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Abstract

This paper will examine policy drivers of EV, and what potential role policy can play in enhancing the innovation and market development of EV, and the anticipated impacts on energy use and carbon emissions at the Nordic and EU scale. We will start with a policy review of key targets in the Nordic countries and the EU, up to 2030, and discuss to what extent they are consistent with industry and expert estimates of how the systems can grow. On the basis of this, the second part elaborates two simple scenarios of EV development in the EU, one rapid EV expansion scenario and one more modest expansion scenario. The third part examines what policy drivers might be needed to enable the two scenarios, using a technological innovation systems (TIS) perspective to describe the needed processes, drivers and developments in policy and technology at different levels (local, national, EU, global) that would lead to the scenarios. The fourth part analyses the energy and climate impacts of the two scenarios, given different assumptions relating to e.g. energy supply systems as well as driving behaviour.

Keywords: TIS, electric vehicles (EV), life cycle assessment, CO₂, innovation policy

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List of Abbreviations

BEV	Battery electric vehicle
CO2	Carbon dioxide
EU	European Union
EV	Electric vehicle
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
OEM	Original equipment manufacturer
PHEV	Plug in hybrid electric vehicle
R&D	Research and development
REV	Range extended electric vehicle
TIS	Technological Innovation System

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Introduction

Over the last ten years, the interest for low-carbon vehicle technologies has surged among both governments and automotive manufacturers across and beyond the European Union. Great hopes have been put, first, on biofuel vehicles and more recently (as the enthusiasm for biofuels cooled off) on electric and hybrid electric vehicles as key technologies to mitigate climate change, enhance energy security and nurture new industry branches within the automotive sector. In particular in the Nordic region, where electricity production has a relatively minor fossil input on average, electrification of transport has been seen as a key strategy to reduce CO₂ emissions from the transport sector.

However, while the market penetration for biofuel vehicles has been relatively high in some countries, the corresponding increases in electrification of vehicles have not materialized so far. An important reason for this is that vehicle prices remain considerably higher for EVs and HEVs compared with ICE based vehicles mostly due to relatively high battery prices. Also, the shape of the learning curve and associated future costs remain uncertain and predictions vary strongly. Lack of experience with battery durability under different climatic and driving conditions poses a significant risk for early adopters investing in a new EV car. Additionally, BEVs, and in some cases also PHEVs or REVs, require new infrastructure (for charging and to some extent the local power grid) and different driving behaviour. As a result, there are major uncertainties in a) future forecasts about BEV/PHEV/REV market penetration, b) what policy frameworks are needed to facilitate the market uptake of these vehicles, and c) what are ultimately the climate implications of these forecasts. We do know that over the coming years, BEV/PHEV technology will require public governance measures of different types, both to induce innovation and market uptake, and to control and mitigate possible environmental and social consequences.

This paper addresses these uncertainties in the context of the Nordic region (Denmark, Finland, Norway and Sweden), through focusing our discussion on the following questions:

How do policies, goals and targets within and across the Nordic countries compare against industry, government and expert forecasts about market uptake?

What are the climate impacts of our scenarios and what are the implications for the attainment of climate targets?

What policy or broader governance initiatives are likely needed to have a plausible chance of reaching a breakthrough scenario?

This paper unfolds as follows. In section 2, we present a review of policies and key targets in the Nordic countries and the EU, and discuss to what extent they align with or deviate from industry and expert estimates of how the systems can grow. On

the basis of this, section 3 elaborates scenarios of EV development in the EU, with a breakthrough expansion scenario and an incremental expansion scenario for the Nordic countries. Building on that is a climate impacts analysis of those two scenarios, given different assumptions relating to power supply in the Nordic region. On top of that section 4 examines what policy drivers might be needed to enable a breakthrough scenario, using a technological innovation systems (TIS) perspective to describe the needed processes, drivers and developments in policy and technology. Section 5 summarizes our results and conclusions.

Policy drivers, policies and targets

Across the EU and globally, policy makers' interest in the electrification of vehicles have surged. Most EU countries have presented national development plans and targets for EVs. The interest is related to at least three political priorities. The first concerns *climate change mitigation*. Road transportation in 2010 accounted for 18.6% of all greenhouse gas emissions in the EU27 excluding land use, land use change and forestry (EEA, 2010). In the Nordic countries that are of interest in this paper the share was 20.0% for Denmark, 16.1% for Finland, 18.7% for Norway and 28.9% in Sweden (the combined Nordic share is 20.9%). It is worth noting that this makes Sweden the second worst in the EU27 in terms of percentage. This is partly a result of Sweden having relatively lower emissions percentages in other sectors. However it still indicates that it is especially in this sector Sweden still has much to gain from mitigation measures. To be more accurate, the emissions per capita numbers for road transport in the Nordic countries are 2.212 tonnes CO₂ for Denmark, 2.243 tonnes CO₂ for Finland, 2.078 tonnes CO₂ for Norway and only 2.047 tonnes CO₂ for Sweden. Generally, rapid action is required to reduce these emissions in line with ratified climate change goals. The second concerns *energy security*. Overall transport accounts for around one-third of energy consumption and with its heavy reliance on fossil fuels, the sector is vulnerable to oil supply and connected price changes. The electrification of vehicles is a prime strategy to decrease the reliance on imported fossil fuels. The third concerns *innovation, job creation and economic growth* (Lerner, 2010, p. 257). Competition globally in the automotive sector is fierce and it is commonly held that manufacturers need to be "ahead of the curve" in terms of technology development in order to stand their ground against emerging low-cost competition from in particular Asia. In the EU this concern can be framed politically in the broader Lisbon strategy of 2006, which set out the EU of becoming a "dynamic and competitive knowledge-based economy" (European Commission, 2007). The European automotive sector is an important sector representing 2.3 million directly employed (7% of all manufacturing employment in the EU27) and indirectly supporting more than 12 million European jobs (suppliers etc.) (ACEA, 2008).

On EU level important policies include the *renewable energy directive* which has the goal of achieving 10 % renewable energy in the transport sector by 2020. Through the *fuel quality directive* a reduction of CO₂ intensity of fuels by 6 % by 2020 has to be achieved. With the *clean vehicle directive* starting December 2012 public procurement of

vehicles needs to take into account the energy consumption as well as CO₂ emissions of the vehicles. In 2011, the EU adopted a roadmap for the next decade to reduce its dependence on imported oil and to cut carbon emissions in transport by 60% by 2050 (European Commission, 2011). Furthermore, EU emissions regulations stipulate that by 2015 130g CO₂/km (phased in starting 2012) and by 2020 95g CO₂/km very likely have to be fulfilled (Creutzig, McGlynn, Minx, & Edenhofer, 2011, pp. 2399–2400; Lewis, 2012; Nemry et al., 2009, p. 18). Furthermore the European parliament has mentioned the possibility of setting a 75g CO₂/km target for 2025 (Kågesson, 2010, p. 124).

Globally as well as in the EU, the economic crisis since 2008 has presented opportunities for stimulus spending in the automotive sector. Governments have provided subsidies, loans and R&D support, the latter typically oriented towards environmentally friendly cars. Piloting and demonstration projects have often been implemented in cooperation with the private sector and in cooperation between universities, public institutions, power industry and the automotive industry both on national level or European level.

Tax incentives such as CO₂-differentiated vehicle taxes and car rebates have been introduced in many countries in the EU. However, the tax level can be quite different from country to country taking into account the full set of measures. Kley et al (2012) found that as of 2010, the EU countries could be grouped into three categories with respect to the total incentives provided when it comes to mid-sized cars (Kley, Wietschel, & Dallinger, 2010, 2012):

- the leaders (incentive from 10,000 to 28,000 euros: Denmark, Norway, Belgium),
- the followers (incentive from 4,000 to 9,000 euros: Netherlands, Spain, UK, France, Switzerland, Austria),
- the laggards (with amounts +/- 3,000 euros: Ireland, Greece, Italy, Germany, Sweden, Poland, and Finland).

Among the Nordic countries, only Sweden has a significant automotive industry (Eurostat, 2012). The sector directly employs roughly 72,000 people in Sweden representing 10.7% of total manufacturing jobs (2009), 6331 in Denmark representing 1.6% of total manufacturing jobs (2008), 7509 in Finland representing 1.9% of total manufacturing jobs (2009) and 3300 in Norway representing 1.4% of total manufacturing jobs (2009). Despite their relatively small automotive industry Norway and Denmark have taken a strong interest in advancing electric vehicle technologies and innovation systems. In terms of market introduction of EVs, Norway currently has the lead in the Nordics. At the end of August 2012 almost 8000 EVs were on Norway's roads which makes it one of the most successful countries in terms of EVs per capita (Grønn Bil, 2012a). By comparison, as of May 2012 there were 907 BEVs registered in Denmark, about 500 as of June 2012 in Sweden and about 60 in Finland as of May 2012 (Dansk elbil komite, 2012; Godske, 2012; hbl.fi, 2012; Helsingborg stad, 2012; Nordgren, 2012). These numbers are

however not a hundred percent accurate as some sources include direct imports while others don't. Also some sources count in four wheel drives that are not classified as cars and some count in PHEVs/REVs while others don't. Below, we describe in more detail the policies and targets for our four Nordic countries.

