as they can be grown on land and use water that is unsuitable for food production (Guo et al., 2015; Mata et al., 2010). The EU argues that "the regulatory uncertainty caused by the long lead political discussion on how to address the risk of Indirect Land Use Change (ILUC) associated to food based biofuels has had a negative impact in the deployment of renewables in the transport sector, concluding that food-based biofuels should contribute no more than 7% to transport fuels by 2020 as their role in decarbonising transport fuels is regarded as "limited". (European Commission, 2016b)

Another core point of the discussion is concerned with the compatibility with petroleum performance and infrastructure. So-called "drop-in biofuels" have been defined as "liquid bio-hydrocarbons that are functionally equivalent to petroleum fuels and are fully compatible with existing petroleum infrastructure" (Karatzos et al., 2014). Industry leaders are pushing drop-in biofuels as the preferred alternative as conventional biofuels can

[7] http://www.biofuelstp.eu/

damage critical vehicle parts (Guo et al., 2015). However, intensive research is needed to improve the economic viability of drop-in biofuels. (Guo et al., 2015).

Technical maturity and cost-competitiveness are key elements for the success of biofuels but significant non-technical issues exist (Fiorese et al., 2013). Biofuels have been contested since their inception, mainly because of food competition (Börjesson et al., 2014). Biofuel policies and regulations suffer the same fate, being regarded as "backfiring", "incoherent", and "exacerbating long-standing problems" (Oliveira et al., 2017). In some cases, the authorities has reacted to public opinion, as with the European Commission's proposal to phase out conventional biofuels gradually. (Harnesk et al., 2017; Michalopoulos, 2016)

The positive and negative impacts associated with biofuels is summed up as follows, see table 3.2 (Dyer et al., 2013; Edwards et al., 2011; Fung et al., 2014; Guo et al., 2015; Lawrence, 2010; Sandén and Hillman, 2011; Suurs et al., 2010):

Table 3.2: Positive and negative impacts associated with biofuels.

Domain	Positive	Negative
Environmental	• Potential to reduce greenhouse gas emissions	• Water and air pollution in production processes • Land use and land use change (LULUC) effects with • Threats to biodiversity
Economic	• Job creation in biofuel industry • Innovation push in fuel industry, maintain leadership in innovation • Contribution to rural prosperity, development in poorer countries	• Increasing food prices due to fuel-food competition • Increasing fuel prices, esp. in aviation • Need for subsidies in order for biofuels to stay competitive
Social/ethical	• Increased energy self-reliance for farmers • Expanded income opportunities for rural population	• Threats to food security • Reduction of value of residential properties that surround biofuel plants and croplands
Political	• Energy security • Independence from fuel imports	• Subsidies/funding spent on biomass/biofuels reduce available funds for other renewables • Diversion from "creating the tough policies necessary to mitigate climate change" (Lawrence, 2010)

The EU is projected to become the world's largest importer of biofuels with an expected import of 15.9 million m^3/year by 2020. At the same time, Germany is the largest biodiesel producer in the globe, which accounts around 40% of the global production. However, 43% (2.4 Mha) of the land used to produce the feedstock for EU-consumed biofuels in 2010 was located outside the EU territory. (Harnesk, Brogaard, & Peck, 2017). Figure 3.5 shows clearly that growth rates for biofuel production have gone down significantly, from 15% in 2014 to an expected 0.2% in 2017.

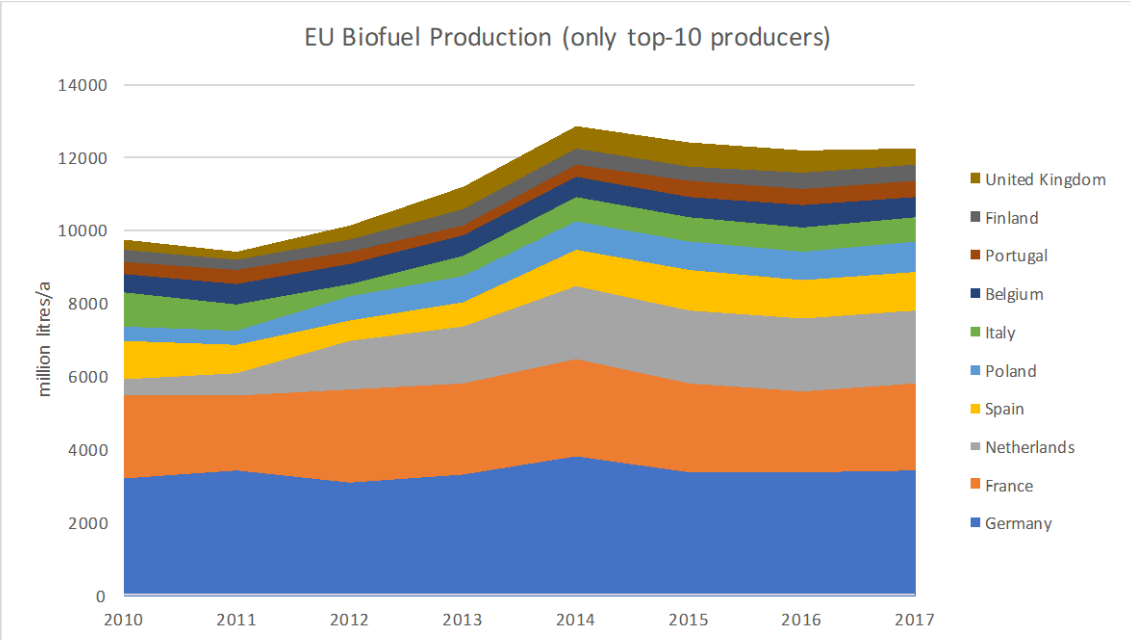

Figure 3.5: EU Biofuel Production Capacity 2010–2017 (Flach et al., 2016).

Biofuels stand out from other alternative drivetrains/fuels as they show significant regional specialisations. Due to the need for regional optimisation of land use and relevant policies the scope and types of biofuels used vary significantly between countries and regions (Heyne et al., 2015). The market share and growth of biofuels is highly correlated to political mandates concerning biofuels. However, the EU's 2030 Framework for Climate and Energy Policies does not propose concrete targets for the transport sector after 2020; while the USA's EPA proposes concrete biofuel shares until 2030. (FAO, 2016)

3.4.2 Developments in The Nordics

Among the Nordic countries, particularly Finland and Sweden have invested in biofuels as an important means for fulfilling their ambitious CO^2 reduction targets (Miljömålsberedningen, 2016, Ministry of Economic Affairs and Employment 12/2017). Forests are major natural resources in both countries and they also have a strong pulp and paper industry. In Sweden, the production of ethanol started as early as World War II when it was used as substitute for import fuels. In the early 90s, there was a recurring governance focus on ethanol, targeting the distribution infrastructure and governance measures like public procurement procedures mandating flexi-fuel vehicle shares (Hansen et al., 2017). By 1990, biogas entered the field, but the ethanol focus was maintained, in the interest of both the Foundation for Swedish Ethanol Development (SSEU), who generally promoted ethanol use in vehicles, and the farmers, who wanted to produce ethanol from surplus grains. The late 90s saw an increase in governance schemes, including tax exemptions, directed at the market for clean vehicles in general. Biogas and particularly ethanol were uniquely positioned to benefit and became dependent on them.[8] However, the assortment of biofuel cars has been limited.

[8] The EU RES directive however decided that the Swedish tax exemptions should only be applicable up to respectively 5 and 6.5 % for biodiesel and ethanol, and for high-level blends. The EU justified this move by pointing out increasing costs with larger volumes of biofuels and clean cars. (Hansen et al., 2017; Hillman and Rickne, 2012)

In the early 2000s, Ethanol and biodiesel were questioned from a sustainability perspective. At the same time researchers and analysts started to communicate a generally positive view on synthetic fuels and gasification. The EU Renewable Energy directive (RES) (2009/28/EC) however, decided that the Swedish tax exemptions should only be applicable up to respectively 5 and 6.5% for biodiesel and ethanol, and for high-level blends. The EU justified this move by pointing out increasing costs with larger volumes of biofuels and clean cars.

The Swedish biogas strategy from 2010 has been criticised for its low ambitions regarding the expansion of biogas. Together with the vague and long-term 2050 goal of a fossil-free transport sector this leads to an overall lack of government stimulation for investments in research, production and infrastructure (Hansen et al., 2017). Current figures show that the transport sector now accounts for a quarter of Sweden’s energy use, largely fossil fuels (Energimyndigheten, 2017). However, the use of renewable energy has grown substantially, primarily regarding biofuels that are mixed into gasoline and diesel, but also alternative fuels like E85, ED95, pure biodiesel and biogas. Pure biodiesel in the form of HVO and FAME has increased in recent years, primarily for buses and heavy trucks.

In 2017 in Sweden biofuels accounted for 21% of all the fuels used for transportation (Energimyndigheten 2018). In terms of renewable energy carriers in the transport sector, biodiesel is by far the main contributor with followed by ethanol and biogas . Finland also has an advanced biofuel strategy in which biomass play a central role in meeting the target of renewable energy sources for transport (Hansen et al 2017). Biofuels also play a major part in the renewable energy strategy of Denmark. The consumption of biofuel has also increased in Norway the past years but the production of biofuel is small. Almost all biofuel for consumption in Norway is imported, mainly from Indonesia. In 2016 the production of biofuel in Norway was 327 GWh, whereas the import of biodiesel and bioethanol in this year was app. 4,5 TWh.

Despite having successfully integrated biofuels in the transport system, Sweden is currently going through a stagnation period regarding biofuels (Curci and Mongeau Ospina, 2016; Hansen et al., 2017). Current import levels of biofuels are substantial while there is scarce interest among domestic key players, suggesting a lack of connection between demand creating activities in the new path establishment process and domestic manufacturing. However, the new Climate Act stating that Sweden aims to achieve carbon neutrality by 2045 might lead the country out of the current period of inertia (Miljömålsberedningen, 2016). Finland on the other hand, has the most ambitious target in EU for renewable energy share in the transport system, production capacity is growing and tax policy support use of biofuel in transport system (Hansen et al 2017).

