Summary

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

TØI Report 1678/2019
Authors: Ove Langeland (ed.), Magnus Andersson, Tom Erik Julsrud, Steven Sarasini, Maria Schnurr & Stefan Tongur
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 development and diffusion	Provision of R&D
Knowledge diffusion through networks		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.