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Impact Analysis of Diffusion of Electric Vehicles in Denmark

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Abstract: This paper undertakes an impact analysis of a nation-wide diffusion of electric vehicles (EVs) at three different levels. It analyses the socio-economic costs and benefits faced by the Danish public, by comparing the environmental benefits, expressed in monetary value, with costs associated with reduced tax revenues. The paper looks to the year 2020, calculating the immediate societal costs/benefits occurring in this one point in time. The analysis shows that from a pure financial perspective EVs are not socially profitable as their reduction in environmental costs is by far offset by the decrease in tax revenues. The general assumption therefore is that this form of mitigation policy is growth restricting as the diffusion of EVs is accompanied by immediate high costs to the Danish Government. Nevertheless, one can argue that this growth restriction is only a short-term phenomenon, likely to be outweighed by other benefits in the long-term; benefits such as increased sector efficiency, spillover effects and increase in productivity growth in general.

Key words: Electric vehicles, social costs/benefits, induced technological change

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Without them I would never have been able to complete this thesis.

Abbreviations

AFV Alternative Fuel Vehicles

CBA Cost-Benefit Analysis

CHP Combined Heat and Power

EC European Commission

EEA European Environmental Agency

EHV Electric and Hybrid Vehicles

EV Electric vehicles

GHG Green House Gases

HV Hybrid vehicles

ICEV Internal Combustion Engine Vehicles

MNB Marginal net benefit

pkm Passenger kilometers

V2G Vehicle to Grid

Terminology – Electric vehicle

Unlike hybrid vehicles, electric vehicles do not have dual mechanical and electrical powertrains. 100 per cent of their propulsion comes from electric motors, energized by electricity stored in batteries. The focus of the study will be only on modern highway EVs, thus eliminating neighbourhood EVs due to their limited speed and therefore overall limitation in representing a suitable replacement for ICEVs.

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If GM had kept up with technology like the computer industry has, we would all be driving $25cars that got 1,000 MPG[1].

Bill Gates

[1] Mile per gallon (=0.425 kilometers per liter)

1. Introduction

1.1. Definition of problem and background

Passenger vehicles are an important contributor to CO_2 emissions and air pollution world-wide. In Denmark, the existing passenger vehicle park of just under 2 million personal vehicles contributes 12 per cent to national CO_2 emissions. This is a significant share, particularly taking into account that in 1990 the share was only 6 per cent. Overall, the volume of CO_2 emissions from the passenger cars sector increased by some 85 per cent between 1990 and 2005. This was particularly due to increased car usage and car ownership rates, though partly offset by increased car efficiency. In the future, further reduction in emissions of new vehicles is expected as a result of the introduction of compulsory Euro V and Euro VI standards, which set emission standards for passenger vehicles. However, with the expected ongoing enlargement of the Danish passenger car park, as well as increased annual mileage, further significant rise in emissions are expected in the transport sector. Indeed, the transport sector is believed to be the only sector experiencing continually rising emissions (Stern, 2006). At the same time, other sectors, such as power generation, are expected to lower its emissions progressively due to increased efficiency.

The key issue is that transport is one of the most expensive sectors to cut emissions from and therefore it is estimated that the transport sector will be among the last ones to bring its emissions below current levels (Stern, 2006). Consequently, as a result of increased pressures concerning emission targets and limits, national governments have been trying to implement various regulatory measures in order to limit the future environmental problems caused by the transport sector: measures of both technical and non-technical nature. But while non-technical measures (public transport, road pricing or speed limits) are difficult to implement as these often incur changes in people's lifestyle, technical measures may represent a possible solution in reducing the climate impact of the transport sector. Electric vehicles (EVs) as a possible technological solution have been intensely discussed in the recent debates on climate change.

1.2. Rationale behind the study

This paper will analyse and quantify the potential impacts of EVs diffusion in Denmark, looking at the social costs/benefits likely to be faced by the Danish society. The paper will only look at one year, namely the year 2020 - and the focus will be solely on EVs while other alternative fuel vehicles (AFVs) are not included.