Finland

Goals: Finland has so far not established a specific national goal for the introduction of electric vehicles. However, the government has presented a climate and energy strategy where two goals are to reduce GHG emissions from traffic and transport by 15% and to increase the energy efficiency of the transport sector by 9% from 2005 to 2020 (Finnish Transport Agency, 2011, p. 10). The government has also developed a vision for 2050 in which the direct specific emission of cars are supposed to reach 80g-90g CO₂ per km by 2030, 50-60g CO₂ per km by 2040 and 20-30g CO₂ per km by 2050 (Finish Government, 2009, p. 106; 156).

Policy instruments: A vehicles tax reform began in 2008. Eventually it is supposed to give the consumer more choice on the level of tax when they buy new or used cars (Finansministeriet, 2011a, 2011b). Today the registration tax as well as the annual vehicle tax are based on CO₂ emissions. The CO₂ based registration tax was introduced in 2008 and the CO₂ based annual vehicle tax in 2010 (Kosk, 2010). In 2012 the lowest registration tax level, for cars with 0 g/km CO₂, was reduced from 12,2% to 5% (Finansministeriet, 2011a, 2011b, 2012; Lindén, 2011). The highest tax level was raised from 48,8 to 50%. Overall the signal is that cars with less than 110 g/km CO₂ will get a lower registration tax compared to before. For new BEVs that means that the previous registration tax is being reduced from 3660 Euros to 1500 Euros for a BEV that costs 30000 Euros. The base tax within the annual vehicle tax is also based on CO₂ emissions and after the 1st of April 2012 can vary between 43 and 606 Euros per year (Finansministeriet, 2011a).

The Finnish government has also identified the electric vehicle as a Finnish export opportunity (FMEE, 2009). Subsequently, in 2011 TEKES (the Finnish Funding Agency for Technology and Innovation) introduced a 5 year program for the development of concepts for the EV and connected infrastructure (Lindén, 2011; Tekes, 2011b). The programme is called EVE – Electric Vehicle Systems programme and also hopes to create a strong community around EVs in Finland (Tekes, 2012). The largest project in the portfolio is the Electric Traffic Helsinki Test Bed project which among other targets has the aim to establish around 850 charging spots in the capital region and enable the driving of 400 EVs during a period of four years (electrictraffic.fi, 2012; Kvisle, 2012; yle Nyheter, 2012). Other significant projects include EVELINA (National Test Environment for Electric Vehicles) (www.evelina.fi, 2012), Eco Urban Living (eco-urbanliving.com, 2012) and SIMBe ((Smart Infrastructures for Electric Mobility in Built Environments) which started in January 2010 and is funded by TEKES Sustainable community programme) (Tekes, 2011a), and the battery research programme SINi (Aalto University, 2012).

Industry position: Finland has a major and experienced EV manufacturing facility through the company Valmet Automotive who mainly builds EVs for other brands (Mellgren, 2010). For example the REV sports car Fisker Karma is being built there. Furthermore, before its recent bankruptcy, the Think car has been produced in Finland at the same factory (Karlberg, 2010). Another Finish EV manufacturer is the company AMC Motors with their model Sanifer (Kronqvist, 2011). Finland is also home to a larger battery manufacturer called European Batteries (Hällén, 2010). Fortum as the major Finish utility is part of several pilot projects across the Nordic countries and is foremost driving developments in the home as well as fast charging area (Albrecht, 2011b; Infrastrukturnyheter, 2011).

Sweden

Goals: The Swedish government has established the goal that the transport system should be “fossil fuel independent” by 2030, but has no precise target for PHEV/BEV penetration. Industry groups have put forward a vision for 600,000 PHEVs and BEVs on Swedish roads by 2020 (Elforsk, TSS, & Power Circle, 2010, p. 17; Hatt, 2012a; Power Circle, Elforsk, & Test Site Sweden, 2009). The 2030 government target is currently not backed up by concrete road maps on how to get there, even though the government recently decided to develop such a road map (Hatt, 2012a). At the same time different industry organisations have established scenarios (Sköldberg et al., 2010; Svensk Energi, 2011). There is significant scepticism and uncertainty about those targets, and government officials think that only a modest 20,000 to 85,000 PHEVs and BEVs by 2020 is actually achievable under current institutional conditions (Elforsk et al., 2010, p. 17; Energimyndigheten, 2009, p. 8; Lewald, 2011).

Policy instruments: Sweden has implemented a number of separate policy measures that are targeted at environmental friendly cars in a seemingly technology neutral way. A major part of Sweden’s policy package, and the debate around it, centres on the green car definition. Confusingly, different definitions persist, emanating from different institutional homes; the road transport law, the income tax law, and from several municipalities developing their own definitions (Miljöförordn, 2012). The road transport law primarily eliminates the yearly vehicle tax for private persons and professional organisations for a period of 5 years for all green cars introduced after the 1st of June 2009 (currently the green car definition translates into 120g/km CO₂ (or cars driven by alternative fuels with fuel consumption per 100km of 9,2 L gasoline equivalents, 9,2 cubic meters of gas or 37 kWh electricity)). A new green car definition is scheduled to be implemented at the beginning of 2013. The income tax law for the income year 2011 foresees that the tax on the private benefit stemming from an employee driven company owned green car is 40% less after it has been set to the tax level of a comparable average e.g. gasoline driven car if the green car is an BEV, PHEV or biogas car (but not more than 16,000 SEK) (Skatteverket, 2011a, 2011b, 2011c). HEVs get 20% reduction (but not more than

8,000 SEK). During 2012 and 2013 a new definition applies which foresees 40% less after it has been set to the tax level of a comparable e.g. gasoline driven car if the car is a BEV or PHEV or a biogas car (but not more than 16,000 SEK) (Skatteverket, 2012). Ethanol cars, HEVs, and a variety of other biofuels are only reduced to the tax level of a comparable average gasoline driven car. In 2012, the government introduced a new 40,000 SEK subsidy for the purchase of “super green” cars (less than 50 g/km CO₂). The current budget will be sufficient to support approximately 5,000 EVs (Swedish Government, 2011a, 2011b). As of August 2012 130 cars have used this more recent incentive (tjänstebilfakta.se, 2012).

Additionally, Swedish efforts are connected to research funding usually for larger industry players (e.g. Volvo, Saab) as well as several pilot projects across Sweden (e.g. Malmö, Gothenburg, Stockholm, Östersund, Sundsvall, Helsingborg) (Lundgren, 2011; Malmö City, 2009a, 2009b; Stockholm City, 2009; Sunnerstedt, 2011; Östermark, 2011). Those efforts are usually all co-financed with a 25-50 % stake by the Strategic Vehicle Research and Innovation program (FFI - a Vinnova funded research program) or the Swedish Energy Agency (SEA) (Lewald, 2011). Other significant incentives include the national procurement plan initiated by the city of Stockholm and Vattenfall and partly financed by SEA (Elbilsupphandling.se, 2011). The purpose of the procurement is to allow the coordinated purchase of 6,000 EVs for companies and public agencies.

Regulatory changes are made to enable EV introductions. Since February 2011 municipalities can reserve parking spots in public spaces for EVs (Lewald, 2011; Swedish Transport Agency, 2011). However when charging parking fees it is not allowed to discriminate different types of vehicles (Sunnerstedt, 2011). As a way to accelerate charging infrastructure development, it now is also possible that charging infrastructure owners for outside parking space (e.g. malls) do not need to pay a grid concession fee to the local grid company (Alpman, 2010; Energimarknadsinspektionen, 2010a, 2010b, 2011; Hatt, 2012b).

Industry position: In Sweden industry is primarily concerned with research and development around electric powertrains. However, Volvo is on the verge of commercialising two cars, namely a BEV and a PHEV, the latter co-financed by Vattenfall. Similar to Volvo, Saab has also developed a BEV which due to Saabs recent bankruptcy currently cannot be pursued further. The company EV Adapt is converting conventional cars to BEVs. Otherwise Sweden has and has had a number of demonstration programs in which e.g. also utilities have been major partners (Albrecht, 2011a, 2011b).

Denmark

Goals: In 2009 the Danish parliament agreed on a common policy for a greener transport system (TRM, 2009). Some of the focus areas of the policy are to bring down greenhouse gas emissions from transport. Furthermore, Denmark aims to become a “green technology laboratory” of transport. Recently the new Danish government adopted the goal to phase out all of the country’s oil, coal and natural

gas until 2050 and to provide 50% of the country's electricity by wind energy already by 2020 (Ritzau, 2012a, 2012b).

Policy instruments: The major EV instrument is the relief from registration fees until 2015 (Dansk Elbil Alliance, 2012; ENS, 2012; TRM, 2011). The registration fee on passenger cars in Denmark in 2011 is 105% of the value until 79.000DKK and 180% of the value above (DMT, 2012), making such a tax relief a very strong incentive. Also the annual taxation of cars has been reformed: the tax was former calculated on basis of weight of the cars, but is now based on fuel economy.