3.4.3 Knowledge development and diffusion

A wide range of organisations are involved in knowledge development (mainly players from the academic and private sector) and diffusion (mainly players from the public and NGO sector). As shown in figure 5, literature on biofuels has increased steadily[9]. Sweden, together with Denmark and Finland, has had among the highest number of publications per capita in the field with 113 papers per million capita (Azadi et al., 2017).

[9] 30th June 2016) 4,730 entries for “biofuels” and “Sweden” were found in the Science Direct

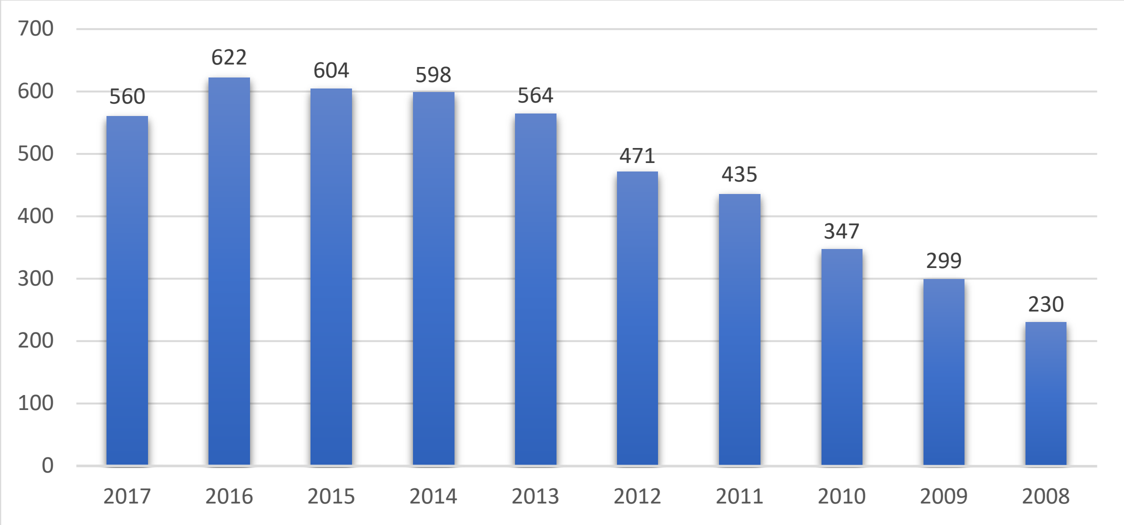

Figure 3.6: Bibliometric values for "biofuels" and "Sweden".

Sweden has hosted several topical international conferences, in 2017 both EUBCS 15th Edition (European Biomass Conference & Exhibition), and International Advanced Biofuels Conference, Gothenburg, 18th-19th May 2017. Applying a very strict selection criteria to the European Patents Office (EPO) database[10,] , Sweden has produced 1 patent in the 1990s and 9 patents in the 2000s with a combined total of 10 patents out of a global total of 245 patents over three decades, ranking fifth globally.

In Sweden, the R&D initially focused on ethanol (E85) and experimental biofuels applied to bus and car flexi-fuels demonstrations by the Swedish Ethanol Development Foundation SSEU (later BAFF). R&D has expanded to synthetic fuels and biogas combining a and now includes cellulosic ethanol and vehicle demonstration, gases from biomass and gas from black liquor, all supported by the Swedish Energy Agency, EU programmes and private organisations. However, the business R&D intensity has diminished (European Commission, 2017) and key challenges are Business R&D spending, Public support for Business R&D, Public-private co-operation, and Product market regulation.

Sweden is currently involved in a number of ongoing H2020 projects on RDI through academic and private organisations, some focused on innovation technology [11] [12], whilst others look at improving sustainable supply chain management for biomass and bioenergy[13] promoting biofuels for sustainable mobility[14]. Chalmers University of Technology is researching gasification of biomass, chemical looping combustion, and oxy fuel combustion.

The Finish Biorefine Programme (2007–2012, 250 million Euros), funded by Tekes, aimed to develop new technologies, products and services related to biomass, and activate SMEs on niche products and markets and commercialize new technologies. Biomass-based fuels

10 Following Curci and Mongeau Ospina (2016), who used the database BioPat. A collection of keywords selected by literature review and catchword tools and validated by ENEA (the Italian National Agency for New Technologies, Energy and Sustainable Economic Development) were used to download patents in the EPO-WIPO-USPTO patent database.

11 http://cordis.europa.eu/project/rcn/199320_en.html

12 http://cordis.europa.eu/project/rcn/193744_en.html

13 http://cordis.europa.eu/project/rcn/194442_en.html

14 http://cordis.europa.eu/project/rcn/194441_en.html

for transport were a particular topic of the programme's first call. General Finish R&D programmes on sustainable communities and transport include. The TransEco Programme, initiated by VTT Technical Research Centre and funded by Tekes and the Ministries of Transport and Communications, of Employment and Economy and of Finance, particularly engages in electric vehicle and biofuel development (www.transeco.fi). It is not a top-down directed policy instrument like the other programmes, but rather a niche-building attempt that has managed to engage governmental organizations.

In 2015 the Swedish Energy Agency (SEA) invested SEK 180 million (€19,2 million) in research aiming to improve efficiency and cost effectiveness of biofuel production. The programmes focus on improving biofuels on existing vehicles and more heavily on lignin-based fuels with most of the investments covering R&D on biochemical and thermochemical conversion of products derived from forestry, agriculture and timber industry. Recent R&D activities include microalgae-based biofuels, lignocellulosic biomass for biofuel production and other synthetic biology-based biofuels (Heyne et al., 2015).

The Probiostål project results from the collaboration between Cortus Energy (a Swedish company in the production of biofuels via pyrolysis and gasification) and Höganäs (a world leader in the iron and steel powder market for vehicle components[15]). The project aims to identify and test innovative ways to curb the steel industry's CO^2 emissions whilst producing energy from biomass. The EU €28.4 million[16] BioDME project (2008-2012) piloted the sustainable production of DME from black liquor through the production of clean synthesis gas. The bio-DME was road-tested and lab-tasted with Volvo trucks since 2008. Since 2004 SEKAB E-technology is running its Domsjö biorefinery demonstration plant in Örnsköldsvik. Innovation developments focus on fractioning lignocellulosic materials (e.g. straw, wood and sugarcane bagasse) and fermenting. SEKAB collaborates with the Technical Research Institute of Sweden (SP) and other international companies.

3.4.4 Influence on the direction of search

The decision of the EU Commission to ban palm oil as feedstock, whilst allowing forestry by products, energy crops and tallol has been greeted by the biofuel industry in Sweden and Finland. In the new Swedish climate framework Biofuels play a major role towards greening Swedish transport. From 1st July 2018, the existing tax exemption for low-blend biofuels will be replaced with a new mandate on increasing energy content in diesel from biofuels.[17] There are also plans to mandate a 50% minimum biofuel blend in both gasoline and diesel fuels by 2030 (21% by 2021). This switch could induce a significant increase in biofuels production and use, but also facilitate long-term planning. For instance, Volvo Cars described the general focus on the environment and climate as crucial for their marketing of methane and flexifuel vehicles. It is worth noticing how since the 1980s, due to the significant availability of wood derived feedstock, R&D on ethanol received considerable support from the government both at the political and financial level (Hillman, 2011). The following policies, regulations, and market development activities have directly and indirectly supported the biofuels sector in Sweden:

[15] Höganäs's other activity areas include high temperature soldering, electrical motors, additive manufacturing and water purification.

[16] The budget was made of €8.2 million from the EU, €9.5 million from the Swedish Energy Agency and the rest from the consortium made of Chemrec, Haldor Topsøe, Volvo, PREEM, Total, Delphi and ETC.

[17] However, the revision of the EU Renewable Energy Directive which will revise targets for the sector by 2030 might affect the national targets.

The overarching Bioeconomy strategy sets the 2050 vision stipulating research areas for Sweden to achieve a green economy and climate neutrality. Key leverages will be efficient use of resources and bio-mass energy (bioenergy) for transport, indoor heating, electricity generation and in various industrial processes (Börjesson *et al.*, 2017).

From 2016 the tax ceiling for low-level blended biofuels was abolished allowing for both low-level blends of ethanol in the petrol up to and including 10% by volume, and fatty acid methyl esters (FAME) in diesel up to and including 7% by volume.

In its Budget Bill 2016 the Government reviewed the vehicle premium for green cars, increasing the appropriation for very low emissions vehicles by SEK132 million for 2015 and SEK 94 million for 2016. Moreover, the Bill stated a reduced taxable benefit for certain green cars, specifically for gas-powered cars, plug-in hybrids and electric cars would apply until the end of 2019. The reduction equates to 40 % of the taxable benefit with a ceiling of maximum SEK10,000 for more expensive cars.

In 2005 the Swedish Government introduced the "Pump Act"[18] to increase accessibility to renewable fuels. The Act stipulate that all fuel stations selling over 1,000 m^3 per year must supply alternative fuels. A follow-up in 2009 reported a significant increase in the possibility to utilise renewable fuels.

However, a lack of long-term vision policy on biofuels (for instance, currently the Swedish Ministry of Finance decides on tax deduction each year) counteracts substantial technological development and commercialisation of advanced biofuels.

One may argue that the dominant science-policy framework during the development of the biofuel sector in Sweden was developed on the assumption that the replacement of fossil fuels by biofuels would lead to a CO^2 emissions reduction (Lazarevic and Martin, 2016). However, amongst many Environmental Systems Analysis tools (ESA)[19] a dominance of carbon footprint focus in environmental studies clearly proves a "carbon vision" influencing the current science-policy framework (Lazarevic and Martin, 2016). This could be attributed to data uncertainty for other environmental impact categories and high level of uncertainty when addressing other impact categories (as they may depend on many other factors such as emissions location).

The 2016 record of 18.6 % in the use of biofuels in Sweden of all the fuels for transportation (SveBio, 2017) might suggest that the country is one of the best in Europe for switching to biofuels for transportation.

