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Electrification of Vehicles: Policy Drivers and Impacts in Two Scenarios

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1.1 Introduction

Over the last 10 years, the interest for low-carbon vehicle technologies has surged among both governments and automotive manufacturers across and beyond the European Union (EU). Great hopes have been put, first, on biofuel vehicles and more recently (as the enthusiasm for biofuels cooled off) on electric vehicles (EVs) and hybrid electric vehicles (HEVs) 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 internal combustion engine (ICE)-based vehicles mostly due to high lithium-ion battery prices. Also, the shape of the learning curve and associated future costs remain uncertain and predictions vary strongly [1–3]. 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, battery electric vehicles (BEVs), and in some cases also plug-in hybrid electric vehicle (PHEVs) or range-extended electric vehicles...
Grid Integration of Electric Vehicles in Open Electricity Markets

(REVs), require new infrastructure (for charging and to some extent for the upgrade of 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 chapter 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 policy or broader governance initiatives are likely needed to have a plausible chance of reaching a breakthrough scenario?
- What are the climate impacts of our scenarios and what are the implications for the attainment of climate targets?

The chapter unfolds as follows. In Section 1.2 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 1.3 elaborates scenarios of EV development in the EU and analyses the energy and climate impacts of the two scenarios, given different assumptions relating to power supply in the Nordic region. Section 1.4 examines what policy drivers might be needed to enable the breakthrough scenarios, using a technological innovation system (TIS) perspective to describe the processes, drivers and developments needed in policy and technology. Section 1.5 summarizes our results and conclusions.

1.2 Policy Drivers, Policies and Targets

Across the EU and globally, policy makers' interests 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. In the Nordic countries, total passenger car emissions in 2010 accounted for 14.10% of total emissions in Denmark, 11.15% in Finland, 12.31% in Norway and 23.05% in Sweden (see Figure 1.1) [4–9]. It is worth noting that this makes Sweden the second worst in the EU27 when just looking at the 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 that Sweden still has much to gain from mitigation measures.

The emission share of passenger cars within road transport is decreasing in most Nordic countries, while emissions from light and heavy trucks are increasing (see also Figure 1.2) [4–9]. The numbers are, however, overshadowed by the financial and economic crisis which reduced economic activity in the other road transport modes. Overall, the long-term trend indicates that some of the transport work is shifted between road transport modes but also that the environmental performance of passenger cars is improving more quickly.
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Figure 1.1 Passenger car’s share of total emissions in the Nordic countries [4–9].

In absolute terms, CO₂ emissions from passenger cars stayed on a relatively high but stable level for Sweden and there are signs of a downward trend. The other Nordic countries are still growing in absolute CO₂ emissions from passenger cars, although from a much lower base. If one looks at the passenger car emissions per capita numbers, the Swedish downward trend becomes more obvious [4–10]. Norway has been able to stabilize its emissions, while Denmark has almost succeeded in doing so. Before the financial and economic crisis, Finland was on a clear upward trend (see also Figure 1.3).

Figure 1.2 Passenger car’s share of total road transport emissions in the Nordic countries [4–9].
Generally, rapid action is required to reduce passenger car emissions in line with ratified climate change goals. Otherwise, extrapolating the current function of environmental performance of the average passenger car in the fleet, we will not see a carbon-neutral road transport sector within the next couple of decades. The data also suggest that, even though passenger cars are the most important challenge right now, we will also have to tackle light and heavy trucks in the near future if one wants to counter given growth trends (see Figure 1.2).

The second political priority 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 [11]. 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 Asia in particular. In the EU, this concern can be framed politically in the broader Lisbon strategy of 2006, which set out the EU becoming a ‘dynamic and competitive knowledge-based economy’ [12]. 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 (taking into account connected services, etc.) [13].

On the 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 CO$_2$ 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 CO$_2$ emissions of the vehicles. In 2011, the EU adopted a road-map for the next decade to reduce its dependence on imported oil and to cut carbon emissions in transport by 60% by 2050 [14]. Furthermore, EU vehicle CO$_2$ emissions regulations stipulate that 130 g/km (phased in, starting 2012) has to be met by 2015.
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Figure 1.4  Average CO₂ emissions per kilometre from new passenger cars [19–21].

and that 95 g/km very likely has to be fulfilled by 2020 [15–17]. Furthermore, the European parliament has mentioned the possibility of setting a 75 g/km CO₂ target for 2025 [18]. To set those numbers into context, the current grams of CO₂ per kilometre data for the average new passenger cars in the Nordic countries can be seen in Figure 1.4 [19–21]. The graph shows that Sweden and Finland are clearly lagging behind Norway and Denmark. In fact, Denmark already is below the 2015 EU emission target.

Globally, as well as in the EU, the economic crisis since 2008 pressed for stimulus spending in the automotive sector. Governments have provided subsidies, loans and research and development (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, the power industry and the automotive industry both on the national level and the 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 very different from country to country, taking into account the full set of measures. Kley et al. 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 [22, 23]:

- the leaders (incentive from €10 000 to €28 000: Denmark, Norway and Belgium);
- the followers (incentive from €4000 to €9000: Netherlands, Spain, UK, France, Switzerland and Austria);
- the laggards (with amounts ±€3000: Ireland, Greece, Italy, Germany, Sweden, Poland and Finland).