The Danish passenger cars sector is notoriously known for having some of the highest tax levels in the world. Revenues from registration tax contribute to nearly 1.5 per cent of the Danish GDP, a share not to be found in any other country. The largest part is generated by registration tax, which is charged at the acquisition of new vehicle and averages 130 per cent of the vehicle's value. Next to vehicle registration tax, Denmark also features high annual circulation tax and motoring taxes (taxes on petrol and diesel). The current taxation makes even hybrid vehicles extremely expensive, which consequently explains the virtually non-existent market for this technology. Currently, EVs are the only passenger cars exempted from registration- and annual circulation tax. This has over the past two decades resulted in a niche market of small electricity driven vehicles concentrated in the major urban areas (neighbourhood EVs).

Recent significant improvements in battery technology and the rising interest in energy efficient vehicles, has led a number of car manufacturers to announce the launch of pure electricity driven models. At the same time, number of service operators spotted the technology's potential and partnered with electricity companies in Denmark with a plan to create a network of charging spots and exchange stations to prepare the grounds for a nation-wide diffusion of electric vehicles.

To further promote the diffusion of EVs, the Danish Ministry of Environment launched an initiative stating that the first EVs for commercial use should appear on Danish roads latest by 2009, with a plan of up to 100,000 EVs on the roads by 2012. Overall, Denmark has the ambition to become a leading country in respect to EVs. It plans to incorporate a large fleet of EVs into its existing energy system which will be increasingly dominated by wind power. (Denmark is currently looking at how to deal with the increasing excess of electricity production that would follow an even larger share of wind power in the electricity grid).

1.3. Outline

The major objective of the paper is to carry out social cost-benefit analysis (CBA) of various levels of penetration of EVs while taking into account the fiscal and environmental impacts of each scenario on the Danish economy in the year 2020. Having arrived at the results of the social CBA, a discussion of possible implications of EVs diffusion in the long-term will follow, considering EVs within the framework of the induced innovation theory.

2. Theory

2.1. Previous Research Review

In order to fully understand the problematic of EVs and their possible socio-economic impact, this paper has conducted an extensive research review, which can be split into two interconnected areas:

- Previous research in the more technological aspects: the technology of electric as well as conventional vehicles and management of surplus electricity from wind power. Including previous assessment studies on the economics of various AFVs conducted for some European countries.

- Research conducted in the field on environmental economics, induced technological change and the impacts of climate change on future economic growth.

Virtually all resources are taken from scientific journals or public bodies (ministries and statistical institutions). The geographical scope of studies published in the field of electric vehicles is dominated by two regions – the EU with a number of national projects and the State of California (USA). At the same time, these regions represent some of the keenest adepts for the mass introduction of electric vehicles, largely driven by new green legislation and public debates. Interestingly, case studies from Japan, which has the highest penetration of hybrids in the world, are rare. China also seems to be lacking behind in terms of research on EV diffusion, which is rather surprising taking into account the strong manufacturing base (steel, cars, and batteries) and the escalating CO_2 emissions of the region.

2.1.1. The economics of EVs

Overall, the amount of previous research conducted on potential costs and benefits of EVs is not vast as many studies focus solely on the calculation of private costs. However, few studies have engaged in the societal costs/benefits approach, which is the major objective of this paper:

Carlsson & Johansson-Stenman (2003) attempted to calculate the costs and benefits of AFVs in Sweden, looking both at electric and hybrid vehicles as well as private and societal costs. Kazimi (1997) estimates the environmental and economic benefits of AFVs in Southern California with a time perspective of 1998-2008. Funk & Rabl (1999) evaluate the social costs and benefits of EVs compared to ICEVs in the Greater Paris region. However, in general the authors conclude that EVs are rather socially unprofitable as they are 'subsidised' by having significantly lower taxes as opposed to high fossil fuel taxes applied on conventional vehicles. This is despite the fact that EVs have lower life-cycle as well as external costs. On the other hand, the environmental benefits of EVs fed by green electricity are clearly acknowledged by these studies.