The recent and swift uptake of biofuels is mainly due to the diffusion of two types of biofuels, i.e. the Hydrotreated Vegetable Oil (HVO) diesel and the Rapeseed-derived biodiesel (RME). Whereas the share of biomethane in the natural gas vehicle (NGV) fuel blend has grown, the share of ethanol has diminished. Despite the increase in the use of biofuels in transportation, some factors such as the taxation of ethanol and RME or the 5 % blend of ethanol in gasoline (long applied according to EU standards) have limited the use of these fuels. (SveBio, 2017)

By 2023, accounting for continued development, Sweden could potentially produce biofuels for transport for approximately 18 TWh (Heyne et al., 2015). By 2030 the potential domestic biofuels production could reach about 26 TWh (Börjesson et al. 2017, (Heyne et al., 2015). Biofuels in road transport might therefore increase on average by 160-180 % by

[18] the Act on the Obligation to Supply Renewable Fuels

[19] Several tools can be used to understand the potential environmental impact of product and service systems have been referred as Environmental Systems Analysis tools (ESA) and they include LCA (Life Cycle Assessment), MFA (Material Flow Analysis), SFA (Substance Flow Analysis), carbon footprinting analysis, etc.

2030 and by the same percentage by 2050 with biomass-based fuels expected to play a critical role in reaching Swedish goal of carbon neutrality.

In Finland, the government climate and energy strategy (set 2016), intends for biofuels to cover 40% of all transport fuels volume by 2030. In addition, the government said that the renewable energy share of market should be raised by 50% or more by 2030, with the ultimate goal to create a 100% carbon-neutral energy base for Finland, utilizing the country's wood resources as a source for energy and fuel. Critics have pointed to such volumes dictating the prioritization of fuel production over potentially more value adding activities using this natural resource, and additionally locking the country into a biofuel TIS foregoing large scale electrification.

3.4.5 Entrepreneurial experimentation

In Sweden 200 cleantech start-ups are currently listed of which 18 in the biofuel sector (NordicGreen.net, 2017). The European Commission Eco-Innovation Observatory has noted the presence of publicly funded environmental technology clusters: Biofuel regions, Bioenergy in Småland, Sustainable Business Regions, Eco-design clusters.

The Biofuel for Aircraft project was part of a Swedish-US cooperation programme to develop alternative fuels. Actors included Swedish Biofuels in collaboration with Sweden's Försvarets Materielverk (FMV), Swedish Defence Materiel Administration, US Government, SAAB, Volvo Aero and GE. The programme consisted of a demonstration, application advanced processes for the conversion and deployment of alcohols into drop-in jet fuels for Saab Gripen fighter. Swedish Biofuels produced and certified its revolutionary jet fuel SB-JP-8 that is a 100% fully synthetic biological equivalent to petroleum based JP-8. Lantmännen Agroethanol is the major ethanol producer and supplier of grain-based fuel ethanol in Sweden, utilizing over 550,000 tonnes of wheat, rye and barley to produce 235,000 m3/year. ST1 has patents for Etanolix that is a method to produce ethanol (called ER85) entirely from local food waste. ER85 is believed to be the world's most sustainable bioethanol for transport with the lowest carbon emissions as it is extracted by food waste and therefore does not require arable land; it uses renewable energy for its production; utilises innovative energy efficient process and technology; and cuts transportation needs.

SunPine AB is the world's first company to extract and produce green diesel from tall oil, which is a residual product of the pulp and paper industry. The company operates a biofuel plant in Piteå and has a capacity of 200,000 m3/year. SunPine AB is owned by PREEM, Sveaskog, Södra and KIRAm AB.

The Finish government reserved 150 million Euros, 2011–2013, for demonstration of biofuel production facilities expecting at least two projects to receive EU funding for biofuel demonstration plants (MiF, 2012). In 2014, the Ministry of Employment and the Economy handed over 30 million euros in energy grants to the planned bioethanol production at a closed down paper mill. However, the project has failed to attract the necessary additional funding. UPM currently is starting an environmental impact assessment for a possible biorefinery in Mussalo, Kotka, in southeastern Finland. The EIA study states that the proposed second UPM biorefinery would use a different raw material base and technology than in the current UPM Lappeenranta Biorefinery. The Kotka Biorefinery would produce approximately 500,000 metric tons of advanced biofuels for transportation, made from several renewable and sustainable feedstocks.

3.4.6 Market formation

Until the year 2000, the volumes of biofuels sold in Sweden were below 0.2 TWh. Since 2005 the volumes of ethanol in E85 and bus ethanol fuel, and the amount of biodiesel blended into conventional diesel increased sharply while the use of biogas increased more slowly. However, the fuel share of biodiesel has stagnated at around 0.8% since 2009. Ethanol blends into gasoline have stagnated at around 1% of total gasoline consumption in Sweden. One reason might be that consumers are uncertain about ethanol's contribution to sustainable transport, and a fear of negative effects on engine performance and wear. (Harnesk et al., 2017; Hunsberger et al., 2017; Swedish Energy Agency, 2016)

The most notable development is the strong increase of HVO biodiesel which made up 64 % of the total biodiesel consumption, and has led to a stagnation of FAME biodiesels. Since HVO is chemically identical with fossil diesel it can be easily blended into conventional diesel or even replace it without affecting performance or wear. Currently, 19% of biodiesel is used in its pure form, up from 3% in 2008. Interestingly, the majority – 84% in 2015 – of the pure biodiesel is FAME, and not HVO.

Biodiesel and other biofuel use is expected to continue to rise in the future, however, this growth is expected to slow down after 2020 (Energimyndigheten, 2017). However, the number of newly registered dedicated ethanol vehicles is expected to decrease by 25% p.a. until 2020, after having halved every year since 2011. Currently, consumers can only choose from different VW Golf variants (Trafikanalys, 2017). However, low variety issues have been noted in EV development as well. (Fulton et al., 2016).

In January 2017, Swedish airport operator Swedavia received its first shipment of aviation biofuel becoming the first commercial partner to purchase sustainable aviation fuel for all flights. Swedish Shipping company Stena Line launched the world's first methanol-fuelled ferry in March 2015.

In Finland, Neste has just become the supplier of its renewable biodiesel for all public vehicles in the city of Espoo in its bid for carbon neutrality by 2030[20], joining a number of similar initiatives in the country.

Sweden has produced biodiesel, ethanol, and biogas since the 1990s (Nilsson et al., 2012): Large-scale units producing biodiesel emerged in the late 2000s, adding some capacity for hydrogenised biodiesel more recently.Though heavily reliant on ethanol imports, Swedish domestic production utilises a by-product of a pulp mill in Örnsködsvik (SEKAB). Another medium-scale ethanol operation in Norrköping uses wheat. Biogas is mainly produced and distributed by municipal companies. The case of biogas is a clear indicator that the biofuel system is closely linked to other technological innovation systems, in this case biomass for energy and heat generation. In Finland, three companies are currently refining biofuels: Neste, UPM and St1.

In 2014, UPM (Sweden) invested 150 mio USD to develop a plant that produces fuel by hydrogenating vegetable oils (HVO) in Finland. Several pilot plants are in operation, converting woody biomass into bio-oil. However, the economic viability of pyrolysis bio-oil as a petrol fuel will still require intensive research (Guo et al., 2015). The financial viability is vividly illustrated by the recent controversy surrounding the loss bringing Gothenburg GoBiGas plant. Between 2012 and 2017, Preem has invested 700 mio SEK in the Göteborg region in production capacities and fuelling stations, offering biofuel blends of up to 50%. (Sundh, 2017)

[20] https://www.neste.com/en/city-espoo-introduces-neste-my-renewable-diesel-take-step-closer-becoming-carbon-neutral

Even though Swedish biofuel is regarded as highly climate-friendly compared to biofuels from other countries, Sweden still imports large amounts of biofuels from other countries. 20% of all EU ethanol imports is shipped to Sweden. (Hansen et al., 2017) While the demand side has had a stable development, the production side still lacks the incentives to become competitive and sufficient. (Hillman and Rickne, 2012). Supply constraints are a heavily discussed issue for another reason as well: Even sparsely populated countries like the Nordics would not be able to substitute fossil fuels by biofuels completely due to a lack of arable land. (Hillman and Sandén, 2008; SveBio, 2016)

Governance arrangements on the European level influence the development in the Nordics. The biofuels distribution obligation (Act 1420/2010) requires that the share of biofuels in transport petrol and diesel consumption shall be 20% by 2020. Finland has decided to pursue a higher share of transport biofuels than required by the EU, based on a double counting rule. The higher share is justified in Government Bill 197/2012 based on seeking the most cost-efficient technologies and creating domestic markets.

The European Technology and Innovation Platform for Bioenergy ETIP[21] lists 18 market development projects in the EU context, the more recent ones focusing on advanced biofuels. It is argued that many of the current market support schemes regarding 2nd and 3rd generation biofuels lack a sound political backing. (Hannon et al., 2010; Wiesenthal et al., 2009) On EU level, there is no "certainty of consistent long-term policies in support of biofuels markets after 2020" (European Biofuels Technology Platform ETIP, 2017). This has led to some of the main market and research actors to withdraw from biofuels and rather invest in less risky alternatives. Swedish biorefining operators have actually started to transfer their attention towards cellulosic products or green chemicals which promise to yield higher value. (Hansen et al., 2017)

3.4.7 Legitimation

The "food vs. fuel" controversy has followed biofuels since their inception, (Börjesson et al., 2014). Biofuels were perceived as economically affordable and environmentally friendly by supporters, and deemed harmful to the environment, public health, and public households by its opponents. A recent study of Finnish consumer attitudes conforms this picture (Moula, Nyári, & Bartel, 2017). Indeed, the ambitious Finish biofuel policy has attracted domestic criticism[22] .

While historically, the support to the agricultural sector and energy security were the main drivers, combating greenhouse gas emissions has become an equally important goal for biofuel support in the EU and in Scandinavia (Lah, 2017; SveBio, 2017; Wiesenthal et al., 2009).