In line with the goal to become a technology leader, the Danish Transport Agency has been assigned to administrate a fund for research activities and demonstration projects on energy efficient transport. The largest single grant of first round was given to the project 'Test-an-EV' where 300 electric vehicles are tested for daily use by 2400 families in turn (testenelbil.dk, 2012). The test is expected to reveal driving and charging patterns and user experiences with electric vehicles. Another large scale project is named EDISON (Electric vehicles in a Distributed and Integrated market using Sustainable Energy and Open Networks). The project uses the island of Bornholm as a full scale laboratory to investigate market solutions, electricity network configurations and interaction between energy technologies for EVs (Edison, 2012). The citizens of Bornholm also participate in the smart-grid project 'EcoGrid EU' and results are exchanged between the two projects (EcoGrid, 2012). Apart from the island of Bornholm also Copenhagen municipality should be put forward as a major actor since it is like Bornholm part of several EU research and demonstration projects. Essential to all those projects is also the cooperation with Danish universities like DTU that are part of multiple projects.

Industry position: Denmark is one of the countries where new business models with regards to electric mobility are being implemented. Such companies dedicated to deployment, service systems and infrastructure for electric vehicles are by some addressed as Electric Mobility Operators (EMOs). Central EMOs in Denmark are for example Better Place Denmark (owned by Better Place Global with Dong Energy as minority stakeholder), ChoosEV which is now also called Clever (owned by the energy companies SE, SAES-NVE and the car rental company SIXT) and CleanCharge (Borking, 2012; CleanCharge, 2012; Clever, 2012). Especially Better Place has received worldwide attention for their business model that among other features relies on battery switching stations to overcome the range problem connected to EVs. ChoosEV has also received attention due to a large three year BEV trial in which 1400 Danish families participate (ChoosEV, 2012).

An important network is the Danish Electric Vehicle Alliance which is a trade association for the electric vehicle industry in Denmark, formed in 2009 by the Danish Energy Association. The Alliance has initiated projects on standardization and roaming within the charging infrastructure. Better Place, ChoosEV and CleanCharge have committed to these projects (Dansk Elbil Alliance, 2012). Members range from electric distribution and utility companies over the automotive industry to research institutes and smaller projects on electric vehicle technology.

Norway

Goals: The electric vehicle network elbil.no has a target of reaching 100,000 EVs by 2020. An even more ambitious industry vision is raised by Energi Norge to reach 200,000 BEVs and PHEVs by 2020. The government regularly releases its ten year plan for development in the transport sector. The latest plan spanning from 2010 to 2019 emphasizes the environmental impact of the transport sector and goals for limiting greenhouse gas emissions. The goal is to limit emissions from transport by 2,5 – 4,0 Mio tons of CO₂ equivalents in 2020 according to continuation of the current development in the sector (NMTC, 2009). The country has also set the target to achieve an average emission level of 85 g CO₂ per km in terms of total new vehicle sales by 2020 (Norwegian Government, 2012, p. 120).

Policy instruments: In order to reach its goals, the Norwegian government encourages the purchase of electric vehicles in various ways. Noteworthy here is that BEVs currently are relieved from the registration tax (also sometimes called onetime tax or import tax) as well as the valued added tax (VAT) and have a much lower annual tax (10 – 20% that of ICE propelled vehicles) (Seljeseth, 2011). These measures are guaranteed until 2017 as long as no more than 50,000 such cars are on the roads (Grønn Bil, 2012b). The current government has even preliminary plans to continue them at least until 2020 (Johansen, 2012). BEVs are further relieved from parking fees at public parking lots, road pricing or congestion charges, charges on ferries (but driver has to pay) and are often allowed to drive in bus-lanes that are otherwise reserved for public transport (Norwegian Government, 2012). Also in Oslo and other areas most public charging spots are free to use for owners of BEVs. Norway arguably has one of the most ambitious institutional frameworks for EV deployment in the world. The Norwegian government has aligned institutionally around the EV technology more than in other countries and many authorities on all levels of government are involved. One player to mention here is the public funding program Transnova that is currently among other initiatives funding fast charging stations across the country. The agency also funds various projects within the reduction of greenhouse gas emissions from the transport sector e.g. trial or pilot programs. The Norwegian Research Council runs a funding program called RENERGI with the objective of ensuring environmentally friendly and economic development of the energy infrastructure, including transport solutions.

Industry position: Norway is or has been home to several EV related start up companies, among them Think, Reva and MoveAbout. The country has active industry associations around electric vehicles that strongly support further developments.

Nordic comparison

Looking at the overall Nordic perspective it becomes apparent that there are in parts large differences in how the countries try to support the deployment of electric powertrains. Especially striking is the significant policy gap that exists in Sweden

where the government set the goal of achieving a fossil fuel free independent transport sector by 2030 as well as an industry vision of 600,000 BEVs and PHEVs by 2020. Instead of deployment Sweden and to a lower extent also Finland have focussed on R&D, annual vehicle tax definition reform and demonstration projects but have not yet made the link to actual deployment. Norway and Denmark however have had a more entrepreneurial policy approach, through actively supporting new start-ups while at the same time giving generous tax exemptions to customers for market uptake. However one can state that in all countries the number of EVs on the street still lack behind the ambitious goals set forward. The table below summarises existing policy frameworks across the four countries.

	Finland	Sweden	Denmark	Norway
EV Targets (Gov. or Ind.)	O No specific EV targets	X Industry: 600,000	O No specific EV target	X Ind.: 100,000 - 200,000 by 2020
Currently registered BEVs and PHEVs	ca. 60	ca. 500	907	ca. 8,000
<i>Economic</i>				
VAT exemption	O	O	O	X Norway exempts BEVs from the valued added tax.
Registration tax	X The registration tax is adjusted according to CO2 emissions.	O A registration tax does not exist in Sweden.	X BEVs are exempted from registration taxes.	X BEVs are exempted from registration taxes.
Annual vehicle tax	X	X	X	X
Company car tax reform		X		X
Direct subsidy	O	X Sweden has a subsidy for super green cars	O	O
Research Programs	X	X	X	X
Demonstration Programs	X	X	X	X
Tolls, congestion charging exemption etc.	O	O	O	X
<i>Regulatory</i>				
Free public charging access	X Some	X Some	X Some	X

	companies and public organisations allow free charging	companies and public organisations allow free charging	companies and public organisations allow free charging	
Allowance to drive in bus lanes	O	O	O	X
Priority parking	X	X	X	X
No parking fee	O	O	O	X
<i>Information</i>				
Demonstration Programs that spread information	X	X	X	X

Table 1 EV policy frameworks across the Nordic countries

The shown policy measures result in different price tags across the Nordic countries, which is exemplified here by using the BEV Nissan Leaf and the fuel efficient diesel driven Golf BlueMotion 1.6 TDI (based on exchanged rates from June 2012). It can be clearly seen that BEVs will have a hard time to compete in Finland and Sweden given current governance regimes. Even though the BEV is likely favourable in terms of operation costs it will be difficult to close the existing cost gap within a reasonable investment time frame.

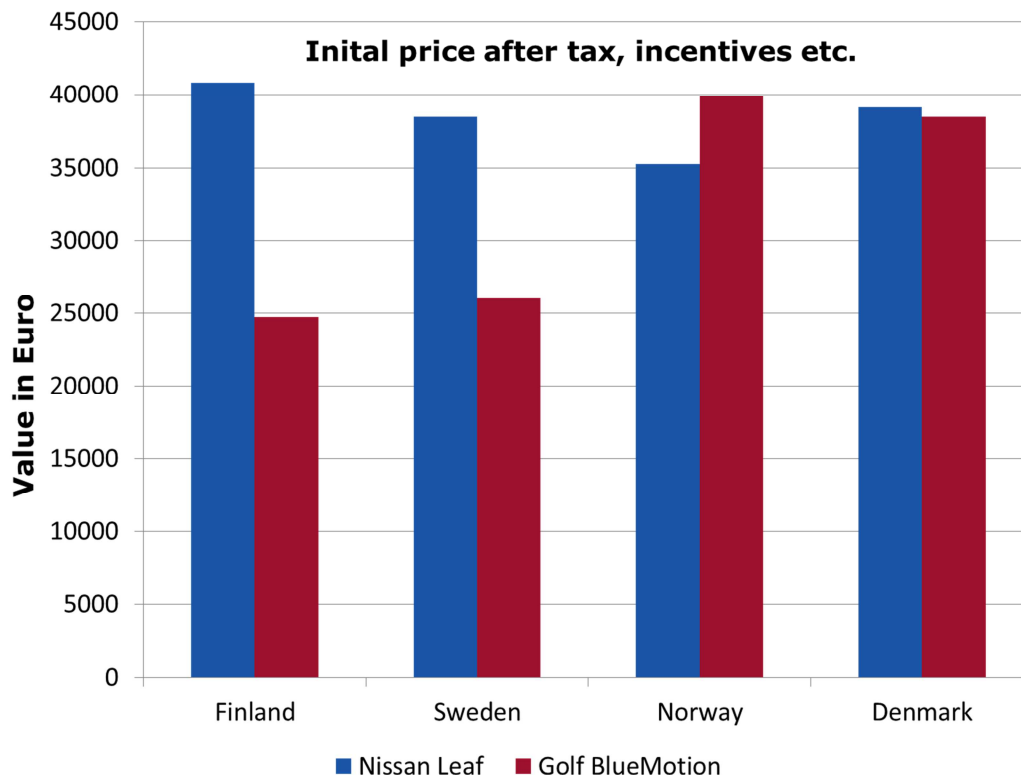


Figure 1 Initial price comparison taking into account existing incentives

Scenarios and environmental impact assessment

On the basis of existing EV related policy targets this section will elaborate two simple future scenarios.