Another type of research papers contributing to the full understanding of topic include writings by Lund et al (2003, 2008) and Short & Denholm (2006) who focus on the management of surplus electricity supply from fluctuating wind energy and assess the impact of large scale fleet of electric vehicles on the network. This is an important issue for the Danish national grid, as maintaining the balance between high share of wind energy and plug-in vehicles is believed to further maximise the economic returns of these two technologies.

Overall, the major drawback of the studies published is unfortunately their outdated data on modern EVs and inferential estimations on potential prices, driving range, battery lifetime and others. This is due to the reason, that although significant progress in respect to EVs has been characteristic over the last few years, the technology is still not mass produced and further product development is crucial for successful wide spread of the technology.

2.1.2. The economics of climate change – induced technological change

The research review on the economics of climate change deals above all with the works of Nordhaus and Lord Stern.

The writings of Nordhaus cover a wide range of topics, focusing primarily on the economic growth and natural resources, including the construction of integrated economic and scientific models of climate change. Attention has been mainly paid to Nordhaus' modelling of induced technological change in climate change policy and particularly the impact of such innovation on carbon reductions and long-term economic growth. The geographical scope of Nordhaus' studies, however, remains limited to the United States.

The Stern review (2006), on the other hand, provides a thorough understanding of the economics of climate change in a broad and global picture. However, only a small fraction of the study is dedicated to the impacts of the transport sector on climate change and possible constraints on the future economic growth.

The list of authors active within the field of economics of climate change used for this paper is, however, far more exhaustive than indicated above. Overall, there is a general content of the seriousness of climate change and its impact on long-term economic growth; however, most attempts to quantify these impacts failed and results of most analyses carried out so far differ significantly. This is primarily due to no historic evidence and high degree of uncertainty associated with predicting environmental damages, something most authors agree on.

2.1.3. TREMOVE and COPERT

Two MS Windows programs designed by the European Commission (EC) are used for emission calculations (see sections 3.1. and 3.2.).

2.2. Theoretical framework

2.2.1. Social Marginal Net Benefit

The concept of social cost/benefit analysis (CBA) is commonly used for studies generating various policy implications by providing decision-makers with monetary assessment of various policies. The drawback of this approach, however, is its focus on immediate effects as it does not incorporate possible costs/benefits in a longer-term. The socio-economic framework is therefore not fully complete when assessing environmental policies, as it is mainly the long-term contribution which is believed to be beneficial.

Within this paper, the social CBA will be presented as an analysis of social marginal net benefit (cost) of an increased number of EVs on the Danish road. Thus the focus is to quantify the social benefits/costs of replacing a certain share of conventional vehicles with EVs. Or to summarize it in the words of Carlsson & Johansson-Stenman (2003:7), "the social net benefit of replacing one conventional vehicle with an EV is the difference between the benefit in terms of decreased external costs", in this case environmental costs, "and the cost in terms of reduced taxation."

Consequently, the calculation applied can be written as follows (Carlsson & Johansson-Stenman, 2003:6):

Social Marginal Net Benefit (MNB) = Δ MD - Δ TR; where

Δ MD is a decrease in Marginal Damage, $\Delta MD = MD^{CV} - MD^{EV}$[2]

Δ TR is a decrease in Tax Revenues, $\Delta TR = TR^{CV} - TR^{EV}$[3]

2.2.1.1. Discussion of the concept of social MNB

The equation above does not include any private costs (for example costs associated with the purchase of the vehicle or maintenance costs), as these are "already taken into account by a rational utility-maximising consumer" (Carlsson & Johansson-Stenman, 2003:7). The aim is therefore not to analyse whether EVs are privately profitable, but whether EVs could be profitable to the Danish society (ibid:21). Generally, one could assume that since EVs do lead to

[2] MD^{CV} = Marginal Damage of Conventional Vehicles, MD^{EV} = Marginal Damage of Electric Vehicles

[3] TR^{CV} = Tax Revenues from Conventional Vehicles, TR^{EV} = Tax Revenues from Electric Vehicles

lower marginal damage (environmental costs), they are socially more profitable than conventional vehicles, as the Danish public can benefit from improved environmental conditions. However, this assumption does not fully hold, as governmental tax revenues from EVs are significantly lower when compared to conventional vehicles, in other words EVs would be "subsidised" indirectly by being exempted from a number of vehicle related taxes. The major objective is therefore to quantify the magnitude of this subsidy, indirectly faced by the Danish public in absolute values for the year 2020.