Among the Nordic countries, only Sweden has a significant automotive industry [24]. 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 EV technologies and innovation systems.

In terms of market introduction of EVs, Norway currently has the lead. At the end of October 2012, 9212 EVs were on Norway’s roads, which makes it one of the most successful countries in terms of EVs per capita [25]. By comparison, as of the end of September 2012, there were 1320 BEVs registered in Denmark, 1067 BEVs and PHEVs as of the end of October 2012 in Sweden and about 60 BEVs in Finland as of June 2012 [26–31]. These numbers are, however, somewhat unreliable, as some sources include direct private imports while others do not. Also, some sources take into account four-wheel drives that are not classified as passenger cars and some take into consideration PHEVs/REVs while others do not.

Below, we describe in more detail the policies and targets for our four Nordic countries. Through this we get a better understanding of the policies that exist and how they compare with the policy drivers presented above.

1.2.1 Finland

Goals

Finland has so far not established a specific national goal for the introduction of EVs. However, the government has presented a climate and energy strategy where two goals are to reduce greenhouse gas (GHG) emissions from traffic and transport by 15% and to increase the energy efficiency of the transport sector by 9% from 2005 to 2020 [32]. The government has also developed a vision for 2050 in which the direct specific emissions of cars are supposed to reach 80–90 g/km CO$_2$ by 2030, 50–60 g/km CO$_2$ by 2040 and 20–30 g/km CO$_2$ by 2050 [33].

Policy Instruments

A vehicles tax reform began in 2008 which eventually is supposed to give consumers more choice on the level of tax when they buy new or used cars [34, 35]. Today, the registration tax and the annual vehicle tax are based on CO$_2$ emissions. The new registration tax was introduced in 2008 and the new annual vehicle tax in 2010 [36]. In 2012, the lowest registration tax level, for cars with 0 g/km CO$_2$, was reduced from 12.2% to 5% [34, 35, 37, 38]. The highest tax level was raised from 48.8% to 50%. Overall, the message is that cars with less than 110 g/km CO$_2$ will get a lower registration tax compared with the tax regime before. For new BEVs, this means that the previous registration tax is being reduced from €3660 to €1500 for a BEV that costs €30 000. The base tax within the annual vehicle tax is also based on CO$_2$ emissions and after the 1 April 2012 can vary between €43 and €606 per year [34].

The Finnish government has also identified the EV as a Finnish export opportunity [39]. 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 [38, 40]. The programme is called EVE – Electric Vehicle Systems programme – and also hopes to create a strong community around EVs in Finland [41]. 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 4 years [42–44]. Other significant projects include EVELINA (National Test Environment for Electric Vehicles) [45], Eco Urban Living [46], SIMBe (Smart Infrastructures for Electric Mobility in Built Environments, which started in January 2010 and is funded by TEKES Sustainable community programme) [47], and the battery research programme SINi [48].

**Industry Position**

Finland has a major and experienced EV manufacturing facility through the company Valmet Automotive who mainly builds EVs for other brands; for example, the REV sports car Fisker Karma [49]. Furthermore, before its recent bankruptcy, the Think car was produced in Finland at the same factory [50]. Another Finnish EV manufacturer is the company AMC Motors with their model Sanifer [51]. Finland is also home to a larger battery manufacturer called European Batteries [52]. Fortum as the major Finnish utility is part of several pilot projects across the Nordic countries and is foremost driving developments in the smart and fast charging area [53, 54].

1.2.2 **Sweden**

**Goals**

The Swedish government has established the vision of a “fossil fuel independent” transport sector by 2030, but has no target for PHEV/BEV penetration. Industry groups have put forward a vision for 600 000 PHEVs and BEVs on Swedish roads by 2020 [55–57]. The 2030 government vision is currently not backed up by concrete road-maps, even though the government recently decided to develop such a road-map [56]. At the same time, different industry organizations have established scenarios [58, 59]. There is significant scepticism and uncertainty about those targets, and even government officials think that only a modest 20 000–85 000 PHEVs and BEVs by 2020 is actually achievable under current institutional conditions [55, 60, 61].