Sweden, has 170,000 ha barren land and 1.1 mio ha of low-productivity grassland. The Swedish Jordbruksverket estimated the available land for bioenergy plants in 2050 to reach 900,000 ha, a third of all agricultural land; Energimyndigheten expects this area to be accessible already by 2035. Despite the favourable opinion on biomass' rural development potential, some installations like biogas plants have been met with considerable resistance from neighbouring communities and inhabitants. (Lantz et al., 2007)

The largest biomass industry association in the Nordics is SveBio, with their platform BioDriv focusing on biofuels. It gathers members and companies to promote sustainable

[21] Hemsida: http://www.etipbioenergy.eu/markets-policies/biofuels-markets)

[22] http://www.eubioenergy.com/wp-content/uploads/2017/10/Open-letter-Finland-impact-on-EU%E2%80%99s-climate-ambition-and-forests-20-Oct-2017-v2.pdf

bio-energy use in the Nordics. In the beginning SveBio and other industry associations favoured biofuel blends, but their interest in pure biofuels grew with increasing market opportunities. Lately SveBio has started promoting advanced biofuels.

Many environmental and development organisations, mainly non-governmental, have lobbied against biofuels due to their harmful effects on food security and soil depletion. At the same time, OEM-led lobbying efforts have been accused of preferring biofuels over electrification of the fleet as this obviously is more compatible with existing fuelling technology.

3.4.8 Resource mobilisation

Tax exemptions were introduced as early as 1990 and subsidising biofuels. Several governance arrangements have followed: Reduction of fringe benefit tax for company cars, Investment grants for biogas projects (Hansen et al., 2017; Hillman and Sandén, 2008; IEA, 2013).

Up until 2009 biofuels were exempted of both CO^2 and energy taxes which would benefit the consumer with a price reduction on E85 and biodiesel of respectively 30% and 40 %. Moreover, the Government established a tax exemption above the previous limit of 15% for hydrogenated vegetable oils (HVO) to be retroactively applied from 1 May 2014 (Government Offices of Sweden, 2016). Currently, energy and carbon dioxide taxes are collected on the supply, import and production of fossil fuels whereas special tax deduction rules for biofuels apply[23] (RES Legal, 2017). It is worth noticing that the increased taxes on fossil fuels have been indexed to boost investments in renewable fuels. In 2015, tax benefits for FAME biodiesel were eliminated, while there are no fuel taxes on HVO biodiesel (Swedish Energy Agency, 2016).

Two large investment programmes in the late 2000s provided considerable volumes of money that enabled municipal investment in biofuels and clean cars. However, from a vehicle manufacturers' perspective the resources provided by the government and/or available inhouse never were enough for advancing biofuel technology in a way that it would have grown into a mature business within the OEM. When it comes to advanced biofuels, the resources freed up for research and development were too low to really advance that market. Globally, Sweden is not competitive in advanced biofuels research. However, it is argued that already 70% of the biofuels used in Sweden reduce emissions by 66% or more, which could reduce the motivation to invest more in advanced biofuels. (Swedish Energy Agency, 2016)

Resource mobilisation is also indicated by the number of people working with an innovation. For biofuels and biofuel-driven vehicles, this is hard to pin down as many statistics will merge biofuels and biomass; and at OEM level, it will be almost impossible to pin down the exact number of engineers working exclusively with biofuels. Market analyses will be even more general as their scope is as large as the "bioeconomy" which encompasses everything from agriculture, forestry to paper milling. (Formas et al., 2012) However, the shortage of skilled engineers across all sectors in Sweden also impacts the ability of OEM and other players in the biofuel economy to recruit professionals. (Svenska Teknik & Designföretagen, 2016)

23 Biofuels are tax exempt and must be certified with sustainability certification according to Chapter 3 § 1b Act No. 2010:598.

3.5 Autonomous vehicles

Autonomous driving and automated vehicle technologies are rapidly evolving as autonomous driving vehicles are tested on the road. (Kröger, 2016; Terrien, Maniak, Chen, & Shaheen, 2016) Automated technologies (including anti-lock brakes, rear view alarm systems, lane departure warning systems, and adaptive cruise control) have been incorporated into cars for a long time, and ICT is spurring their rapid deployment and integration. (Schreurs & Steuwer, 2016) There exists considerable uncertainty regarding the technical feasibility and market diffusion (commercialization) of autonomous vehicles. (Igliński & Babiak, 2017) While some analysts don't see full autonomous vehicles before 2040, many OEM have been stating they will have models ready as early as 2020. Examples of AVs in development include the Nissan Leaf, Chevrolet Bolt, Chrysler Pacifica Hybrid, Ford Fusion, Volvo XC 90, Mercedes-Benz F 015 and Hyundai Ioniq and Tucson. However, these vehicles allow for semi-automated driving in certain traffic conditions and contexts (e.g. traffic jams, on highways, and on parking lots) only; fully automated vehicles that can handle complex traffic environments or may even operate "driverless" are expected by 2030 and beyond. Expectations for penetration rates also vary significantly; generally, a significant market penetration is not expected before 2050. (Bansal & Kockelman, 2017; Igliński & Babiak, 2017)

Autonomous driving will change the mobility sector significantly as new mobility services and routines are enabled, new stakeholders emerge and new demands are placed on policies. (Beiker, Hansson, Suneson, & Uhl, 2016; Bjelfvenstam, 2016; Schreurs & Steuwer, 2016) Conditions for adaptation will heavily depend on regulation and on road traffic conditions. (Schreurs & Steuwer, 2016) At the time of writing, full AVs are restricted in most countries; those AVs that are operating do so either in restricted test areas (like university campuses or industrial facilities) and/or with a driver on board or following the vehicle for emergency intervention. (Beiker, 2016) However, policies to reduce some restrictions are emerging, and hands-free driving and testing of fully driverless vehicles are allowed in certain areas. (Fulton, Mason, & Meroux, 2017)

The extent of automation is currently divided into 5 levels, based on the SAE's international standard J3016 (Society of American Engineers, 2016), see figure 3.7. Level 1 is widespread and level 2 is rapidly being introduced in many models. (Igliński & Babiak, 2017) Level 3, including hands-free driving, is just emerging and only legal in some areas. Levels 4 and 5, with true full-time driverless operation, is not known to be fully legal anywhere in the world as of early 2017, except for operation by test fleets.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 3.7: SAE Automation levels 0-5 (Society of American Engineers, 2016).

AVs in the decarbonisation context

While the main motivation for vehicle automation is increased safety and comfort, and reduced costs, it may also contribute to decarbonisation in the transport sector by improving traffic flows and reducing energy use (see overview in Table 3.2. This contribution is however highly contested and uncertain. (Gruel & Stanford, 2016) For one does it depends on market penetration, with many of the (positive) effects not expected before 2040. (Litman, 2015) Secondly, performance and effects of AVs depend on the transport systems and policy frameworks they are embedded in. (Igliński & Babiak, 2017; Lenz & Fraedrich, 2016). EU strategy documents and research strategy have long called for the deploying ICT in order to make the transport system more sustainable. The EU transport roadmap which describes dual goal of increasing transport and mobility within the Union while reducing greenhouse gas emissions by 60% until 2050 repeatedly calls for research in ICT to optimize transport flows and increase efficiency (European Commission, 2011) However, it does not establish a clear link between autonomous/automated driving and decarbonisation. Even the EU transport research agenda "Research and innovation for Europe's future mobility (European Commission, 2012) Developing a European transport-technology strategy" does not establish the link – it does not even mention the terms "autonomous" or "driverless". Thirdly, effects depend on how and by whom AVs are used, i.e. on use cases ("scenarios") and user groups, and on AV service models. (Litman, 2015; Wachenfeld et al., 2014). Aarhaug et al (2018) points out that if the introduction of AVs follows a traditional pathway it may lead to a strong icrease of the transport volum and a shift in the modal split which favours autonomous cars but may have negative envirnmental impacts.

Table 3.3: AVs' possible impacts on transport sector decarbonisation (Anderson et al., 2014; Fulton et al., 2017; Heinrichs, 2016; Igliński & Babiak, 2017; Litman, 2015; Meyer, Becker, Bösch, & Axhausen, 2017; Snow, 2017; Trommer et al., 2016).

Positive impacts on decarbonisation	Negative impacts on decarbonisation
Apply principles of eco-driving Improves traffic flows Facilitation of ride-sharing, reducing vehicle miles Facilitation of on-demand travel, reducing number of vehicles Higher usage of transit as it is improved by autonomous vehicles on flexible schedules and routes	Induced demand through better accessibility (new locations; new user groups) Induced demand through reduced costs (through eliminating labour costs) Higher usage due to possibility to use time more effectively Decreased vehicle lifespan due to higher usage of vehicles
Positive impacts on other sustainability aspects	**Negative impacts on other sustainability aspects**
Lower land use through reduced parking requirements Lower land use as route capacities are freed up due to higher possible vehicle densities ("platooning"), reduced lane width demands, and improved traffic flows Transport equality through better access for (new) user groups Higher quality of (urban) life through reduced pedestrian risks and parking demands	Increased resource use with lower vehicle lifespans (due to higher usage of vehicles) Higher land use, esp. suburban sprawl and increase in other automobile-dependent locations, as costs/burden of driving decrease

Currently, a common strand of argumentation points out that in order to avoid or minimize the negative effects of AVs, their advent will need to be combined with the paradigm shifts of electrification and shared mobility patterns. (Johnson & Walker, 2016, Aarhaug et al 2018) This combination supposedly yields much higher decarbonisation benefits than the three paradigm shifts on their own[24] as "the positive and negative aspects of each revolution will interact in many complex and difficult-to-predict ways".[25] (Fulton et al., 2017) Interestingly, many simulations and modelling exercises focus on urban environments as they are expected to become key markets for AVs. (Bloomberg Philantropies & Aspen Institute, 2017) while the first future use cases are more likely to be long-distance applications (e. g. on highways) or for goods transport. (Lamondia et al., 2016)

Another major shortcoming in research and practice however is that urban and transport planning activities (e. g. urban master plans, transport master plans) have barely started to not consider the potential effects of future AV deployment sufficiently. This is particularly significant as many of these activities, e.g. urban master plans, are long-term oriented and could easily take into account long-term developments like autonomous mobility. (Fagnant

[24] In a similar vein, the massive diffusion of e.g. one-way carsharing could lead to an oversized fleet and underused vehicles as there is a need to guarantee a level of vehicle availability coupled with an imbalance between stations. This imbalance however could be encountered with self-driving vehicles which make available vehicles more flexible regarding their location. (Terrien et al., 2016)

[25] The ITDP (Fulton et al., 2017) made the first attempt to quantify the effects of the combination of shared mobility with automation and electrification on a global level. Similar attempts have been conducted for smaller geographical areas, e.g. for autonomous taxi networks for New Jersey (Brownell, 2013) or automated mobility-on-demand system on the Stanford University campus in California, based on the Navia vehicle by French company Induct (Beiker, 2016).