2.2.2. Induced Technological Change

Within this study it is likely that the social MNB analysis will lead to negative results (based on previous research as well as peculiarities of high vehicle taxes in Denmark in particular). However, the major aim is to illustrate that green policies (even when considered unprofitable in the short term) can improve long term growth rates. Therefore, due to its shortcomings and in order to provide a theoretical explanation of this phenomenon, the results of social impact analysis will be further discussed with a view of sustainable long-term economic growth. Theories of induced technological change as well as new growth theory and development blocks are to be linked to the diffusion of EVs in Denmark. Based on these theories, the paper will examine and assess the sources of potential impact that the diffusion of technological innovation (EVs) could have on economic growth.

3. Data

Large amount of data have been collected in order to provide a thorough understanding of the transport sector as well as energy sector. The data presented within this chapter have been used as background information for further calculations, and importantly serve as a guideline for assumptions made concerning future developments in the Danish as well as EU transport and energy sector. Majority of primary data used within this paper originate from administrative records (government and EU statistics). Although the data used in this paper has been collected for other purposes, it is very useful, as it has been collected over a number of years and represent a source of coherent and reliable background information to be used for assumptions when modelling the future passenger car park as well as the electricity demand. At the same time, multiple sources of data on one particular phenomena have always been used in order to cross-check their quality, consistency and usefulness as well as establish common linkages among various data.

In addition, TREMOVE (computerized program of the EC) will be used for an estimation of the Danish vehicle stock by vehicle type. Having modeled the future passenger car park for the BAU scenario, the same methodology is applied to remaining scenarios by taking BAU as a reference. The calculation of consumption factors and emissions of conventional vehicles will be generated by COPERT IV for each scenario.

3.1. TREMOVE (http://www.tremove.org/index.htm)

Model TREMOVE has been used only for the forecasting part of the Danish vehicle stock, particularly data sheet with a forecast on the future composition of the vehicle park. The program is a "policy assessment model, designed to study the effects of different transport and environment policies on the emissions of the transport sector" (www.tremove.org). The program concerns both passenger and freight transport and covers the period 1995-2030.

3.2. COPERT IV (http://lat.eng.auth.gr/copert)

COPERT is a MS Windows program designed to calculate emissions from road transport. COPERT calculates emissions of all major pollutants and GHGs which are produced by various vehicle categories. For the purposes of this study, emission and GHGs calculations of the passenger vehicles are to be used by taking into account the characteristics of the current and future Danish vehicle park as well as other driving activity data which are distinct for Denmark (for more detail see Appendix 6). The strength of the program is its high degree of detail by including all passenger vehicle technologies, incorporating also Euro V and Euro VI technology in the analysis.

Fig 3.2-1 Summary of all vehicle classes covered by the methodology

Vehicle type	Class	Legislation
Passenger Cars		PRE ECE
		ECE 15/00-01
		ECE 15/02
		ECE 15/03
	Gasoline	ECE 15/04

	<1.4l 1.4 - 2.0l >2.0l	Improved conventional Open loop Euro 1 - 91/441/EEC Euro 2 - 94/12/EC Euro 3 - 98/69/EC Stage 2000 Euro 4 - 98/69/EC Stage 2005 Euro 5 – EC 715/2007 Euro 6 – EC 715/2007
	Diesel <2.0l >2.0l	Conventional Euro 1 - 91/441/EEC Euro 2 - 94/12/EC Euro 3 - 98/69/EC Stage 2000 Euro 4 - 98/69/EC Stage 2005 Euro 5 – EC 715/2007 Euro 6 – EC 715/2007
	LPG	Conventional Euro 1 - 91/441/EEC Euro 2 - 94/12/EC Euro 3 - 98/69/EC Stage 2000 Euro 4 - 98/69/EC Stage 2005
	2 Stroke	Conventional
	Hybrids <1.6l	Euro 4 - 98/69/EC Stage 2005