**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 [62]. The road transport law primarily eliminates the yearly vehicle tax for private persons and professional organizations for a period of 5 years for all green cars introduced after 1 June 2009 (currently, the green car definition translates into 120 g/km CO₂ – or cars driven by alternative fuels with fuel consumption per 100 km of 9.2 L gasoline equivalents, 9.2 m³ of gas or 37 kWh electricity). A new green car definition is scheduled to be implemented early in 2013.
For the income year 2012 and 2013 the income tax law foresees that the tax on the private benefit stemming from an employee-driven but company-owned BEV, PHEV or biogas car to be 40% less than a comparable average model. The reduction takes place after the tax level has already been reduced to the average model; but all in all, the total reduction cannot be higher than 16 000 SEK [63]. Ethanol cars, HEVs and a variety of other biofuels are only reduced to the tax level of a comparable average model but are not reduced further. 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 budget will be sufficient to support the equivalent of about 5000 EVs [64, 65]. At the end of September 2012 the maximum budget for 2012, which was 20 million SEK, had been reached [66]. Additionally, Swedish government 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) [67–72]. Those measures are co-financed with a 25–50% stake by the Strategic Vehicle Research and Innovation programme (FFI – a Vinnova-funded research programme) or the Swedish Energy Agency (SEA) [61]. Other significant incentives include the national procurement plan initiated by the city of Stockholm and Vattenfall and partly financed by SEA [73]. The purpose of the procurement is to allow the coordinated procurement of 6000 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 [61, 74]. However, it is not allowed to discriminate different types of vehicles when it comes to parking fees [71]. As a way to accelerate charging infrastructure deployment, there is no longer a need to pay grid concession fees to the local grid company for connecting outside charging infrastructure (e.g. in malls) [75–79].

**Industry Position**

In Sweden, industry is primarily concerned with R&D of electric powertrains or aspects related to them. However, Volvo is on the verge of commercializing two cars, namely a BEV and a PHEV, the latter co-financed by Vattenfall. Similar to Volvo, Saab has also developed a BEV, but the future of this project due to the company’s recent bankruptcy remains uncertain. The new owner expects that they will sell a Saab EV by 2014 [80]. The company EV Adapt is converting conventional cars to BEVs and there is also a company called Hybricon that will be selling electric buses. Otherwise, there are also a number of companies that are active in the charging infrastructure business (e.g. Park&Charge, ChargeStorm, Easycharge). Moreover, Sweden has, and has had, a number of demonstration programmes in which, for example, utilities have been major partners [53, 81].

**1.2.3 Denmark**

**Goals**

In 2009, the Danish parliament agreed on a common policy for a greener transport system [82]. The new Danish government recently adopted the goal to phase out all of the country’s
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Oil, coal and natural gas until 2050 and to provide 50% of the country’s electricity by wind energy already by 2020 [83, 84].

Policy Instruments

The major EV instrument is the relief from registration fees until 2015 [85–87]. The registration fee on passenger cars in Denmark in 2011 is 105% of the value until 79 000 DKK and 180% of the value above [88], making such a tax relief a very strong incentive. Also, the annual taxation of cars has been reformed: the tax was previously calculated on the basis of car weight, but is now based on fuel economy.

In line with government goals, the Danish Transport Agency has been assigned to administer a fund for research activities and demonstration projects on energy-efficient transport. The largest single grant of the first round was given to the project ‘Test-an-EV’, where 300 EVs are tested for daily use by 2400 families during certain time periods [89]. The partner company for the project is Clever and the test is expected to reveal driving and charging patterns as well as user experiences with EVs. 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 [90]. The citizens of Bornholm also participate in the smart-grid project ‘EcoGrid EU’, and results are exchanged between the two projects [91]. Apart from the island of Bornholm, Copenhagen municipality should also 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 regard to electric mobility are being implemented. Such companies dedicated to deployment, service systems and infrastructure for EVs 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), CleanCharge and Clear Drive [92–95]. Better Place, in particular, 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. Clever has also received attention owing to the largest BEV trial within the EU in which 1600 Danish families have so far participated within a period of 3 years [96, 97]. Clever is building up a national charging network and among slow charging stations wants to reach 350 fast charging stations by 2015. An important network is the Danish Electric Vehicle Alliance, which is a trade association for the EV industry in Denmark, formed in 2009 by the Danish Energy Association. The Alliance has initiated projects on standardization and roaming within the charging infrastructure and has recently prepared a long-term EV strategy [26]. Members range from electric distribution and utility companies over the automotive industry to research institutes and smaller projects on EV technology.
1.2.4 Norway

Goals
The EV 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 10-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 GHG emissions. The goal is to limit emissions from transport by 2.5–4.0 million tons of CO$_2$ equivalents in 2020 according to continuation of the current development in the sector [98]. The country has also set the target to achieve an average emission level of 85 g/km CO$_2$ in terms of total new vehicle sales by 2020 [99].

Policy Instruments
In order to reach its goals, the Norwegian government encourages the purchase of EVs in various ways. Noteworthy here is that BEVs currently are relieved from the registration tax (also sometimes called one-time tax or import tax) as well as valued-added tax (VAT) and have a much lower annual tax (10–20% that of ICE-propelled vehicles) [100]. These measures are guaranteed until 2017 as long as no more than 50,000 such cars are on the roads [101]. The current government has even preliminary plans to continue them at least until 2020 [102]. BEVs are further relieved from parking fees at public parking lots, road pricing or congestion charges, charges on ferries (but the driver has to pay) and are often allowed to drive in bus lanes that are otherwise reserved for public transport [99]. Also, in Oslo and other areas, most public charging spots are free to use for owners of BEVs.

Another actor to mention here is the public funding programme Transnova that is currently among other initiatives funding fast charging stations across the country. The agency also funds various other projects aiming at reducing GHG emissions from the transport sector (e.g. trial or pilot programmes). The Norwegian Research Council runs a funding programme 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 the car manufacturers Think and Reva as well as the car sharing company MoveAbout. Unfortunately, Think has not yet been able to restart production after its latest bankruptcy in 2011. Furthermore, Norway has active industry associations around EVs that strongly support further developments.