The primary variable in the two scenarios is the rate of market uptake of BEVs and PHEVs. This variable will be specified relying on existing market uptake scenarios focussing on Europe that were identified in a literature review. It becomes apparent that there are quite large differences between those reports and studies (Bloomberg, 2012; Book, Mosquet, Sticher, Groll, & Rizoulis, 2009, pp. 6–8; Dinger et al., 2010, p. 7; Kampman, Essen, et al., 2011, p. 145; Mosquet et al., 2011, pp. 8, 16).

In terms of *annual vehicle sales* in percentage, BEVs range between 1% to 12% in 2020 and 11% to 18% for 2030. In the same way PHEV and REV combined can be found to be between 4% to 8% in 2020 and 41% to 66% in 2030.

In terms of *total car fleet* in percentage, BEVs range around 0-1% in 2020 and 3% to 7% for 2030. In the same way PHEV and REV combined can be found to be between 0-1% in 2020 and 15% to 26% in 2030.

Due to the different varieties in the scenario studies found we decided to consider an incremental as well as a breakthrough scenario largely based on an existing study written for the European Commission (Kampman, Essen, et al., 2011).

At one end, we hence consider an incremental growth outlook of EV developments given a continued business as usual governance regime. This **incremental growth scenario** assumes an 18% vehicle fleet share by 2030 for PHEVs, REVs and BEVs combined. The assumptions for this scenario are as follows:

- Battery improvements lack substantial breakthrough
- Lack of coordinated and long term policy support
- Only limited public acceptance for EVs
- ICE technology will achieve EU transport targets for 2020 which gives OEMs less incentive to push for EVs in the near future (Mosquet et al., 2011, p. 9)

At the other end we consider an EV breakthrough scenario, where market shares increase rapidly until 2020 and 2030. This **breakthrough scenario** assumes reaching a vehicle fleet share of 33% by 2030 for PHEVs, REVs and BEVs combined. In order for this to be possible we use a number of important assumptions:

- OEM prices for lithium ion batteries in the case of BEVs continue to decrease to roughly 400 US Dollar per kWh in 2020 and to between 150-200 US Dollar per kWh in 2030 (Bloomberg, 2012; Duleep, van Essen, Kampman, & Gruenig, 2011, p. 30; van Essen & Kampman, 2011, p. 12)
- Strong long term and coordinated policy support

- Strong public acceptance and behavioural changes in transport (Anable, Brand, Tran, & Eyre, 2012)

Before focussing on policies on how to achieve e.g. a breakthrough scenario we will first focus on the environmental impact of the described market uptake options. The electrification of vehicles is currently being discussed as a major lever for a more environmentally-friendly form of transport. Emissions of NO_x and particulate matter can be avoided locally and climate impact may be reduced if low-carbon electricity is used.

Here we will estimate the potential effect of the EV scenarios regarding greenhouse gas emissions. A life-cycle perspective is used, which means that emissions associated with vehicle manufacturing and maintenance as well as emissions caused by electricity production are considered, in addition to tail-pipe emissions. First we calculate life-cycle emissions for three typical vehicles in 2030. These results are then combined with the shares for plug-in hybrids (includes also REVs) and all-electric vehicles in the scenarios, to estimate approximate emission changes for the passenger car fleet in 2030.

The three types of vehicles are; an efficient diesel car emitting 80 g CO₂/km according to the New European Drive Cycle (NEDC), a plug-in hybrid with a 50 km electrical range and an all-electric car with a 150 km range. All cars are assumed to be the size of a Volkswagen Golf. The key assumptions behind the calculations are presented in Table 2.

		References:
Tail-pipe emissions for a "80 g diesel car" in real traffic:	100 g/km	(Burgdorf, 2011; Patterson, Alexander, & Gurr, 2011)
Tail-pipe emissions for plug-in hybrid in petrol mode:	95 g/km	20% lower than present Toyota Prius in highway driving
Electricity consumption in electric mode (plug-in hybrid and all-electric car):	0,16 kWh/km	20% lower than present energy use according to Patterson et al (2011)
Emissions from electricity production:	160 g CO ₂ /kWh (50 and 600 g in sensitivity analysis)	(Sköldberg & Unger, 2008)
Emissions from production of fuels from oil sand:	40% addition to direct emissions	(Charpentier, Bergerson, & MacLean, 2009)
Share of driving distance in electric mode for plug-in hybrid:	60%	(Åkerman, Isaksson, Johansson, & Hedberg, 2007)

Total driving distance during vehicle life for diesel car and plug-in hybrid:	200 000 km	Based on (Kampman, Essen, et al., 2011)
Total driving distance during vehicle life for all-electric car:	150 000 km	Based on (Kampman, Essen, et al., 2011)
Emissions of CO ₂ from manufacturing and maintenance of cars during their life length:	Diesel car: 3.3 ton Plug-in hybrid: 4.0 ton All-electric car: 4.8 ton	(Althaus & Gauch, 2010; Hussain, Dincer, & Li, 2007; Patterson et al., 2011; Samaras & Meisterling, 2008; Zamel & Li, 2006)

Table 2: Key assumptions used to calculate life-cycle emissions

Since we analyse the effect of changes in the vehicle fleet we use marginal emissions for 2030 in the calculations. With such a long term perspective we need to consider both the build margin and the operating margin. The former is caused by the fact that an increase in electricity demand that may be forecasted well in advance will increase the building of new power plants. The latter is the marginal electricity source used with a fixed set of production plants, given an increased electricity demand. We use one of the scenarios developed by Sköldbberg and Unger (2008), which incorporates climate policies roughly in line with the two-degree target. The marginal emissions in that scenario amounts to 160 g CO₂/kWh as an average for the period 2009-2037. Since the carbon intensity is uncertain we also use two other levels for a sensitivity analysis 50 and 600 g CO₂/kWh. In a similar way marginal reasoning is applied to emissions associated with production of fossil diesel. We apply a 40% addition to the direct emissions, which corresponds to producing diesel from Canadian oil sand (Charpentier et al., 2009).

Regarding emissions from manufacturing and maintenance of vehicles, key assumptions used are found in Table 2. It is assumed that emissions per car produced are reduced by 40% until 2030, compared to 2005.

In Figure 2 the resulting life-cycle emissions for the three types of cars are shown. At 160 g CO₂/kWh the electric cars are better than the diesel car, although the relative difference is smaller than if only tail-pipe emissions are considered.