& Kockelman, 2015; Litman, 2015) At the same time, AVs might not become the most important game changer to future mobility and cities, but it will rather be their interaction with other developments (e. g. demographic trends, changing user preferences, planning innovations). (Beiker et al., 2016; Gao, Kaas, Mohr, & Wee, 2016; Litman, 2015).

Regarding the TIS analysis, it should be noted that the technology and market for AVs is barely unfolding, they don't have a long (hi)story to tell. This is even more true for their decarbonisation potential which will not unfold until a certain market penetration is reached, not to speak of their blending into low-emission mobility service concepts. The TIS analysis will therefore mainly focus on current and future developments and will include observations about the past only where necessary and possible.

3.5.1 Global Developments

Global research on AVs is vast and encompasses disciplines reaching way beyond conventional automotive engineering. This is due to the equipment of AVs that differs significantly from conventional vehicles (automatic transmissions, sensors, wireless networks, navigation, automated controls, servers, software and power supplies) as well as their capacity to change mobility systems significantly. (Litman, 2015) Research areas for AVs reach all the way from software, electronics, vehicle concepts, simulation and testing to socio-economic disciplines working with policies, business models and environmental effects.

A main part of the research on AVs consists of defining roadmaps for research as the field is not yet entirely mapped and investigated. A significant part of these roadmaps has its origin in international / supranational organizations striving for standardization and harmonization for the economy's benefit. Key research roadmaps by manufacturers and (lobby/state/research) organizations include:

- ERTRAC Automated Driving Roadmap ERTRAC Task Force "Connectivity and Automated Driving" (ERTRAC, 2015)
- EPOSS European Roadmap Smart Systems for Automated Driving (Dokic, Müller, & Meyer, 2015)
- SAE (Society of American Engineers, 2016)

As the advancement towards highly Automated Driving is seen as an evolutionary process to ensure that all involved stakeholders can develop and evolve with the adequate pace, knowledge and research also develops in an evolutionary manner. (ERTRAC, 2015) Evolutionary relates to the advancement of vehicle development through automation levels 0 to 5, with more and more tasks taken over by intelligent systems. (see also Figure 3.8: Assistance systems on the market/in development (ERTRAC, 2015).

for Assistance Systems already on the market) Between level 4 and 5 this advancement goes from one to several to all "use cases".[26] While past efforts in automotive engineering focused on achieving partial automation in all situations (the "something everywhere" paradigm or SAE level 2-3), current efforts focus on accomplishing full automation for specific use cases (the "everything somewhere" paradigm or SAE level 4). After successful completion of level 4, efforts for achieving full automation in all situations (SAE level 5) will be taken up. However, R&D strategies differ, with some actors mixing paradigms or changing their order.

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[26] Use cases can be characterized by variables and values like occupant type, velocity, scenery (urban, rural, confined) or dynamic elements, to name just a few. (Bartels et al., 2015; ERTRAC, 2015; Wachenfeld et al., 2014)

Current ADAS on the market	Future ADAS for Automated passenger car path
Level 0 • **Lane Change Assist** • **Park Distance Control** • **Lane Departure Warning** • **Front Collision Warning** **Level 1** • **Adaptive Cruise Control** • **Park Assist** • **ACC (incl. Stop & Go)** • **Lane Keeping Assist**	Level 2 • Park Assistance • Traffic Jam Assist Level 3 • Traffic Jam Chauffeur • Highway Chauffeur Level 4 • Parking Garage Pilot • Highway Pilot • Highway-Pilot with ad-hoc platooning

Figure 3.8: Assistance systems on the market/in development (ERTRAC, 2015).

The European Union has a long history of funding collaborative research projects contributing to the development of automated driving. Projects are mainly conducted in four different categories: a) Networking and Challenges, b) Connectivity and Communication, c) Driver Assistance Systems and d) highly automated urban transport systems. (ERTRAC, 2015) Important EU initiatives/programmes include:

- iMobility Forum: working groups that produces R&I roadmaps and deployment scenarios
- C-ITS Platform: dialogue, exchange of technical knowledge and cooperation, among the Commission, public stakeholders from Member States and local/regional authorities
- EPoSS European Technology Platform on Smart Systems Integration): developed an European roadmap on "Smart Systems for Automated Driving" (Dokic et al., 2015) based on surveys and consultations among major companies

According to The Science Direct database[27] publication activity in the AV field has more than doubled in the last 8 years, from 3619 I 2009 to 8923 in 2016. However, it should be noted that a major share of research is going on in the private sector which tends to publish much less than public research.

The advent and adoption of the autonomous car

By now, there exist numerous AV market forecasts, impact studies and scenarios for a range of countries and regions around the world. (Beiker et al., 2016; Brenden, Mattsson, & Kristofferson, 2017; Giesel & Nobis, 2016; Milakis, Snelder, Arem, & Homem de Almeida Correia, 2017; Mosquet et al., 2015; Trommer et al., 2016) Some do inform policy making and industrial strategy while others have a pure scientific objective. Besides shedding light on the opportunities, they are not short on pointing out barriers and challenges. Unlike with EVs, technological challenges and unsolved challenges are in focus. Despite that, the major AV players never stop to be enthusiastic about the bright future of AVs. However, similar to EV situation, prices could slow down adoption of full autonomous capability. At current level, full autonomous capability could incur an extra $10,000 extra cost. (Mosquet et al., 2015)

However, when using these studies, caution is necessary since there are many and contradictory factors affecting future vehicle fleet sizes and vehicle kilometres/trips.

27 http://www.sciencedirect.com

(Brenden et al., 2017; Gruel & Stanford, 2016) Not surprisingly, the forecasts of quantitative and qualitative effects of AV and their related services differ significantly, only allowing for approximate estimates, and cannot inform urban or transport planning so far. This may explain the urban and transport planning sector's reluctance or inability to account for AV expansion in a satisfactory way. (Litman, 2015)

However, many experts point out that the logistics and servicing industry is poised to be the fastest adopter of driverless cars compared to private vehicles:

- Urban deliveries and services: Some experts point out that especially urban roads are filled mainly with trucks, lorries, taxis and other service vehicles, all of which are much more likely to adopt self-driving technology very fast. Last-mile delivery will be revolutionized through shared cars, parcel station loading and even self-driving parcels; store deliveries can be optimized greatly by automation and using a few smaller vehicles instead of one large vehicle unloading goods in narrow alleyways; taxi services can be fulfilled with driverless, shared vehicles in a service solution (automated taxi / automated on-demand mobility)
- Long-distance transport: More organized convoys and assisted highway trucking mean more trucks and better conditions for truck drivers. "Truck platooning" is one of the main research areas in AV technology and may yield significant benefits from an environmental, safety, and economic perspective.
- Warehouse and other indoor logistics. Indoor sites with no public provide the ideal environment for controlled, automated vehicles as external conditions (light, view, temperature) hardly change. The same could be possible for other large indoor sites with public that handle large amounts of material, like hospitals or shopping centres.
- Other confined areas (factory sites, mines, ports and logistics centres): confined sites are already at the forefront of automation. Despite challenging conditions as they exist in mines they nevertheless provide a controlled area with only limited "dynamic elements", i.e. passengers or cyclists. Automated loading and unloading on ports already improves operations and productivity significantly.

The development of AVs has sparked a vast number of new start-ups and niche companies to rise to significance, sometimes overtaking incumbents, often trying to keep up through mergers, acquisitions, and collaborations at an incredible pace. The main influx of new players comes from the IT side, and it creates a much more diversified and dynamic market landscape. At the same time, suppliers are spearheading some major developments in parts, processing, and controls, and could quickly outcompete OEMs. Bosch, Continental, Delphi Automotive, Mobileye, Valeo, Velodyne, and Nvidia are the most prominent and powerful among them.

More than any technological innovation in mobility, AV technology will change not only transportation with ever more diversified vehicles and services but also the automotive market landscape. (Bartels, Eberle, & Knapp, 2015; Beiker et al., 2016; European Commission, 2011; Gruel & Stanford, 2016; Milakis et al., 2017) Supply chains will be altered, business models revolutionized, and incumbents' competitive edge threatened by rising niche players. Traditionally, the automotive sector is characterized by a strong vertical integration whereas new tech players and service providers are more focused on horizontal expansion. With that strategy, none of the new players will likely dominate the complete value chain but rather hollow out parts of the value chain, disrupting the vertical expansion strategy of incumbents. (Beiker et al., 2016)

3.5.2 AVs in The Nordics

The Nordics had not been at the forefront of automatization for a long time, but ever since the launch of the Swedish DriveMe initiative which will put 100 Volvo AVs on 50 km of public roads they have become a more internationally heard player. This was made possible by the deep, but sometimes less-known/hidden engagement into safety and comfort enhancing assistance systems (ADAS) of OEM and suppliers, but also new market/niche players in the Nordics. Quite naturally, Sweden is at the forefront of activities as it has domestic OEMs. But there is also a lot of testing activity and policy/regulatory discussion going on in Norway (Aarhaug et al 2018) and Finland, especially in relation to the countries' ambitious decarbonisation and mobility goals. Denmark is home to several suppliers which are quite active in research, along with academic research, but has no demos, pilots or test regulation changes announced yet. On the infrastructure side, all countries are busy in developing smart and connected roads to be prepared for autonomous vehicles. In general, a lot of activity is happening within the goods logistics sector.

3.5.3 Knowledge Development and Diffusion

In the Nordic countries, mainly Finland and Sweden have initiated major research lines on AVs. In addition, all countries are participating in international (mainly EU-financed) research projects. By now, technology maturity allows for real-life tests and demonstration projects, and changes in regulations that allow tests with self-driving vehicles on public roads have sparked test and demonstration activities[28].