1.2.5 Nordic Comparison
Looking at the overall Nordic perspective, it becomes apparent that there are 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, but few policies suggest such a development. Instead of deployment, Sweden and, to a lesser extent, Finland have focused on R&D, annual vehicle tax definition reform and demonstration projects but have not yet made the link to actual deployment of EVs. 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, taking into account the slow renewal rate of vehicle fleets, one can argue that in all countries the number of EVs on the street still lag behind the ambitious goals set forward. Table 1.1 summarizes existing policy frameworks across the four countries in terms of economic, regulatory and cognitive/normative governance mechanisms [103].

The range of policy measures results in different price tags across the Nordic countries, which is exemplified here in Figure 1.5 by using the BEV Nissan Leaf and the fuel-efficient diesel-driven Golf BlueMotion 1.6 TDI (based on exchange rates from June 2012). The figure solely focuses on initial prices at the point of purchase and, hence, does not include operational costs or benefits. The price information is gathered from the original equipment manufacturers’ (OEMs’) web sites and then combined with the policies that exist in the Nordic countries at the point of sale. It can be clearly seen that BEVs will have a hard time competing in Finland and Sweden given current governance regimes. Even though the BEV is likely favourable in terms of operational costs, it will be difficult to close the existing cost gap within a reasonable investment time frame.

1.3 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 focusing on Europe that were identified in a literature review. It becomes apparent that there are quite large differences between those reports and studies [1, 104–107].

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

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

Owing 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 [1]. 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 [107].
Table 1.1 EV policy frameworks across the Nordic countries.

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<th>Finland</th>
<th>Sweden</th>
<th>Denmark</th>
<th>Norway</th>
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<tbody>
<tr>
<td><strong>EV targets (Gov. or Ind.)</strong></td>
<td>O</td>
<td>X</td>
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<td>X</td>
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<td>No specific EV target</td>
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<td>No specific EV target</td>
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<td>Industry: 600 000</td>
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<td><strong>Currently registered BEVs and PHEVs</strong></td>
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<td>c. 1000</td>
<td>c. 1300</td>
<td>c. 9200</td>
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<td><strong>Economic</strong></td>
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<td>VAT exemption</td>
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<td>O</td>
<td>X Norway exempts BEVs from VAT</td>
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<td>Registration tax</td>
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<td>The registration tax is adjusted</td>
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<td>according to CO₂ emissions</td>
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<td>Annual vehicle tax reform</td>
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<tr>
<td>Company car tax reform</td>
<td>n/a</td>
<td>X</td>
<td>n/a</td>
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<tr>
<td>Direct subsidy</td>
<td>O</td>
<td>X</td>
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<td>Subsidy for super green cars</td>
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<td><strong>Research programmes</strong></td>
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<td>Tolls, congestion, charging fee,</td>
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<td>parking fee exemption, etc.</td>
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<td><strong>Regulatory</strong></td>
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<tr>
<td>Free public charging access</td>
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<tr>
<td>Some organizations allow free charging</td>
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<td>Allowance to drive in bus lanes</td>
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<td>Priority parking</td>
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<td>Cognitive/normative</td>
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<td>Demonstration programmes that</td>
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At the other end, we consider an EV breakthrough scenario, where market share increases 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 USD 400/kWh in 2020 and to between USD 150/kWh and USD 200/kWh in 2030 [104, 108, 109];
- strong long-term and coordinated policy support;
- strong public acceptance and behavioural changes in transport [110].

Before now focusing on policies on how to achieve those scenarios, we will first focus on the environmental impact of the market uptake options described. The electrification of vehicles is currently being discussed as a major lever for a more environmentally friendly form of transport. Emissions of nitrogen oxides (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 GHG 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 PHEVs (includes also REVs).
Table 1.2 Key assumptions used to calculate life-cycle emissions.

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tail-pipe emissions for an ‘80 g diesel car’ in real traffic</td>
<td>100 g/km</td>
<td>[111, 112]</td>
</tr>
<tr>
<td>Tail-pipe emissions for PHEV in petrol mode</td>
<td>95 g/km</td>
<td>20% lower than present Toyota Prius in highway driving</td>
</tr>
<tr>
<td>Electricity consumption in electric mode (PHEV and all-electric car)</td>
<td>0.16 kWh/km</td>
<td>20% lower than present energy use according to [112]</td>
</tr>
<tr>
<td>Emissions from electricity production</td>
<td>160 g CO$_2$/kWh (50 and 600 g CO$_2$/kWh in sensitivity analysis)</td>
<td>[113]</td>
</tr>
<tr>
<td>Emissions from production of fuels from oil sand</td>
<td>40% addition to direct emissions</td>
<td>[114]</td>
</tr>
<tr>
<td>Share of driving distance in electric mode for PHEV</td>
<td>60%</td>
<td>[115]</td>
</tr>
<tr>
<td>Total driving distance during vehicle life for diesel car and PHEV</td>
<td>200 000 km</td>
<td>Based on [1]</td>
</tr>
<tr>
<td>Total driving distance during vehicle life for all-electric car</td>
<td>150 000 km</td>
<td>Based on [1]</td>
</tr>
<tr>
<td>Emissions of CO$_2$ from manufacturing and maintenance of cars during their life length</td>
<td>Diesel car 3.3 ton, PHEV 4.0 ton, All-electric car 4.8 ton</td>
<td>[112, 116–119]</td>
</tr>
</tbody>
</table>

and all EVs 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/km CO$_2$ according to the New European Drive Cycle (NEDC), a PHEV 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 1.2.