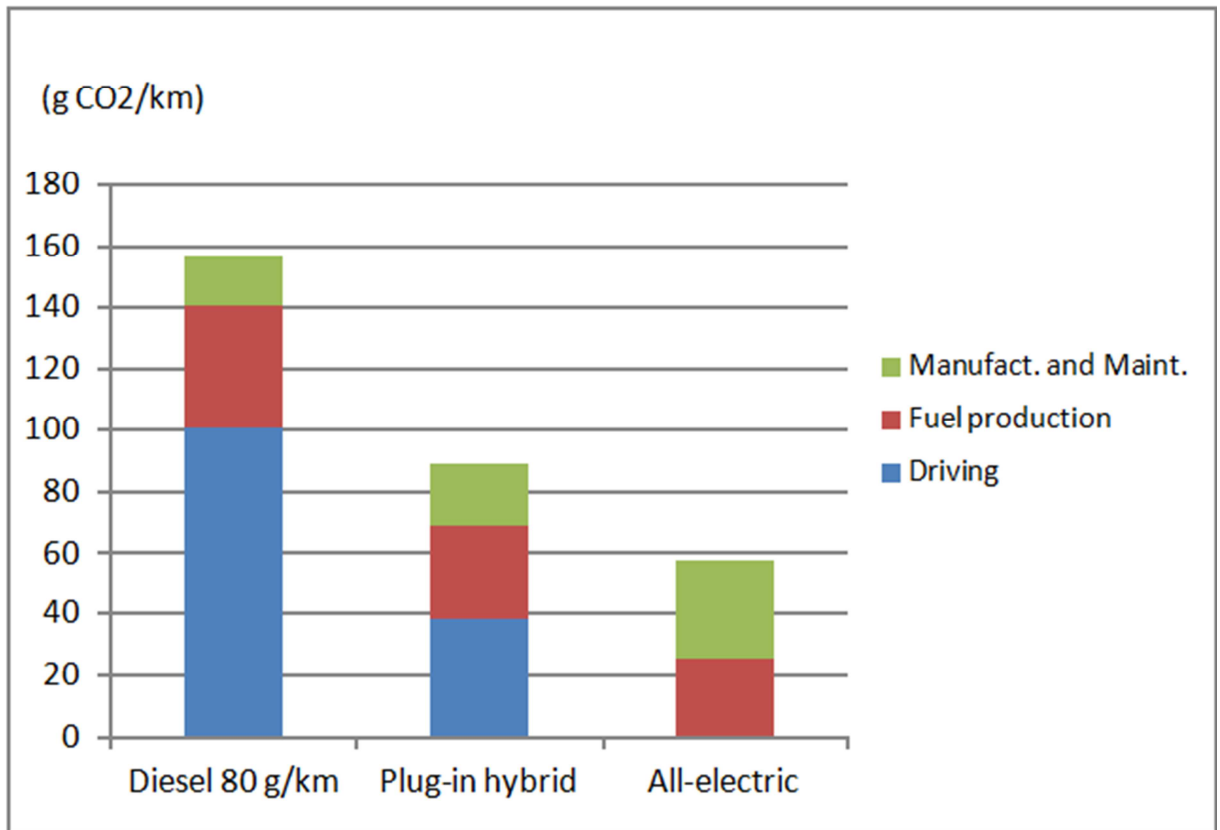


Figure 2: Calculated life-cycle emissions 2030 for three types of vehicles (all three sized as a Volkswagen Golf) given a marginal carbon intensity of 160 g CO₂/kWh.

We then combine these results with the two scenarios for market penetration; Incremental growth with 18% electric vehicles (BEV&PHEV&REV) in the fleet 2030 and Breakthrough with a 33% share in 2030. We assume that the average emissions (according to NEDC) for fossil fuelled non plug-in vehicles are 110 g per km in 2030 (WSP, 2008), corresponding to life-cycle emissions of 212 g per km. Furthermore, we assume that biofuels stand for 20% of total energy used for passenger cars, and that they achieve a 70% reduction of greenhouse gas emissions compared to fossil fuels.

The resulting changes in life-cycle emissions for passenger cars are shown in Table 3. With the middle carbon intensity alternative (160 g), the emission reductions become 6 and 13% respectively. With a very low carbon intensity like 50 g CO₂/kWh the emission reduction amounts to 7 and 15% while a high carbon intensity of 600 g CO₂/kWh GHG give small emissions reductions. The break-even level is calculated to be 800 g CO₂/kWh, that is this is the level which would make emissions unaffected.

In all cases it is assumed that 70% of the electric cars are plug-in hybrids and 30% all-electric cars. This is roughly in line with most forecasts. For instance Kampman et al. (2011) assumes an 80% share for plug-in hybrids.

	50 g CO ₂ /kWh	160 g CO ₂ /kWh	600 g CO ₂ /kWh
Incremental growth, 18% of electric vehicles in the fleet	7%	6%	2%
Breakthrough, 33% of electric vehicles in the fleet	15%	13%	5%

Table 3: Reduction of greenhouse gas emissions in 2030 for different EV market penetration and different CO₂-intensity for electricity production.

All attempts to estimate the impact of new technologies by 2030 are associated with considerable uncertainties, and this is particularly pronounced for electric vehicles. The estimates presented here should be regarded as an indication of the magnitude of impacts on emissions that electric vehicles may have. Although electric vehicles by 2030 probably may give a significant contribution to emission reductions in road transport, it is clear that many other changes will also be needed to reach sustainable urban transport systems. For instance, cycling and electrified public transport will in city traffic have lower energy use than electric cars, while also being more space efficient.

Future policy drivers for an BEV&PHEV breakthrough

On the basis of existing EV related policy targets this section will elaborate a general breakthrough scenario for strong EV uptake as opposed to more incremental changes. With this we hope to contribute to an understanding of what such ambitious goals would actually mean in terms of policy without taking into account too much uncertain predictions of future battery prices. While doing so we have gathered existing literature on policy instrument research in the transport sector or more specifically on hybrids or electric vehicles when available.

First of all it can be valuable when thinking about technology development and technology shifts to adopt an evolutionary perspective of technical change. From such a point of view technology develops in technology cycles which can be started by a new “technological discontinuity” that challenges the old technology (Anderson & Tushman, 1990, p. 606). The period in which a new technology challenges the old technology can also be called an “era of ferment” in which different design options and reactions are triggered around the new technology (Anderson & Tushman, 1990, pp. 610–611; Pohl & Yarime, 2012, p. 3; Tushman & Anderson, 1986, p. 440). These options are also referred to as different “technology trajectories”. Eventually the era of ferment might end with a new dominant design which becomes the new industry

standard since it is the only one that survives the competition for resources (Anderson & Tushman, 1990, p. 613; Tushman & Anderson, 1986, pp. 441, 462).

However, new technologies can also fail or have setbacks and it has to be kept in mind that the development of new technology does not necessarily take place in short time frames but rather necessitates a long term policy perspective. This can be nicely demonstrated by the fact that electric vehicles were first introduced around the end of the 19th century. Also, a new technological discontinuity usually is not alone in challenging an old technology, but itself has many competitors. At the same time the old technology can react with a strong “sailing ship effect” in the sense that it improves while it is being challenged (Pohl & Yarime, 2012, p. 3). Overall the technology cycle cannot just be seen from the technology perspective as such but also has to take into account the overall sociotechnical perspective. The reason for this is that the eventual definition of a new dominant design or technology regime is at least as much shaped by technological, market, legal, social factors as well as normative and cognitive frames (Anderson & Tushman, 1990, p. 617; Arentsen, Kemp, & Luiten, 2002, p. 61; Tushman & Anderson, 1986, pp. 444, 462–463; Unruh & del Río, 2012, p. 233).

The evolutionary point of view also stresses that technology usually develops incrementally over time since the development builds on past achievements, ideas and cumulative knowledge (Arentsen et al., 2002, p. 61). As such technology is developing along paths which are typically directed at system optimisation with reference to the current system logic (Arentsen et al., 2002, pp. 65, 67). Trying to change or influence this direction can be met with a lot of reluctance and prove rather difficult due to sunk investments in existing assets which are part of path dependencies (Arentsen et al., 2002, p. 65). This again can be demonstrated how much resistance the Californian Zero Emissions Vehicle policy faced in the early 90s. Changing the system logic would be a system innovation which would satisfy a societal function in a completely new way that is different from the current sociotechnical system (Arentsen et al., 2002, p. 65). System innovation requires the use of new technology, new markets, new knowledge, new linkages, different rules and roles and major organisational change through e.g. new business models (Albrecht, 2011b; Arentsen et al., 2002, pp. 65, 67).

The system innovation then can be analytically divided into four different diffusion phases along the S-Curve introduced by Rogers, namely pre-development, take-off, acceleration and stabilization (Arentsen et al., 2002, p. 69; Rogers, 2003). Those different phases have important policy implications when one takes a look at the specific technology maturity. Also, as mentioned before, it has to be stressed that technology development is not linear but is subject to setbacks, competition, positive and negative feedback loops and continuous interaction between multiple processes (Anna Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008, p. 407; Suurs, Hekkert, & Smits, 2009, p. 9640; van Alphen, Hekkert, & Turkenburg, 2010, p. 397). One of the most important debates in technology and innovation policy is also the question whether policies should be technology specific or general (Sandén & Azar,

2005). Much of that is related to the old evolutionary perspective of nurturing both variation and selection (Arentsen et al., 2002, p. 74). Overall there is merit in the following statement:

“The most important point of departure for developing technology policies is that innovative technologies differ, economic sectors differ, existing technological systems and regimes ruling those systems differ, and hence processes of technological change towards a more sustainable mode of operation differ. There is no standard recipe for directing or accelerating technological change in more climate-friendly directions.” (Arentsen et al., 2002, p. 71)

Drawing on that one can argue that technologies need specific policies which directly interfere into the dynamics of technical change and try to make one path more attractive than others (Arentsen et al., 2002, p. 74). This is especially necessary if one tries to achieve change on the scale of system innovation in a relatively short time frame. However these need to be embedded in generic or “technology neutral” policies, which develop a variety of technology options to be able to select from (Arentsen et al., 2002, p. 76). Both types of policies have its pros and cons and each will differ according to the technology case and its maturity (Arentsen et al., 2002, p. 74). What is more important however is to give a long term and clear perspective as a meaningful context for industry and other actor’s investment decisions (Arentsen et al., 2002, p. 75). That is not to say however that more policy is always good – policy can also simply be unnecessary (due to e.g. free-rider problematic or unnecessary transaction costs) (Arentsen et al., 2002, p. 73). Subsidies for technologies with environmental benefits can however be legitimized by the fact that their environmental or social benefits are not included in the market price. The crucial question for specific policy is when the technology is at such a mature level that it can continue without governmental support.