Sweden's strategic innovation program DriveSweden is a government-sponsored collaboration platform for designing the next generation mobility system, based on Connected, Automated and Shared vehicles. Partners range from public authorities, car manufacturers and suppliers all the way to mobility service operators and municipalities. Its most prominent project is DriveMe, which tests self-driving cars on public roads. Besides Volvo Car Group, the Swedish Transport Administration, the Swedish Transport Agency and the City of Gothenburg are involved in the pilot. Over approximately 50 kilometers of selected roads in and around the area of Gothenburg, 100 self-driving Volvo cars will be daily used by real costumers. The main objective of the project is to conduct necessary research on how autonomous driving will affect road transport (both vehicle and infrastructure), infrastructure requirements, traffic situations, sur-rounding interactions and social benefits of autonomous driving.

DriveSweden is also piloting new types of vehicles that are expected to be develop with the advent of autonomous technology, such as mini shuttle buses. Pilots have been conducted in Kista/Stockholm, more are planned for Göteborg and Umeå. The pilots have the main goal to analyze user behavior and acceptance and try out new business models. The vehicles are purchased by French manufacturer Navya. Sweden is also operating the largest test facility for AVs in the Nordics, AstaZero. The facilities and simulation possibilities are constantly expanded according to current technology development.

Finland and Norway are part of a cross-boundary project, the "Aurora Borealis Intelligent Corridor and Test Ecosystem for CAD". It includes a 38 km test track on the E8 between Finland and Norway and the SnowBox testing facility. The region above the polar circle has 6 months of snow and 25 days of polar night which makes it ideal for testing AVs in

[28] For a global översikt of testsites/demoprojects in cities see Bloomberg's "AVs in Cities" map: http://avsincities.bloomberg.org/

severe weather conditions. Additionally, the E8 features 26% of freight traffic, a comparatively high share. The Aurora project enables testing on public roads as well as on closed tracks. Results will concern vehicle automation as well as intelligent infrastructure.

Another cross boundary project Sweden is involved in is the EU initiative on standardization and classification of Automated Driving and Parking Functions "AdaptIVE"[29], (2014-2017) where a consortium led by Volkswagen developed criteria for the classification of different autonomous vehicle functions. In Norway AV technology is a key topic in the new transport research program published by the research council of Norway (RCN) although the number of research projects is still relatively limited. Most current research involves small scale field trials with focus on ITS.

Two initiatives that have gained attention is Smart Feeder and E6 Borealis; both initiatives that involves some elements of research although the key focus are on technology testing. *Smart feeder* is a long-term projects with automated shuttlebuses. Mostly development of systems and simple trials within safe areas. Involving SINTEF, National Railroad Administration, ITS Norway, National Road Administration. *E6 Borealis* is a larger scale project mainly addressing intelligent transport systems over a 40-km road in Tromsø in northern part of Norway (E6- in Tromsø)[30]. A central objective is to develop road infrastructure that is prepared for future AVs and trials with technical systems where road based information interact with vehicles, is tested out. The project collaborates closely with the Finnish *Aurora* project[31].

There are a limited number of AV pilots in Norway, all launched during the last years (2016/17). Three tests/field trials are currently running in three city regions; Oslo, Stavanger and Kongsberg.

The public transport service provider in *the larger Oslo region*, Ruter, is will start pilot trials with autonomous busses in 2018, involving multiple geographical regions. They intend to test a smaller fleet of vehicles operating in mixed urban environments, and it will involve segments of their current customer base. The test period is scheduled for 2-3 years, although each pilot may be of shorter duration. The first trials will be conducted in the larger Oslo region, and the goal is to have 10-20 busses operative during 2018/19. It will be possible to book the AC through the regular ticket and route information app.

In *Stavanger*, in Rogaland county the public transport provider (Kolumbus), has started a pilot with driverless busses (started 2017). So far, the busses have mainly been used in a restricted area. When a new legislative framework for autonomous vehicles are in place, the pilot study will be extended to tests on public roads. In the third stage the bus will drive a fixed route between the 3000 enterprises at the industrial area north of Forus.

In *Kongsberg* there has been launched plans to start up pilot trials with self-driving busses in 2017. The marine industrial cluster in Kongsberg has a strong position in the market for sub-sea automation technology, and there is an ambition to exploit this knowledge for the development of automated road transport. The municipality is involved in an EU project where the objective is to test one automated busses during winter time. According to the plans, the buss will follow a 2 km route involving open streets and real traffic situations.

In addition to these pilots, there has been *demonstrations* of AVs facilitated by technology developers. Acando, a Norwegian based technology and software company, has launched 15 demonstration projects in Norwegian cities the last year. The demos have got significant publicity and member of the government, local politicians and car manufacturers have used

29 Press release: http://www.volvotrucks.se/sv-se/news/press-release.html?pubid=20892

30 https://www.vegvesen.no/Europaveg/e8borealis

31 https://www.liikennevirasto.fi/web/en/e8-aurora#.WiAX1aaouUN

it actively to promote AV as an emerging transport technology. Smart mobility is one of Acandos key business areas and they are importer of automated coaches to Norway (see picture). Promotion of AVs is a central part of their market strategy, and together with Bertel O. Steen, a major Norwegian car provider they plan pilot projects in several cities next year

Denmark is home to a very visible and unique player in self-driving vehicles, namely vehicle operator "Autonomous Mobility". The company imports and operates self-driving mini buses from French and US operators and has been involved in demonstration projects in Sweden (s. above). Ever since test regulation in Denmark also allows for tests with self-driving vehicles on public roads[32], test activity has been sparked and includes 4 self-driving shuttle buses in Copenhagen (Lungby campus and Albertslund)[33] as well as the city of Aalborg planning to include a mini shuttle bus in their regular services.[34] Besides mini buses, BMW and public transport operator Arriva plan to roll out a test with 10 self-driving BMWs on a hospital campus in Copenhagen by 2018.[35]

Besides personal cars, there is massive research going on in the heavy vehicles (trucks and bus) segment. Volvo CE and Volvo Trucks both are developing autonomous heavy vehicle prototypes and concepts[36] and are conducting real-world tests[37]. They expect advantages related to optimization of traffic flow, reduction of fuel consumption, and road safety improvements. AB Volvo is focusing on highway automation, automation in confined areas for trucks & construction equipment and highway platooning. Scania has been trialing automated transport with heavy trucks starting with mining carriage in 2016. The next step will be automated platooning for long distance transport which is planned in 2018. (ERTRAC, 2015) Norway has a strong focus on AV applications in the freight, construction and maritime sector. It is place of the first demonstration project of an autonomous boat (SoUrCe) and will trial self-driving snow plows on Bodø airport in 2018.

32 https://www.njordlaw.com/manglende-dansk-lovgivning-blokerer-selvkorende-robotter-2/

33 http://www.nobina.com/en/nobina-technology/news/nobina-i-nytt-stort-pilotprojekt-med-sjalvkorande-fordon-i-storkopenhamn/; https://www.hightechsummit.dk/denmarks-first-self-driving-vehicle-is-tested-at-dtu/

34 http://cphpost.dk/news/driverless-electric-bus-to-be-tested-in-aalborg.html

35 https://www.thelocal.dk/20170714/driverless-cars-to-hit-the-road-in-denmark

36 e.g. prototype autonomous wheel loader and articulated hauler, prototypes revealed in September 2016 (see Press release: https://www.volvoce.com/-/media/volvoce/global/global-site/our-offer/brochures/volvo-construction-equipment-reveals-prototype-autonomous-machines-final-16-09.pdf?v=bE4yPw); HX1 Autonomous Load Carrier

37 Self-driving truck for refuse handling (see Press release: http://www.volvotrucks.se/sv-se/news/press-release.html?pubid=21939); self-steering harvest truck (see Press release: http://www.volvotrucks.se/sv-se/news/press-release.html?pubid=22024); self-driving trucks at inland harbor in Borås (see Press release: http://www.volvotrucks.se/sv-se/news/press-release.html?pubid=21853); self-driving mining truck in Kristinebergs mine in Sweden (see Press release: http://www.volvotrucks.se/sv-se/news/press-release.html?pubid=20892)

3.5.4 Influence on the direction of search

As a major part of AV technology is rooted in ADAS, safety has been a main driver for the development of AVs for a long time. Together with increased comfort, the technology is perceived and presented as a promising, if not essential solution for future traffic. Decarbonisation or sustainability effects still play only a minor role among manufacturers and investors. However, they are beginning to play a major role among academia, public authorities and municipalities who expect to solve many of the urban traffic problems by introducing electrified AV fleets. The major precondition for the sustainability effects to realise is that they be operated in fleets and not as a supplement to private cars. Without an operation in fleets they could increase some traffic problems, most of all congestion. These diverse drivers are represented by public authorities and public research efforts on the one hand and by manufacturers'/suppliers' announcements on the other.

Sweden's "National Transport Plan 2018–2029" defines that "connected, autonomous and electric vehicles combined with mobility services have the potential to radically transform road transport." (Trafikverket, 2017). The same message is to be found in the Norwegian National Transport Plan (Meld 33 2017). These priorities are reflected in the funds and efforts that are put into AV development in various public research programs in the Nordic countries[38]. A major direction which these public actors push concerns the actual sustainability effects of autonomous vehicles. It is assumed that AVs will not automatically reduce emissions, congestion and other negative effects of transport, but quite the opposite – if they are not, or less sufficiently, integrated in shared services they can cause an increase in both the number of vehicles and trips.

The direction of search is also influenced by the automotive industry in Sweden. While Volvo Group (trucks and buses) and Scania communicate their efforts and achievements in automatization quite clearly, Volvo Cars Corporation is much more cautious about public announcements. Another group of stakeholders that is setting the agenda are transport and fleet operators. Public transport operator Nobina is clearly planning to include AVs in their future vehicle fleet and is demonstrating this engagement by conducting pilots with self-driving mini buses in Stockholm. At the same time, all manufacturers and operators are part of the large research projects in Scandinavia, like DriveSweden or Aurora Borealis.