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 Sköldberg and Unger [113], which incorporates climate policies roughly in line with the 2°C target. The marginal emissions in that scenario amount to 160 g CO$_2$/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 CO$_2$/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 [114].
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Figure 1.6 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 CO\(_2\)/kWh.

Regarding emissions from manufacturing and maintenance of vehicles, key assumptions used are found in Table 1.2. It is assumed that emissions per car produced are reduced by 40% until 2030, compared with 2005.

Figure 1.6 shows the resulting life-cycle emissions for the three types of cars. At 160 g CO\(_2\)/kWh the electric cars are better than the diesel car, although the relative difference is smaller than if only tail-pipe emissions are considered.

We then combine these results with the two scenarios for market penetration: incremental growth with 18% EVs (BEV + PHEV + REV) in the fleet in 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/km in 2030 [120], corresponding to life-cycle emissions of 212 g/km. Furthermore, we assume that biofuels stand for 20% of total energy used for passenger cars, and that they achieve a 70% reduction of GHG emissions compared with fossil fuels.

The resulting changes in life-cycle emissions for passenger cars are shown in Table 1.3. 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 CO\(_2\)/kWh the emission reductions amount to 7% and 15%, while a high carbon intensity of 600 g CO\(_2\)/kWh GHG gives small emissions reductions. The breakeven level is calculated to be 800 g CO\(_2\)/kWh; that is, this is the level which would make emissions unaffected.

<table>
<thead>
<tr>
<th>Reduction (%)</th>
<th>50 g CO(_2)/kWh</th>
<th>160 g CO(_2)/kWh</th>
<th>600 g CO(_2)/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incremental growth, 18% of EVs in the fleet</td>
<td>7</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Breakthrough, 33% of EVs in the fleet</td>
<td>15</td>
<td>13</td>
<td>5</td>
</tr>
</tbody>
</table>
In all cases it is assumed that 70% of the electric cars are PHEVs and 30% all-electric cars. This is roughly in line with most forecasts. For instance, Kampman et al. [1] assume an 80% share for plug-in hybrids.

All attempts to estimate the impact of new technologies by 2030 are associated with considerable uncertainties, and this is particularly pronounced for EVs. The estimates presented here should be regarded as an indication of the magnitude of impacts on emissions that EVs may have. Although EVs 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.

1.4 Future Policy Drivers for a BEV and PHEV Breakthrough

On the basis of existing EV policy targets, this section will elaborate a general breakthrough scenario for strong EV uptake. With this we hope to contribute to an understanding of what an ambitious EV policy goal would actually mean in terms of policy instruments. While doing so, we have gathered existing literature on policy instrument research in the transport sector, or more specifically on hybrids or EVs when available.

First, when analysing technology development and technology shifts it can be valuable to adapt 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 [121]. 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 [121–123]. 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 [121, 123].

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 [124]. This can be demonstrated by the fact that EVs were first introduced around the end of the nineteenth century [125]. 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 [122]. 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 and social factors as by normative and cognitive frames [121, 123, 126–128].

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 [126]. As such, technology is developing along paths which are typically directed at system optimization with reference to the current system logic [126]. 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 [126, 129]. This, again, can demonstrate how much resistance the Californian Zero Emissions Vehicle policy faced in the early 1990s. Changing the system logic would be a system innovation which would satisfy a societal function in a way that is different from the current sociotechnical system [126]. More precisely, it requires the use of new technology, new markets, new knowledge, new linkages, different rules and roles and major organizational change through, for example, new business models [53, 126].

System innovation can be analytically divided into four different diffusion phases along the S-curve introduced by Rogers, namely pre-development, take-off, acceleration and stabilization [126, 130]. Those different phases have important policy implications when one takes a look at the technology maturity level [131 (p. 397), 132 (p. 407), 133 (p. 9640)].

One important debate in technology and innovation policy is also the question of whether policies should be technology specific or general [134]. Much of that is related to the evolutionary perspective of nurturing both variation and selection [126]. From the selection point of view one can argue that technologies need specific policies which directly interfere with the dynamics of technical change and try to make one path more attractive than others. 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 [126]. Both types of policies have their pros and cons and each will differ according to the technology at hand and the technology’s maturity level [126, 135]. What is more important, however, is to give a long-term and clear perspective as a meaningful context for industry and other actors’ investment decisions [126].