Source: EC based on COPERT

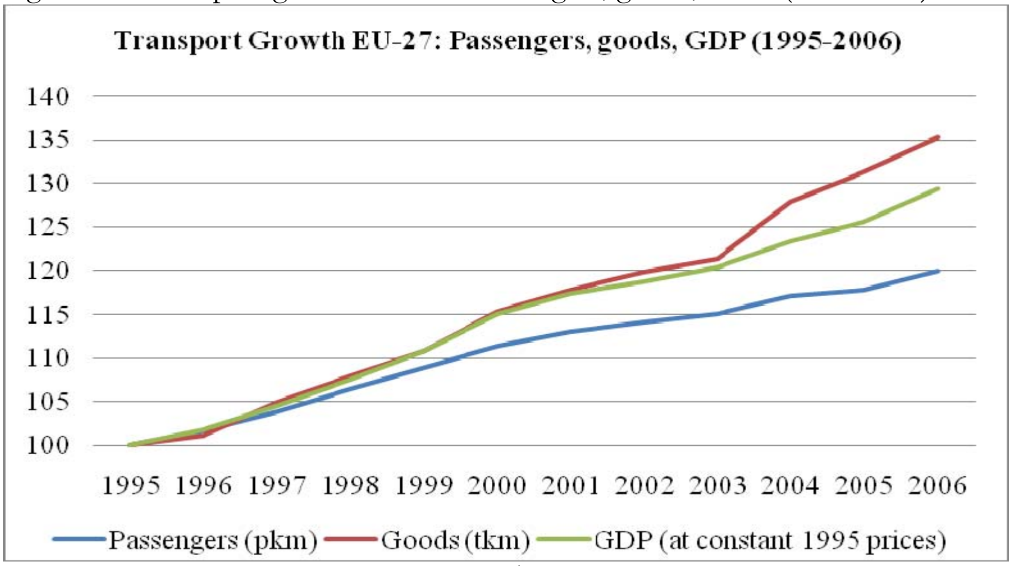
3.3. EU Data

Following points concerning EU and Danish statistics on road transport and energy are included for better understanding of the topic and represent background data for calculations performed in section 4.

3.3.1. The EU transport sector overall

As illustrated in Fig 3.3.1-1, the demand for both passenger and freight transport has been growing annually leading to increased transport emissions in the EU.

Fig 3.3.1-1 Transport growth EU-27: Passengers, goods, GDP (1995-2006)



Source: EU energy and transport in figures (2007/2008)

3.3.2. The emissions of the transport sector and the EU environmental strategy

In order to understand the importance of the transport sector in the challenges of the climate change, it is important to consider its share in emissions overall. According to the European Environmental Agency (EEA), transport sector remains the major obstacle in achieving a low-carbon society in Europe as it continues to gradually increase its emissions of GHGs. In the EU27 total GHG emissions in 1990 were 5,572 Mt CO_2-equivalent, falling to 5,143 Mt CO_2-equivalent in 2006 (a decrease of 7.7 per cent, EU energy and transport in figures, 2007/2008)). In the same period, emissions from the transport sector increased by 26 per cent and in 2005 accounted for 22 per cent of all EU emissions of GHGs. Historically, efficiency improvements in engine technology (ICE) have not been able to offset the growth in transport demand, mainly due to increased passenger and freight transport (as illustrated above) together with high car ownership levels. The European Commission (EC) further estimates that transport activity for passenger and freight transport will nearly double between 1990 and 2020, consequently leading to increasing emissions of the sector.

The reduction of air pollutants and GHGs has long been a concern of many EU policies. The major objectives of the current European Energy Policy are:

- 20 per cent cut of GHG emissions by 2020 (compared to 1990 levels)
- 50 per cent cut in carbon emissions by 2050 (compared to 1990 levels)
- 10 per cent share of biofuels by 2020

3.3.3. EU strategy on biofuels and emission reductions in the transport sector

3.3.3.1. Biofuels

Directive 2003/30/EC sets minimum share of biofuels to replace conventional petrol and diesel passenger cars. The major objective of this directive is to reduce emissions of CO_2, CO, NO_x and particles, with a target of 10 per cent share of biofuels by 2020, and with an immediate 5.75 per cent target by 2010. Importantly, EVs can be included within this share, thus large scale introduction of EVs could help Denmark to meet this target.