3.5.5 Entrepreneurial experimentation

October 2017 saw the first announcement of an industrial trial of AV technology when LIDL and Einride announced they would test autonomous delivery vehicles for goods logistics between a warehouse and a supermarket in Halmstad.[39] This trial adds to the numerous pilots and demonstrations in the goods logistics area which are taking place all over Sweden and/or are initiated by Swedish companies (see section on "Knowledge Development and Diffusion" above). It is expected that industrial trials – and market formation – in personal AVs will be preceded by goods/logistics AV applications. One of the reasons is of technological nature as goods transport often operate in limited or less-complex environments; another reason is the size of the customers which makes it easier to collaborate and start a market with.

November 2017 saw another surprizing announcement: Ride-hailing company Uber ordered 24,000 SUVs from Volvo which Uber is planning to operate and deploy in a

[38] In Sweden, amongst other FFI=Fordonsstrategisk forskning och innovation, Drive Sweden=Innovationsprogram för framtidens fordon, Closer=Nationell arena för transporteffektivitet, K2=Nationellt kunskapscentrum för kollektivtrafik.

[39] https://www.einride.eu/en/PressReleaseLidl

proprietary self-driving fleet in the US by 2019. Even though a flexible contract, it is by far the largest order ever placed on self-driving vehicles and has moved the Nordics ahead in the entrepreneurial landscape.[40]

Besides industrial trials Sweden has several active players within IT and systems development that are not dependent on public funding. Besides suppliers who have developed expertise in AV computation like Bosch or Delphi, Volvo Cars Corporation founded its own AV software venture, Zenuity, in 2016. Operating on a commercial basis, it is expected to deliver market-ready solutions for Volvo's future autonomous vehicles. Other players involved in AV development are those contributing to DriveSweden platform projects[41].

3.5.6 Legitimation

Since July 2017, Sweden has changed its regulatory framework in a way that it allows for pilots with AVs on public roads. This is supposed to spark AV piloting and testing around the country. However, there are significant shortcomings when it comes to type approval of AVs. The relevant framework is based on technological specifications instead of functional requirements which makes it virtually impossible to seek type approval for vehicles that lack conventional human-operated elements like brake pedals and steering wheels. However, discussions are ongoing to change this – otherwise the new test regulation becomes an empty promise.

Since 2017, test regulation in Denmark allows for tests with self-driving vehicles on public roads[42].

In Norway's National Transport Plan for 2018-2029, the need for intensified development of vehicle technology, including ITS and AV, is underscored (Meld 33 2017). The plan claims that the government will marshal trials and testing with automated vehicles. This include extension of the pilot trials in E8, with six more major roads. The NTP proposes to develop a new legal framework that can remove legal barriers and obstacles for further use of AVs. A draft bill and resolution was presented for the parliament summer 2017 and was authorized and approved late November same year. The government also invites to local competitions addressing smarter mobility in Norway and a 100 mill kr fund has been set aside for this. Norway's National Road Administration is involved in activities working towards international harmonization of AV and ITS standards. This involves the International ITS cooperation, ETSI, IEE and IETF.

The three countries Norway, Finland and Sweden signed the EU joint statement on connected and automated mobility which includes a commitment to cross-border testing in Finland, Norway and Sweden. (http://europa.eu/rapid/press-release_STATEMENT-17-3272_en.htm). It will include the Nordic Way corridor as well as corridors in Tromsø (NO) and Oulo (FI).

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40 https://www.forbes.com/sites/bizcarson/2017/11/20/uber-volvo-xc90-driverless-autonomous-car-deal/#14539fff7a03

41 see https://www.drivesweden.net/partners

42 https://www.njordlaw.com/manglende-dansk-lovgivning-blokerer-selvkorende-robotter-2/

3.6 Mobility as a Service

Mobility as a Service (MaaS) refers to a novel concept that has emerged in the past years and which aims to provide a valid and service-based alternative to private car ownership. Across Europe, there is currently a high level of interest in MaaS, with several pilots and demonstrations underway. Given the present lack of agreement on what constitutes MaaS and how it is defined, Sochor et al. (2017; see also: Kamargianni et al., 2016; Lisson et al., 2015), have developed a MaaS 'topology' (figure 3). The topology builds on differing degrees of integration – a parameter that has been noted by other scholars as important to transport services (e.g. Kamargianni et al., 2016).

The topology consists of different levels. Level 0 represents the status quo in many cities across the developed world, and is characterised by fragmented mobility services that each compete for customers. Level 1 refers to integrated informational services, such as multimodal travel planners (e.g. Google), which provide information on available mobility services and routes in different cities. Level 2 refers to services that facilitate online bookings and payments via third parties, such as Hannovermobil. Level 3, which is currently given much attention in and around the transport sector, refers to the integration of different mobility services into a single, seamless offering that is made available to users via subscription-based smartphone applications (see also: Beutel et al., 2014; Goldman and Gorham, 2006; Sochor et al., 2015). Organisations such as MaaS Global (FI) and UbiGo Innovation (SE) are active at level 3. Finally, level 4 refers to the integration of societal goals such as transport policy objectives and sustainability into MaaS ecosystems and services at levels 0-3.

Figure 3.9: The MaaS topology developed by Sochor et al. (2017).

Given the current attention given to level 3 MaaS services, the text that follows focuses on MaaS in terms of mobility services that serve to combine different transport modes. Within the Nordics (and beyond), the following functions are of relevance: F1: Knowledge development and diffusion; F2: Influence on the direction of search; F3: Entrepreneurial experimentation. This selection of functions is reflective of the available literature on MaaS, and also the current, pre-commercial phase of MaaS developments.

3.6.1 Global developments and developments in the Nordics

Sweden was arguably the birthplace of the MaaS concept via two R&I projects that were conducted between 2011-2014. The first, entitled 'The Flexible Traveller', investigated business opportunities associated with MaaS (Boethius and Arby, 2011). The second project was a *VINNOVA*-funded action-research project in Gothenburg entitled Go:Smart, which comprised a field-operational test (pilot) of a mobility service that combined public transport, car- and bicycle-sharing services, car rentals and taxis in 2012-14. The success of the latter project created interest in the MaaS concept. However, barriers to collaboration among partners have hindered the commercialisation of MaaS services ever since. Hence the role of pioneer within the Nordics has arguably been taken up by Finland, which has run a set of pilots funded by *TEKES* since 2015, resulting in several ambitious start-ups (Smith et al., 2017c). Interest has also spread to other Nordic countries. In Denmark, pilots are currently underway via the EC2B project, run by the Swedish consultancy *Trivector* and funded by the Climate KIC. EC2B links Malmö and Copenhagen. In Norway, the public transport operator *Ruter* has recently started to discuss the MaaS developments in Oslo (Aahaug 2017).

The MaaS concept has now gained international recognition, with pilots and related R&I activities underway in Scotland, the Netherlands, Austria, Australia and Singapore. Several R&I projects in this field have received funding, such as MaaSiFie, Eccentric, IMOVE and MaaS4EU. International networks such as the MaaS Alliance, Polis and UITP, alongside conferences such as the ITS World and European Congresses, and IcoMaaS (marketed as the first international conference on MaaS by the University of Tampere) are useful channels for knowledge dissemination and networking.

3.6.2 Knowledge development and diffusion

In Finland, a series of pilots were established in 2015 as a means to trial the MaaS concept and create market opportunities. Sweden has recently established a R&I initiative entitled KOMPIS to supply funds for pilots and trials of MaaS services, also focusing on sustainability assessment. In Denmark, a pilot entitled EC2B aims to trial MaaS in the *Öresund* region that links Malmö and Copenhagen. In Norway, developments are somewhat lagging, although discussions are underway regarding a MaaS pilot in Oslo. Notable R&I initiatives in the Nordic region are described in table 3.3.

Table 3.4: MaaS initiatives in the Nordics.

R&I initiative/project	Funding agencies	Main Nordic actors involved
KOMPIS (SE)	The Swedish Ministry for Enterprise and Innovation Drive Sweden Vinnova	KTH RISE Viktoria
IRIMS (SE)	Vinnova	Chalmers University Lund University Trivector RISE Viktoria Samtrafiken K2
EC2B (SE/DK)	Climate KIC EU Horizon 2020	Trivector Malmö municipality Copenhagen municipality Movia
MaaS Joint Programme (FI)	TEKES The Finnish Ministry for Transport and Communications	MaaS Global Tuup Sito Ylläs Around
IMOVE (EU)	Horizon 2020	RISE Viktoria UbiGo Västtrafik
Eccentric (EU)	Civitas	KTH Stockholm Municipality UbiGo Regional Council of Southwest Finland Turku University of Applied Sciences
MaaS4EU	Horizon 2020	MaaS Global
MaaSiFie	CEDR Transnational Road Research Programme	Chalmers University of Technology VTT Technical Research Centre of Finland

Despite the high level of interest in MaaS, and the various pilots that have trialled and tested the concept, several barriers remain to be resolved by R&I activities. One significant barrier is the set of perceived risks associated with collaboration in new networks and ecosystems. Research has been performed to document these barriers (e.g. Mukhtar-Landgren et al., 2016; Smith et al., 2017a), but little has been done to resolve them, except for some prescriptive studies that outline different models for collaboration (e.g. Holmberg et al., 2015; Kamargianni et al., 2016; Smith et al., 2017b). Another barrier relates to the lack of a validated business case for MaaS, and the concurrent development and validation of business models. there is also a lack of knowledge related to the sustainability impacts of MaaS, which, if proven to be positive, can generate legitimacy for the concept among policymakers and government agencies (Sarasini et al., 2016b).

A further lack of knowledge relates to user perspectives, relating to motives for adoption, willingness to pay, and behavioural aspects of MaaS. Whilst pilots can assist in resolving these issues, there is a current lack of documented evaluations of MaaS. In fact, the most documented trial is that encompassed in the UbiGo project, which demonstrated the potential for MaaS to encourage more sustainable travel behaviour compared to private car ownership and use (e.g. Karlsson et al., 2016; Sochor et al., 2016, 2015b, 2014a, 2014b; Strömberg et al., 2016).