To incorporate the mentioned multidimensional aspects, a TIS perspective 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 and the Swedish agency Vinnova [132 (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’ [131, 136–138]. The TIS at its heart has a system structure which consists of actors, networks, institutions and artefacts [132 (pp. 408, 413), 138 (p. 817), 139 (pp. 629–630)]. Apart from that, several crucial system processes have been identified and modified in past years [131, 137, 138]. One recent version consists of entrepreneurial activities, knowledge development and knowledge diffusion, positive external effects, resource mobilization, guidance, market creation, creation of legitimacy and materialization. Some of these interactive processes need to be addressed by, for example, policy makers at the same time in order to allow reinforcement, feedback mechanisms or complementary action. Also, these processes cannot be seen as disconnected from the system structure and the spatial location of the TIS even if many supply chains are global today. Apart from that, these processes depend heavily on the stage of technology development according to the stages in the ‘S-curve’.

Looking at our selection of countries, it is quite possible that Norway and Denmark, for example, are at a different phase of development for their national EV TIS and that in Sweden and Finland, for example, the TIS is still very much facing resistance from the incumbent TIS
based around the ICE. After having set up those analytical categories, the following subsection will show policy options that have been identified as potentially supporting an EV TIS. The main focus in the following will be on the mentioned system processes.

1.4.1 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 automobile OEMs, some new EV manufacturers like Think have had mixed results, which is at least partly due to the high entry barriers in the automotive industry [122]. Other start-up companies, like Better Place, Clever and MoveAbout, are slowly starting to become more economically viable. All in all, it is essential to make resources (not just monetary) and knowledge (venturing process, lawyers, marketing, etc.) available for entrepreneurs [140, 141]. This will help to mitigate the real or perceived risks involved of being an entrepreneur and perhaps leaving a secure job [142]. 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 do not yet exist or for those that are too small to organize their interests [81].

In a breakthrough scenario it is vital to overcome path dependencies often inherent when dealing with established actors and technologies [128, 142]. 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 (e.g. as in R&D support) [142]. Also, in an early stage of technological development, as is the case with electric cars and lithium-ion batteries, start-ups and entrepreneurs are essential for experimenting around the new technology options and probing ways to commercialize new knowledge [11, 143, 144]. Without commercialization and finding functioning business models, new technologies will not have any value [145–147]. This function should receive special attention in countries with ‘big business’ bias, like it has been in parts historically found in, for example, Sweden [148–150]. Building up an entrepreneurial environment is essentially also a long-term process that requires patience – in much the same way as it can take several years to find a working business model [11, 150]. Some breakthrough recommendations for this system process hence include:

- Inclusion of entrepreneurial firms in existing government-funded R&D, pilot and demonstration programmes.
- Matching funds and loans for new business ventures.
- Incubator parks, shared office space, shared testing facilities (e.g. like Innovatum or TSS in Sweden) should be more directly supported and increased where reasonable [151].
- 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 [11]. This has been successfully practised in countries like Israel and New Zealand to get investor interest and reduce some of the risk connected with high-tech start-ups.
- Effective evaluation of supported entrepreneurs, in much the same way that is practised by venture capitalists.
1.4.2 Knowledge Development and 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 [152]. There have been several European-wide programmes of that kind financed by, for example, the European Investment Bank and the EU’s Seventh Research Framework Programme (FP7), as well as several Interreg programmes between countries [1]. Also, in the Nordic national context, there have been several public–private pilot and demonstration projects and some are still ongoing. Owing to the fact that there are still important research efforts to be made when it comes to, for example, battery development or business models, there is a need to keep up such programmes at least in the coming 5–10 years [152].

Also, networks created through research and demonstration programmes can help to build up a national or Nordic knowledge base [61]. This, in turn, helps in creating research, development and demonstration partnerships, industrial partner investments and good practice exchange.

1.4.3 Positive External Effects

Through developing a knowledge base and knowledge networks, supporting entrepreneurs and similar measures, opportunities are created that lead to knowledge spillovers in and between industries [141, 153]. These opportunities can be seized 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 force incumbents to reconsider their own strategic position in the industry and its value chain [149]. Creating positive externalities that cannot entirely be covered by patents is also an argument for the government giving matching funds and subsidies for start-ups and demonstration projects.

1.4.4 Resource Mobilization

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 [2]. Similar efforts have been and can be done to provide matching funds for other pilot and demonstration projects.

It is also interesting that, in the case of Sweden, industrial partnerships have been established to push and commercialize the PHEV technology [53]. In this case, Volvo and Vattenfall together financed the development, making Vattenfall one of the few utilities that directly invested in EV technology [154]. 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 ongoing consequences of the financial crisis and due to the heavy reliance of regional small and medium enterprises (SMEs) on traditional bank loans [140]. In Sweden, it has been shown that it is a general problem to generate spinoffs from university research in more regional areas, particularly in the case of knowledge-intensive SMEs [140].
1.4.5 Guidance

Across the globe, several national development plans and road-maps for EVs do exist. If all of those were to be achieved, 1.5 million PHEVs/EVs would be sold by 2015 and 7 million by 2020 [155]. OEMs have so far not had the same level of production capacity that would be necessary to reach those targets [155]. Overall, there is a need for national and supranational road-maps and coordination that specifies goals in the national or, for example, Nordic context. Regional and local authorities need to translate those national goals into concrete local goals.