To incorporate the mentioned multidimensional aspects, a technological innovation system (TIS) framework is being adopted which has its strengths in seeing innovation from a systems perspective surrounding the technology. The TIS framework has been adopted by major institutions such as the OECD, the European commission, UNIDO as well as different Nordic institutions such as the Nordic Council as well as Swedish institutions like Vinnova (Anna Bergek et al., 2008, p. 407). In the literature a TIS is being defined as “[...] a network or networks of agents interacting in a specific technology area under a particular institutional infrastructure [e.g. norms and regulation] to generate, diffuse, and utilise technology.” (Carlsson & Stankiewicz, 1991, pp. 94, 111; Hekkert & Negro, 2009, p. 586; Jacobsson & Bergek, 2004, p. 817; van Alphen et al., 2010, p. 397). The TIS at its heart has a system structure which consists of actors, networks and institutions (Anna Bergek et al., 2008, pp. 408, 413; Jacobsson & Bergek, 2004, p. 817; Jacobsson & Johnson, 2000, pp. 629–630). Apart from that several crucial system processes have been identified and modified over the past years (Hekkert & Negro, 2009, pp. 586–587; Jacobsson & Bergek, 2004, p. 818; van Alphen et al., 2010, p. 397).

One recent version is namely consisting of *entrepreneurial activities, knowledge development & knowledge diffusion, positive external effects, resource mobilisation, guidance, market creation, creation of legitimacy and materialisation*. Some of these interactive processes need to be addressed by e.g. policy makers at the same time in order to allow reinforcement, feedback mechanisms or complementary actions. Also these processes cannot be seen disconnected from the system structure and the spatial location of the TIS even if many supply chains are global today. Also the processes depend heavily on the stage of technology development according to the stages in the “S-curve” mentioned previously. For this see also Figure 3.

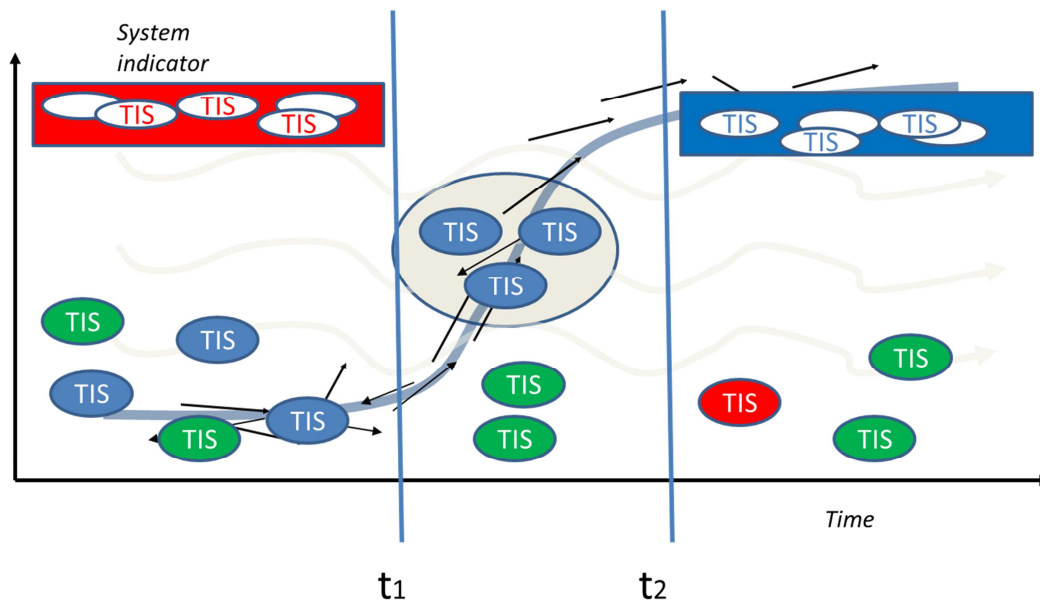


Figure 3 TIS and S-Curve: indication of how old and new TIS interact.

Looking at our selection of countries it is quite possible that e.g. Norway and Denmark are at a different phase of development for their national TIS and that e.g. in Sweden and Finland the TIS is still very much facing resistance from the incumbent TIS based around the ICE. After now having set up those analytical categories for the breakthrough scenario the following paragraph will show policy options that have been identified in a literature review as strongly supporting EVs. The main focus here will be on the mentioned system processes.

Entrepreneurial activities

Both Norway and Denmark have several companies that have been offering EVs as OEMs or offering EVs in a business model in the form of mobility services. In the case of OEMs some new EV manufacturers like “Think” have had mixed results which at least partly is due to the high entry barriers in the automotive industry (Pohl & Yarime, 2012, p. 5). Other start-up companies like Better Place, ChooseEV and MoveAbout are starting to become successful. All in all it is essential to make

resources (not just monetary) and knowledge (venturing process, lawyers, marketing etc.) available for entrepreneurs essentially in an early phase of TIS development (Berggren & Silver, 2010, p. 241; Lerner & Täg, 2012, p. 5). This will help to mitigate the real or perceived risks involved of being an entrepreneur and perhaps leaving a secure job (Wüstenhagen & Menichetti, 2012, p. 3). Hence it is necessary to not design innovation policy instruments only with the known and established actors in mind but also to account for actors that don't yet exist or for those that are too small to organise their interests (Albrecht, 2011a, pp. 13–14; 17).

In a breakthrough scenario it is vital to overcome path dependencies often inherent when dealing with established actors and technologies (Unruh & del Río, 2012; Wüstenhagen & Menichetti, 2012, p. 5). This makes entrepreneurs that challenge existing technology trajectories a key stepping stone and there needs to be a good balance between policies supporting entrepreneurs and incumbents (as e.g. in R&D support) (Wüstenhagen & Menichetti, 2012, p. 6). Also in an early stage of technological development, as is the case with electric cars and batteries, start-ups and entrepreneurs are essential for experimenting around the new technology options and probing ways to commercialise new knowledge (Audretsch, Heblich, Falck, & Lederer, 2011; Anna Bergek, 2012, p. 212; Lerner, 2010, p. 258).

Without commercialisation and finding functioning business models new technologies will not have any value (Teece, 1986, 2006, 2010). This function should receive special attention in countries with “big business” bias like it has been in parts historically found in e.g. Sweden but also in general as policymakers tend to favour incumbents (Eliasson, 2009; Hockerts & Wüstenhagen, 2010, p. 490; Jakobsson, 2011). Building up an entrepreneurial environment is essentially also a long term process that requires patience – much in the same way as it can take several years to find a working business model (Jakobsson, 2011; Lerner, 2010, p. 262). Some breakthrough recommendations for this system process hence include:

- Inclusion of entrepreneurial firms in existing R&D as well as official pilot and demonstration programs.
- Matching funds and loans for new business ventures should be provided.
- Incubator parks, shared office space, shared testing facilities (like e.g. Innovatum or TSS in Sweden) should be more directly supported and increased where reasonable (Anna Bergek & Norrman, 2008).
- Legal and business developing support is perhaps even more important than monetary support for some entrepreneurs as they might lack the necessary business skills and network capital.
- A venture capital fund that is initially matched by government funds could be an interesting instrument if there is a lack of start-up finance in the EV sector (Lerner, 2010, pp. 259–264). This has been successfully practised in countries like Israel and New Zealand to get investors interest and reduce some of the risk connected to high tech start-ups.

- Effective evaluation of supported entrepreneurs much in a similar way that is practised by venture capitalists.

Knowledge development & knowledge diffusion

Universities, research networks, pilot projects and demonstration projects are essential to build up the knowledge base in the early stage TIS. On a global level public funded research, development and demonstration spending on EVs and PHEVs increased from USD 265 million in 2003 to USD 1.6 billion in 2010 (Fulton, 2011). There have been several European wide programs of that kind financed by e.g. the European Investment Bank (EIB) and the EU's Seventh Research Framework Programme (FP7) as well as several Interreg programs between countries (Kampman, Essen, et al., 2011, pp. 83–84). Also in the Nordic national context several public-private pilot and demonstration projects have been and are still on going. Due to the fact that there are still important research efforts to be made when it comes to e.g. battery development or practical aspects like business models there is a need to keep up such programs at least in the coming 5-10 years (Fulton, 2011). Also, networks created through research and demonstration programs can help to build up a national or Nordic knowledge base (Lewald, 2011). This in turn helps creating RD&D partnerships, industrial partner investments and good practice exchange.

Positive external effects

Through developing a knowledge base and knowledge networks, supporting entrepreneurs and similar measures, opportunities are created that lead to knowledge spill overs in and between industries (A. Bergek, Jacobsson, & Sandén, 2008; Lerner & Täq, 2012, p. 4). These opportunities can be seized for example by entrepreneurs that can combine this knowledge in a new way. This in turn nurtures positive feedback cycles and helps the industry and the economy to grow. Also those feedbacks will lead to the fact that incumbents are forced to reconsider their own strategic position in the industry and its value chain (Hockerts & Wüstenhagen, 2010). Creating positive externalities that cannot entirely covered by patents is also an argument for the government giving matching funds and subsidies for start-ups and demonstration projects.