3.6.3 Influence on the direction of search

Generally, two distinguishable sets of factors drive innovation in the MaaS field. The first is linked to sustainability, and is rooted in a set of generic, transport-related problems such as climate change, oil dependency, air pollution, traffic congestion, traffic safety, and the underutilisation of passenger and goods vehicles (Sarasini and Linder, 2017). Further, the automotive industry in particular faces economic and environmental sustainability problems (Dooley et al., 2010; Wells, 2010). Traditional automakers are faced with pressures to find new growth trajectories, especially since younger generations appear to be less willing to purchase automobiles (Wells, 2010; Abrenica, 1998; Humphrey and Memedovic, 2003). The emergence and enabling potential of information and communication technology (ICT), which has been harnessed by new entrants such as Google, Apple, Tesla, Zipcar and Uber is also creating pressures for new growth trajectories in the auto-industry. Against this backdrop, mobility services are increasingly seen as a means to a more sustainable transport system, and are linked to better urban management; improvements in energy efficiency and urban air quality; greater use of renewable fuels; reduced congestion and improved accessibility (Greenblatt and Saxena, 2015; Greenblatt and Shaheen, 2015; Rydén and Morin, 2005).

The second set of factors related to different megatrends that are driving a set of radical innovations in the transport sector. *Urbanisation* is one such megatrend. People increasingly move to cities, which can lead to more congestion, but has also resulted in a more acute focus on land use, 'attractive' urban development and sustainability in urban planning. A further trend is the emergence of the *sharing economy*. By harnessing collaborative modes of production and consumption, the sharing economy is currently challenging dominant logics within the field of transport following the successes of AirBnB, crowdfunding, the maker movement and numerous applications in the field of transport itself (e.g. peer-to-peer vehicle sharing, vehicle pools and ride-sharing). Coupled to the sharing economy is a growing interest in *servitised product offerings* (e.g. sales of 'mobility' as a function rather than sales of automobiles) (Williams, 2007), whereby some demographic groups are showing less interest in owning products. A growing interest in sustainability is also partly responsible for changes in attitudes about shared ownership or non-ownership have made possible the growth of services for car sharing and ride sharing (Birdsall, 2014; Shaheen and Cohen, 2013) and attitudinal changes linked to health and the environment have accelerated everyday cycling (Fishman and Cherry, 2015). One final megatrend of relevance is linked to *digitalisation*, which has emerged following technological developments in the fields of embedded systems, wireless networking and automation, and is currently unfolding in the drive towards connected and autonomous vehicles. Taken together, these pressures for change influence the entire transport system, and the emergence of MaaS is arguably a natural consequence of such pressures.

In Sweden, public transport authorities and operators have linked MaaS developments to the so-called "doubling goal", which aims to double market share of public transport passengers. The Swedish Ministry of Enterprise and Innovation (*Näringsdepartementet*) has also prioritised MaaS, having established a 'collaborative group' in 2017 to outline a MaaS roadmap (Pernestål Brenden et al., 2017) and the KOMPIS R&I programme, which is administered by the Swedish agency for Innovation (*VINNOVA*). MaaS is also prioritised by the Swedish Transport Agency (*Trafikverket*) via its action plan for Intelligent Transport Systems (ITS) (Andersson et al., 2014), and by the Swedish Energy Agency (*Energimyndigheten*) via a forthcoming R&I initiative entitled 'Challenge from Sweden'.

MaaS developments in Finland are supported by a stronger set of incentives than in Sweden, including the strong need for innovation given the consequences of the economic downturn and the decline of Nokia (Smith et al., 2017c). Hence influential organisations such as *ITS Finland* and *LVM* (The Finnish Ministry of Transport and Communications) have helped to create support for MaaS, directed in part via its 'Transport Revolution' programme, published in 2009, and the reformation of the Finnish Transport Code in 2016. The latter aims to remove barriers to the deployment of MaaS developments, including regulations that force transport providers to provide operational data and allow for third-party ticket resales (LVM 2017). Further, in 2015 LVM allocated strategic funds for pilots made available via *TEKES* (The Finnish funding agency for innovation). Pilots and trials have been useful in generating knowledge on the functionalities and utilities of the MaaS concept. Export Finland has also created support for MaaS developments, focusing on the attraction of foreign investment (Smith et al., 2017c).

Little has been published regarding the generic set of factors that influence MaaS developments in Denmark. Exceptions include Hedegaard Sørensen (2017), which outlines a roadmap for MaaS developments in Sjælland, Movia (2017), which outlined a roadmap for MaaS in Copenhagen, and Movia (2017) / Rooijakkers (2016) which discussed the benefits and drawbacks of different operator models. Our literature search produced no results for Norway, adding credence to the fact that MaaS has not yet taken off. However, the possibilities for introducing a MaaS-concept in the Oslo-region has been discussed on a theoretical basis (Aarhaug 2017).

3.6.4 Entrepreneurial experimentation

As noted in the above sections, Sweden, Finland and Denmark are currently hosting a range of pilots and trials of MaaS services. In Sweden, the success of the Go:Smart project (Gothenburg) resulted in a start-up (UbiGo, later UbiGo Innovation) and also created interest for the MaaS concept within the public sector. Following the project, the public transport operator in Gotenburg (*Västtrafik*) has experimented with different means of procuring MaaS services, and other public transport authorities and operators (notably *SLL* in Stockholm and *Skånetrafiken* in Southern Sweden) have become interested in MaaS. Swedish public sector interest in MaaS is also channelled via the Smart Mobility Programme, hosted by *Samtrafiken*, which is a national umbrella organisation for different types of mobility service providers. *Samtrafiken* is currently investigating the possibility of developing a national platform for MaaS that would allow different types of operators to connect their sales and ticketing systems for resale via third-party MaaS operators such as UbiGo. UbiGo is planning a relaunch of its service in Stockholm in 2018 as part of a partnership with the local public transport operator (SLL) under the eccentric project. EC2B is now established as a further Swedish start-up, focusing on MaaS services for property owners in the *Öresund* region.

In Finland, several start-ups have emerged following the MaaS Joint Programme. The most notable include MaaS Global, Tuup, Sito and Ylläs Around. These companies differentiate themselves in terms of the type of service offered, customer segments and geographical coverage (Ylläs Around, for instance, provides MaaS for ski resort tourists). MaaS Global is arguably the most renowned Finnish start-up, having established partnerships in Helsinki and in foreign locations such as the UK, the Netherlands and Singapore. The Whim app is currently available for beta users in Helsinki, and in summer 2017 MaaS Global successfully garnered €10m of venture capital, with notable investors including Toyota Financial Services (Smith et al., 2017c).

In Norway, not much experimentation on MaaS has taken place so far. It is discussed in national transport plans and among some transport operators (Aarhaug 2017), and possible pilots and research projects are under way in the Oslo region.

4 Summary and conclusions

This report has reviewed different transport innovations for decarbonising the transport system in the Nordic countries. It focuses mainly on vehicle and fuel technologies but it also deals with organisational innovations, such as mobility as a service (MaaS). A TIS-approach is applied in the analysis of the transport innovations and it focuses particularly on functions in the innovation system. Since the innovations are in different development states, some are still in its testbeds while others are already on the market, not all functions are relevant to analyse for all technologies, fuels and services. The report mainly focuses on the development in Norway and Sweden, Denmark and Finland are mentioned more occasionally. Sweden differs from the other Nordic countries as the only country which currently hosts automakers and the presence of these actors differentiates Sweden from the other Nordic countries. The table below summarises key functions for the different transport innovations in the Nordics.

Table 4.1: Main functions for the different transport innovations in the Nordics.

	EV	ERS	Hy	Bio	AV	MaaS
Knowledge dev. & diff.	X	X	X	X	X	X
Direction of search	X	X	X	X	X	X
Entrepreneurial experimentation	X	X	(X)	X	X	X
Market formation	X			X		
Legitimation	X	X	X	X	X	
Resource mobilisation	X	X		X		

The analysis of all functions in the innovation systems are carried out only for three of the transport innovations - electric vehicles, electric road systems and biofuels. These represents either partly developed technologies and/or they are already introduced on the market. This is particularly so for EVs and biofuel, whereas ERS are still in their infancy and subject to pilots and tests. For hydrogen vehicles, autonomous driving and Mobility as a service there are still not much sign of market formation or any substantial mobilisation of resources, some entrepreneurial experimentation takes place and the question of legitimation is on the agenda, particularly related to autonomous driving.

Knowledge development and diffusion relies heavily on public funding for all transport innovations and large national and international research programs and projects exists for all the innovations mentioned here. The international car industry is also heavily involved, now particularly in the testing of autonomous driving.

The development of all the technologies and fuels mentioned here are influenced by national and international policy regulations. All the Nordic countries have established climate targets and introduced fiscal incentives which promote the electrification of cars or cars which use hydrogen or biofuel. AVs and mobility as a service are also regarded as innovations that will radically transform transport system.

Entrepreneurial experimentation takes place via tests and demonstration projects for all transport innovations. The Swedish car industry carry out several pilots for the development of EVs and ERS, in cooperation with Nordic research institutions. Likewise, pilots also take place for AVs and mobility services where both private companies and public transport operators are involved.

Real market formation can only be traced for EVs and biofuel. There is no commercial market for ERS or for hydrogen cars. ERS is still in a test phase and hydrogen still suffers from technological barriers and lack of infrastructure. AV is in an early test stage and MaaS are for the present primarily ideas rather than realities but interesting experimentation is taking place.

The development and potential market uptake of transport innovations relies heavily on the acceptance of new technologies. EVs seems to have climbed high on the legitimation ladder together with biofuel, although the last one still suffers from the food vs fuel controversy. Both ERS and AVs have still to prove its functionality and operability whereas hydrogen has to overcome technological barriers particularly related to the infrastructure.

Sufficient resources are necessary for transport innovations to develop and to be commercialised. Most innovations are dependent of support from public funding of research and own efforts from relevant industries. All the technologies and fuels described here have received public support to a varying degree in the Nordics. AD and particularly MaaS, are so novel that resource mobilisation until now has been limited.

There are several possible pathways to a more sustainable transport systems in the Nordics countries related to innovations in technologies and fuels and to new mobility services. Further research on future transport innovation in the Nordics should in particular examine the interplay (potential synergies and conflicts) between different innovations, and study possible technological trajectories that follows from different innovations. It would be highly interesting to get a better understanding of why different trajectories vary, and to reveal what are the most important drivers and barriers between the different pathways. Such knowledge would make it easier to foresee possible implications of different technological trajectories for the development of sustainable transport systems in the Nordics?

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