Apart from national road-maps, an important issue with new technology is standardization. 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 [156]. A European-wide standard is expected for 2012, but globally not before 2017 [1]. 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 EU 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 with other technologies [1]. 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 subsidize new ones. Using such standards in common labelling schemes would hence be the next step to not only improving information on \( \text{CO}_2 \) per kilometre, but also costs per kilometre [18, 157]. 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 [18, 81, 142].

1.4.6 Market Creation

As we have seen in Figure 1.5, 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 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 focusing on total cost of ownership and learning curves have shown that without strong policy support it can take several years and possibly decades until PHEVs and BEVs will break even with HEVs or ICEs [158–163]. 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 compared with 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 and the future electricity and oil prices. Furthermore, in such studies, the operational cost advantages of an EV like, for example, lower fuel costs, lower maintenance costs and lower insurance costs are more difficult to capture;
hence, an important aspect of EV ownership is being missed [2]. In that context one major 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 within 3–5 years [2, 18, 155].

In theory, the economic incentives needed 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 [22]. 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, reduction of annual vehicle tax, reduction of registration tax, increased fossil fuel tax, differentiated congestion charges and parking fees, joint or public procurement, subsidies for installing charging infrastructure, quotas for OEMs or CO₂ certificates [1, 2, 22].

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 [17, 22, 164, 165]. These would, for example, be a reduction of the registration taxes and/or VAT as is, for example, applied in Norway and partly in Denmark. Similarly, direct subsidies instead of tax reductions are also valued by the customer, but the practicality depends a lot on the system that is used. Feebate or bonus malus systems are also accepted by the customers, but here success depends a lot upon how the system is set up [17, 157]. For example, if the feebate system is set up stepwise instead of as a gradual linear system, important improvement possibilities will be missed [18]. Likewise, the pivot point of the feebate system should be sufficiently low. The overall problem, however, is that these sorts of incentives also potentially favour high-income groups in society who can or could have bought more expensive environmentally friendly cars anyway [165–167]. However, if, for climate reasons, the priority is to increase the market share of EVs, then the free-rider phenomenon 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 [22]. One of the reasons for this is again that consumers are taking operational costs less into account and that the yearly vehicle tax is relatively low in most countries. However it has been shown that the gas price, which is connected to the level of fuel taxes, had a large impact on, for example, hybrid sales in the USA [165]. Through modelling higher fuel taxes it has also been shown that this increases shares of HEVs and BEVs as well as reduces or at least stabilizes total car fleet size [168]. CO₂-based fuel and yearly vehicle taxes have also some published successes [169].

Having exemptions or reductions for congestion charges, road and ferry tolls, road pricing and parking fees have also proved to be a useful economic instrument in, for example, London, Stockholm and in major municipalities in Norway [1, 170].

In line with 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’) [17, 18]. This could be necessary since in Sweden, for example, almost 50% of the vehicle fleet’s emission are caused by cars that are 10 years and older [17, 171]. A recent review of scrapping schemes showed that, overall, old cars were traded in for smaller more fuel-efficient vehicles [167]. However, one has to keep in mind the emissions during other life stages of a car [17]. It is thus necessary to make sure that one of the primary conditions for scrapping schemes is that only high-performing environmental cars are being used as the substitute (e.g. in line with the super green car definition in Sweden).
In general, it is important to realize that transport-related economic instruments interact with each other and can be very dynamic when combined and, in turn, have a significant impact on the willingness to pay of consumers [172]. For example, an increased fuel tax combined with an annual vehicle tax based on CO₂ has a larger effect on willingness to buy than when implemented individually. Also, instruments will differ in terms of their short-term and long-term effectiveness.

The economic instruments applied should be adaptable or revised according to learning curves when it comes to, for example, battery development. Policy makers need to closely monitor costs and technology developments and adapt policy schemes accordingly as economics of scale kick in [1, 2]. 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; as mentioned before, however, this could be regulated through road pricing and similar instruments [1]. It has also been shown that the rebound effect, at least within the transport sector, is not as significant as often suggested and is also limited by, for example, time constraints [18].

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 – in much the same way that companies differentiate their business model according to customers or markets [142, 173]. Examples for EVs here are different markets for private customers, public entities, organizations with fleets and car pools and companies that typically lease cars. This differentiation is especially important in countries like Sweden, for example, where company cars make up more than 50% of new car sales. Hence, another important component in creating a market for EVs is different public or joint procurement initiatives. Here, the procurement program by Stockholm can be mentioned as an example which organized a joint procurement initiative for 6000 EVs [73].

Based on the information gathered, we conclude that in 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 is an effective instrument for the introduction of new automotive technologies.
- Instead of a VAT exemption, a feebate (or bonus malus) system with an ambitious pivot point like, for example, 95 g/km CO₂ that gradually moves towards e.g. 50 g/km CO₂ during a 5–10 year time frame is an effective option [17]. The argument to use this policy is that it is a ‘cheaper’ option for the government since it is potentially revenue neutral. Furthermore, it is also technology neutral and provides a long-term investment environment.
- A 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/km CO₂ (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, for example, an existing feebate system (the ad hoc programmes after the financial crisis were around €3000) [167]. The scrapping scheme could also be used to support other low...
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CO₂ transport modes through vouchers for cycling, train travel or collective transport. This would also help to reduce total vehicle fleet size. Similarly, it has to be evaluated if upgrading old vehicles with new technology would be possible. EVAdapt in Sweden is a company that offers such services.