Resource mobilisation

Developing EV drivetrains and infrastructure has usually been helped by governments with R&D support. Having public research programmes that sponsor 25-50 % of research efforts made by companies in this area actively encourages OEMs to invest in drivetrain or battery development (Kampman, Braat, Essen, & Gopalakrishnan, 2011, p. 20). Similar efforts have been and can be done to match funds for pilot and demonstration projects. Those programs should be kept up at least for the next 5 years.

It is also interesting that in the case of Sweden industrial partnerships have been established to push and commercialise the PHEV technology (Albrecht, 2011b). In this case Volvo and Vattenfall together financed the development, making Vattenfall one of the few utilities that directly invested in EV technology (Frieser, 2011). This has originally been facilitated by the Swedish government and through a lot of trust between Vattenfall and Volvo. Obviously that trust is a particular case but it could still be seen as an example for further measures.

An interesting option is to more strongly support venture capital funds in general or start new funds where public funds would only be used in the beginning to attract further investors to the fund. This could be especially important in light of the on-going consequences of the financial crisis and due the heavy reliance of regional SMEs on traditional bank loans (Berggren & Silver, 2010, pp. 236, 239). In Sweden it has been shown that it is a general problem to generate spin offs from university research in more regional areas, particularly in the case of knowledge intensive SMEs (Berggren & Silver, 2010, p. 241).

Guidance

Across the globe several national development plans and road maps for EVs do exist. If all of those would be achieved 1.5 million PHEVs/EVs would be sold by 2015 and 7 million by 2020 (IEA, 2011, p. 17). In the Nordics the combined industry and government visions add up to at least 800,000 by 2020. Opposed to that OEMs have so far not the same level of production capacity that would be necessary to reach those targets (IEA, 2011, p. 22). Overall there is a need for national and supranational roadmaps and coordination that specifies goals in the national or e.g. Nordic context. Regional and local authorities need to translate those national goals into concrete local goals.

Apart from national plans an important issue with new technology is standardisation. This on the other hand limits the extent to which entrepreneurs can experiment with the new technology and it could also represent an entry barrier. However common plug and charging standards are also a crucial element for a further breakthrough of EVs as different standards create disincentives (Brown, Pyke, & Steenhof, 2010). A European wide standard is expected for 2012 but globally not before 2017 (Kampman, Essen, et al., 2011, pp. 80–81). In this area perhaps a common Nordic standard would be a good start for further market uptake.

In a similar vein it is necessary to reform current fuel standards in the European Union since the increasing availability of alternative fuels misguides customers. Hence harmonized accounting and assessment methodologies are needed to understand the well-to-wheel emissions of EVs compared to other technologies (Kampman, Essen, et al., 2011, p. 63). Similarly common efficiency or energy consumption standards could be used. Harder regulations on average fleet performance will force car manufacturers to get EVs onto the market, perhaps by having conventional vehicles subsidise new ones. Using such standards in common

labelling schemes hence would be the next step to not only improve information on CO₂ per km but also costs per km (Kågesson, 2010, p. 122; Wüstenhagen & Sammer, 2007). What is of utmost importance when dealing with new technologies is also to create a long term policy environment that reduces risks and manages expectations for companies and investors (Albrecht, 2011a, p. 18; Kågesson, 2010, pp. 91–92; Wüstenhagen & Menichetti, 2012, p. 5).

Market creation

As we have seen in Figure 1, often a mid-sized EV's initial investment is still substantially larger than the average mid-sized ICE. The higher initial investment cost of EV technologies as compared with conventional ICEs suggests that currently market creation is still a key barrier in the technological innovation system, and that a policy framework must include an arsenal of long term and short term economic incentives to bring down the initial cost. Recent studies focussing on total cost of ownership and learning curves have shown that it can still take several years and possibly decades until PHEVs and BEVs will break even with HEVs or ICEs without strong policy support (Ernst et al., 2011, pp. 5880–5881; Karplus, Paltsev, & Reilly, 2010, p. 640; Pasaoglu, Honselaar, & Thiel, 2012, pp. 418–419; Thiel, Perujo, & Mercier, 2010; van Vliet, Brouwer, Kuramochi, van den Broek, & Faaij, 2011, p. 2308; Weiss et al., 2012, p. 11).

Those studies however have mostly been conducted in countries like Germany, the Netherlands, USA, and Japan or have taken the EU average, which results in lower initial tax levels when it comes to general car ownership as compared to countries with high registration taxes like Norway or Denmark. Also such studies have some inherent uncertainties when it comes to battery price development, battery densities, the choice of battery technologies as well as the electricity and oil price. Overall one problem is that customers are reluctant to take into account the total cost of ownership over a longer time frame and typically expect a payback time of 3-5 years (IEA, 2011; Kampman, Braat, et al., 2011, p. 25; Kågesson, 2010, p. 35). Still, the operational cost of EVs can be lower when compared with ICE based vehicles due to lower fuel costs, lower maintenance cost, lower insurance cost etc. which are more difficult to include in a total cost of ownership study (Kampman, Braat, et al., 2011, p. 11).

In theory the needed economic incentives can be given before, during or after purchase, they can be designed as a one time or recurring payment and they can be technology neutral or technology specific (Kley et al., 2010, pp. 5–6). Recently several economic incentives have been applied throughout Europe, among them tax reduction on sales price, tax reduction after purchase, pure subsidy, scrapping scheme, feebate system (as e.g. used in France), reduction of annual vehicle tax, reduction of registration tax, increased fossil fuel tax, differentiated congestion charges and parking fees, joint or public purchasing, subsidies for installing charging

infrastructure, quotas for OEMs or CO2 certificates (Kampman, Essen, et al., 2011, pp. 72–75; Kampman, Braat, et al., 2011, p. 18; Kley et al., 2010, p. 2).

Among those incentives, the literature suggests that direct tax reductions are effective, more practical and more appreciated than other instruments by the customer if they are applied at the time of purchase and if directed at the customers instead of subsidizing car dealers (de Haan, Peters, & Scholz, 2007, pp. 1083–1084; Diamond, 2009, p. 982; Kley et al., 2010, p. 6; Nemry et al., 2009, p. xi–xii; 21). These would be e.g. a reduction of existing one time registration taxes and/or VAT taxes as is e.g. applied in Norway and partly in Denmark. Similarly direct subsidies instead of tax reductions are also valued by the customers but the practicality depends a lot on the system that is used. Feebate or bonus malus systems are also accepted by the customers but also here it depends a lot on how the system is set up (Nemry et al., 2009, p. 71; Wüstenhagen & Sammer, 2007). For example if the feebate system is set up stepwise instead of a gradual linear system, important improvement possibilities will be missed (Kågesson, 2010, pp. 87, 92–93). The overall problem however is that these sort of incentives also potentially favour high income groups in society which can or could have bought more expensive environmentally friendly cars anyway (Chandra, Gulati, & Kandlikar, 2010, p. 93; Diamond, 2009, p. 982; Schweinfurth, 2009, p. 5). However, if for climate reasons, increasing market share rapidly is the primary goal asked for the free rider potential might be a necessary risk.

Tax rebates after the purchase for deduction in income tax or the reduction of the yearly vehicle tax have been found to be less effective or less practical for customers (Kley et al., 2010). One of the reasons here is again that consumers are taking operational costs less into account and that the yearly vehicle tax is relatively low. However it has been shown that the gas price which is connected to the level of fuel taxes had a large impact on e.g. hybrid sales in the USA even though that higher gas prices might be less accepted politically (Diamond, 2009, p. 982). Through modelling higher fuel taxes it has also been shown that this increases shares of HEVs and BEVs as well as reducing or at least stabilizing total car fleet size (Kloess & Müller, 2011, pp. 5059–5060). CO2 based fuel and yearly vehicle taxes have also some published successes in the literature (Rogan, Dennehy, Daly, Howley, & Ó Gallachóir, 2011, p. 597).

Having exemptions or reductions for congestion charges, road and ferry tolls, road pricing and parking fees has also proved to be a useful economic instrument in e.g. London, Stockholm and in municipalities in Norway (Börjesson, Eliasson, Hugosson, & Brundell-Freij, 2012; Kampman, Essen, et al., 2011, p. 85).

In line with a breakthrough scenario and tough climate goals a one time scrapping scheme could also be considered in order to accelerate the replacement of the current vehicle fleet (“scrappage for replacement”) (Kågesson, 2010, p. 101; Nemry et al., 2009, p. xii–xiii). This could be necessary since e.g. in Sweden 46,5% of the vehicle fleet’s emission are caused by cars that are ten years and older (Nemry et al.,

2009, p. 22; SCB, 2012). A recent review of different recent scrapping schemes showed that overall the old cars were traded in with smaller more fuel efficient vehicles (Schweinfurth, 2009, pp. 4–5). However one has to keep in mind the emissions during other life stages of a car and that recycling could be a major problem (Nemry et al., 2009, p. 34). It is thus necessary to make sure that one of the primary conditions for scrapping schemes is that highly environmentally cars are being used as the substitute.