- Even though it is less accepted politically, increasing the fuel tax and annual vehicle tax (based on CO₂ content of the fuel) is effective. This could also include a minimum price tag so that entrepreneurs can count on a minimum gasoline price for their 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 a car’s life cycle is an effective mechanism to improve local environmental conditions in cities, but also provides the option of mitigating rebound effects.
- A compulsory labelling scheme that shows cost per kilometre as well as CO₂ per kilometre based on, for example, a well-to-wheel life cycle could be an improvement to existing labelling schemes. A study focusing on hybrid sales in Switzerland has shown that labels affect automotive purchase decisions [157].
- 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.

1.4.7 Creation of Legitimacy

Arguably, public acceptance and legitimacy are still huge problems when it comes to this technology trajectory, since misunderstanding and misinformation are 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 in, for example, trial programmes.

A general problem in this regard is also the fact that most customers do not consider total cost of ownership when they are purchasing a vehicle [2]. Hence, governments should guide customers by introducing clear labels that take into account the total cost of ownership.

Also, the electrification of transport is highly dependent on decarbonization strategies in the power sector [174, 175]. Only this will give it legitimacy and acceptance 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 [110, 176].

1.4.8 Materialization

Materialization addresses the development of the physical products, factories and infrastructure [153, 177]. Here, crucial elements also are demonstration projects, pilot projects and R&D programmes 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.
1.5 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, the country with the largest automotive industry and the goal of a fossil-fuel-free transport, that has engaged most aggressively with the BEV/PHEV 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 strengthen the idea of path dependencies inherent in the arena of policy, industry and other parts of sociotechnical systems [127–129]. Industry in Sweden, while in-house engaging with electrified powertrains, has been cautious about the right moment to commercialize the technology [178]. 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.

What is also apparent is that the most successful country in terms of EV deployment, Norway, is the country that uses the full arsenal of governance mechanisms (economic, regulatory and cognitive/normative) and has guaranteed this policy framework at least until 2017 [103]. The difference becomes more apparent between Denmark and Norway, which both have very strong economic incentives when it comes to initial investment, as can be seen in Figure 1.5. However, Norway facilitates day-to-day EV usage much more through operational economic incentives and regulatory measures that are in place. This saves time and money in operation on top of the favourable initial investment incentives. Denmark might not yet have the high EV sales that were originally anticipated, but it has done important groundwork, especially when it comes to charging infrastructure, cognitive prerequisites (largest EV trial programme in Europe) and initial investment incentives. Finland, at this stage, has not yet prioritized EV deployment even though it does have the necessary industrial base that participates in EV technological innovation systems in other countries, including other Nordic countries.

Looking at the environmental impact of our scenarios, the life-cycle analysis performed indicates that electric cars may by 2030 reduce GHG emissions from passenger cars by up to 15% compared with a reference scenario without any electric cars. The estimates presented in this chapter should be regarded as an indication of the magnitude of impacts on emissions that EVs may have. Although EVs by 2030 may thus 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 general breakthrough policy recommendations for BEVs/PHEVs have been given in this chapter. To implement those policies, some Nordic governments have to shift from path-dependent, incremental-change types of policies towards entrepreneurial policies. This includes both support to start-ups and incumbents on the OEM side, but also a clear long-term and short-term policy arsenal to take into account the different development phases of a TIS according to the S-curve. In this regard, it seems prudent to also differentiate between governance mechanisms that interfere at the initial purchase decision and mechanisms that focus on day-to-day operational usage of an EV.
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To accelerate developments it seems timely, effective and economic for governments to implement a feebate system. That system could have a pivot point of 95 g/km CO\textsubscript{2} that gradually moves towards 50 g/km CO\textsubscript{2} until 2020 at the latest. On top of that, a scrappage scheme is an interesting option that would accelerate vehicle fleet renewal. This should be done upon ambitious emissions requirements like, for example, the 50 g/km CO\textsubscript{2} which is in line with the Swedish super green car incentive. Instead of trading the old car for a new car, the scheme could also be used to obtain a voucher for collective transport usage, train travel, technology upgrade of the old car or the purchase of bicycles. While the feebate system would be the long term and technology-neutral policy signal, it is very likely that EV power trains will also need a short- to mid-term dedicated policy incentive like, for example, a direct subsidy. To supplement the economic instruments and raise awareness of the total cost of ownership of a car, labelling schemes should be compulsory (with information on CO\textsubscript{2} emissions as well as estimated cost per kilometre).

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References

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[54] Infrastrukturnyheter (2011) Fortum i storsatsning på elbilar | Infrastrukturnyheter.se, 2 September.


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[150] U. Jakobsson (2011) Interview with the Managing Director of Move About AB.


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