In general it is important to realise that transport related economic instruments interact with each other and can be very dynamic when combined and in turn have significant impact on the willingness to pay of consumers (Mandell, 2009). For example an increased fuel tax combined with an annual vehicle tax based on CO₂ has a larger effect on willingness to buy than implemented each on their own. Also instruments will differ in terms of their short term and long term effectiveness.

Overall the choice of instruments still is very dependent on the case at hand since for e.g. Norway and Denmark have high initial costs for cars and fossil fuels, which would be more difficult or less acceptable to implement in other countries. One has to keep in mind that most of the scientific studies are still mostly available for hybrids as case studies.

In general the economic instruments applied must be adaptable or reviewed according to learning curves when it comes to e.g. battery development. Policy makers need to closely monitor costs and technology developments and adapt policy schemes accordingly as economics of scale kick in (Kampman, Essen, et al., 2011, p. 56; Kampman, Braat, et al., 2011, p. 21). It should be argued that the instruments are phased out after EVs have reached a certain market share or when battery prices have reached a certain policy target. Also, subsidies can create rebound effects where total passenger transport increases which however could be, as mentioned before, regulated through road pricing and similar instruments (Kampman, Essen, et al., 2011, p. 74). It has also been shown that the rebound effect, at least within the transport sector, is not so significant as often suggested and is also limited by e.g. time constraints (Kågesson, 2010, pp. 112–114).

As mentioned before Denmark and Norway are the only countries in Europe where EVs can be economically attractive today with existing policy in place (Kley et al., 2010, 2012). The reason is the high level of taxes applied on conventional cars, which makes the tax reduction scheme very powerful. However, given remaining cost gaps especially in Sweden and Finland, for a fast EV market penetration, economic support schemes need to be strengthened up and preferably aligned not only across Nordic countries but also on the EU scale in order to implement a harmonised internal market.

Another important component in creating a market for EVs is different public or joint procurement initiatives. Here the procurement program by Stockholm City can

be mentioned as an example which organised a joint procurement initiative for 6,000 EVs (Elbilsupphandling.se, 2011).

In all the four simplified stages of technology development government policies should consider taking into account the potential markets of such vehicles. This will ask the question of which specific market a policy is created for - much in the same way that companies differentiate their business model according to customers or markets (Dewald & Truffer, 2011; Wüstenhagen & Menichetti, 2012, p. 4). Examples for EVs here are different markets for private customers, public entities, organisations with fleets and car pools and companies that typically lease cars. This differentiation is especially important in countries like e.g. Sweden where company cars make up more than 50% of new yearly car sales. Those aspects will however differ from country to country.

Based on the information gathered we conclude that for a breakthrough scenario which tries to achieve very ambitious goals, the following arsenal of instruments can be applied:

- In line with other environmentally friendly cars PHEVs and BEVs could benefit from a reduced or exempted VAT. This would put technologies that are still at an early market stage near established technology in terms of initial price. A reduction or exemption of VAT has been found an effective instrument for the introduction of new automotive technologies.
- Instead a feebate (or bonus malus) system with an ambitious pivot point like e.g. 95 g CO₂ per km that gradually moves towards e.g. 50 g CO₂ per km during a 5-10 year time frame is an effective option instead of reducing the VAT (Nemry et al., 2009, p. xi, 54). The argument to use this approach is that it is a potentially “cheaper” option for the government since it is roughly revenue neutral. Furthermore it is technology neutral and gives a long term incentive.
- Similarly other low carbon transport modes could benefit from the recommended VAT or feebate systems if one applies it to several transport sectors (e.g. within light and heavy road transport, as well as rail etc.).
- Scrapping scheme for cars that are older than 10 years in order to accelerate the replacement of the existing car fleet. The new car should at least manage 50 g CO₂ per km (which is in line with the current super green car rebate in Sweden) or a similar threshold according to a well to wheel calculation. In order to avoid free riders a number of preconditions should be established. The incentive should not be major monetary wise, but rather a complement to e.g. an existing feebate system (the ad hoc programmes after the financial crisis were around 3000 Euro (Schweinfurth, 2009)). The scrapping scheme could also be used to support other CO₂ low transport modes if vouchers for cycling, train or collective transport are given when the old car is traded in. This would also help to reduce total fleet size. A proper recycling and reuse of materials must be evaluated and ensured beforehand. Similarly it has to be evaluated if upgrading old vehicles with new technology would be more beneficial from a life cycle and

economic perspective. If that is the case such projects under certain conditions could also be included in the scheme.

- Even though it is less accepted politically, increasing the fuel tax and annual vehicle tax (based on CO₂ content of the fuel) has been found effective. This could also include a minimum price tag so that entrepreneurs can count on a minimum gasoline price for their new business models. Such an increase in prices should be phased in gradually.
- The introduction of congestion charges in major cities that also reflect CO₂ emissions in the cars lifecycle will be an effective mechanism to improve local environmental conditions in cities, but also provides the option of mitigating rebound effects.
- A labelling scheme that shows cost per km as well as CO₂ per km based on a well to wheel lifecycle could be an improvement to existing labelling schemes. A study focussing on hybrid sales in Switzerland has shown that labels affect automotive purchase decisions (Wüstenhagen & Sammer, 2007).
- If higher fuel taxes and other mentioned incentives are implemented, lower taxes for low income groups (e.g. income tax) should be implemented to not disproportionately harm vulnerable groups in society.

Creation of legitimacy

Arguably public acceptance and legitimacy is still a huge problem when it comes to this technology trajectory since misunderstanding and misinformation is common both in terms of what EVs can achieve and what they cannot achieve given current technology performance. This requires more information campaigns and possibilities to come into contact with the new technology.

A general problem in this regard is also the fact that most customers don't consider total cost of ownership when they are purchasing a vehicle (Kampman, Braat, et al., 2011, pp. 25, 29). Hence governments should guide customers by helping with clear labels that take into account the total cost of ownership.

Also the electrification of transport is highly dependent on decarbonisation strategies in the power sector (R. T. Doucette & McCulloch, 2011; Reed T. Doucette & McCulloch, 2011). Only this will give it the legitimacy and acceptance the electric vehicle needs in the long term.

Supporting a breakthrough in PHEV and BEV technology can only be one of several measures needed in the transport sector to reach the climate targets. An important factor is also the support of other transport alternatives and modes as well as behavioural changes (Anable et al., 2012; Cuenot, Fulton, & Staub, 2012)

Materialisation

Materialisation addresses the development of the physical products, factories and infrastructure (A. Bergek et al., 2008, p. 578; Hellsmark & Jacobsson, 2008). Here

crucial elements also are demonstration projects, pilot projects and R&D programs that provide matching funds for developing the physical infrastructure that is needed. Institutional alignment is also needed to facilitate the charging infrastructure for PHEVs and BEVs.

Results and conclusion

Looking at the current policy measures and ambitions in the Nordic countries it is interesting to acknowledge that it has not been Sweden as the country with the largest automotive industry that engaged most aggressively with the technology. Instead countries like Norway and Denmark are leading policy developments and have also been home to some of the most innovative business models in the area. This seems to confirm the hypothesis of path dependencies inherent in the arena of policy, industry and other parts of the socio-technical system. Industry in Sweden while internally engaging with electrified powertrains has been cautious about the right moment to commercialise the technology. This is partly explained by the fact that it requires considerable investment to create new vehicle platforms while at the same time receiving ambivalent policy signals about long term support mechanisms and having sunk investments in existing vehicle platforms.

Looking at the environmental impact of our scenarios, the life-cycle analysis performed indicate that electric cars may by 2030 reduce greenhouse gas emissions from passenger cars by up to 15% compared to a reference scenario without any electric cars (BEVs, PHEVs & REVs combined). The estimates presented in this paper should be regarded as an indication of the magnitude of impacts on emissions that electric vehicles may have. Although electric vehicles by 2030 thus may give a significant contribution to emission reductions, it is clear that many other changes will also be needed to reach sustainable urban transport systems. For instance, an increased share for cycling and (electrified) public transport will be needed in cities. These modes of transport have even lower energy use than electric cars and are more space efficient.

To reach the existing ambitious climate goals in the transport sector a number of breakthrough policy recommendations for BEVs/PHEVs have been given in this paper. To implement those policies some of the Nordic governments have to shift from path dependent, incremental change towards entrepreneurial policies. This includes both support to start-ups, incumbents on the OEM side but also a clear long term and short term policy arsenal. To accelerate developments it seems timely, effective and economic for governments to implement a feebate system in the countries that so far have been laggards or as a harmonised Nordic system. That system could have a pivot point of 95 g CO₂ per km that gradually moves towards 50g CO₂ per km until 2020. On top of that a scrappage scheme is an interesting option that would accelerate vehicle fleet renewal. This should be done upon the same g CO₂/km conditions as the feebate system. Instead of trading the old car for a new car the scheme could also be designed in a way that a voucher for collective

transport, upgrade of the old car, or the purchase of bicycles can be obtained. While the feebate system would be the long term policy signal it is very likely that electric vehicle power trains will also need a short to midterm policy incentive like e.g. a direct subsidy. To supplement the economic instruments and help customers in their total cost of ownership perception, labelling should be introduced in line with the feebate system.

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