3.3.3.2. Euro Standards

The Regulation (EC) No 715/2007 sets emission standards for passenger vehicles, vans, and commercial vehicles intended for the transport of passengers or goods in two standards (see APPENDIX 1) – Euro 5 Standard will come into force 1st January 2011 and Euro 6 standard 1st January 2015 for the registration and sale of new cars. Vehicles that do not comply with limits set in the Euro 5(6) standard must be refused registration in the member state.

Fig 3.3.3.2-1 EU Emission standards for passenger cars (g/km)

Tier	Date	CO	HC	HC + NOx	NOx	PM
				Diesel		
Euro 1	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)
Euro 2	1996.01	1.0	-	0.7	-	0.08
Euro 3	2000.01	0.64	-	0.56	0.50	0.05
Euro 4	2005.01	0.50	-	0.30	0.25	0.025
Euro 5	2009.09a	0.50	-	0.23	0.18	0.005c
Euro 6	2014.09	0.50	-	0.17	0.08	0.005c
				Petrol (gasoline)		
Euro 1	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-
Euro 2	1996.01	2.2	-	0.5	-	-
Euro 3	2000.01	2.3	0.2	-	0.15	-
Euro 4	2005.01	1.0	0.1	-	0.08	-
Euro 5	2009.09a	1.0	0.1b	-	0.06	0.005c
Euro 6	2014.09	1.0	0.1b	-	0.06	0.005c

a 2011.01 for all models
b and NMHC = 0.068 g/km
c proposed to be changed to 0.003 g/km using the PMP measurement procedure
Source: http://www.dieselnet.com/standards/eu/ld.php (accessed 16/02/2009)

3.3.3.3. CO_2 emission limits on new vehicles

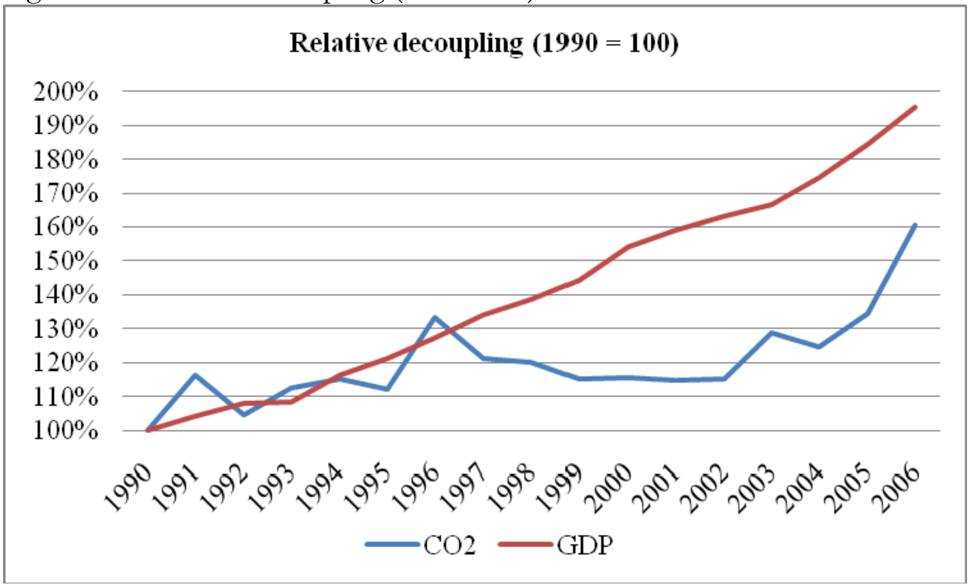
Actions targeting reductions of CO_2 emissions in the transport sector have been discussed since early 1990s. In 2007, a new objective target for emissions was proposed at a level of 120 CO_2 g/km by 2012. The target was, however, later moved to a level of 130 g/km. The manufacturers who do not meet these criteria will be penalized (for a historical development of CO_2 emission limits in the EU see Appendix 24).

3.4. National data (Denmark)

3.4.1. Danish energy policy

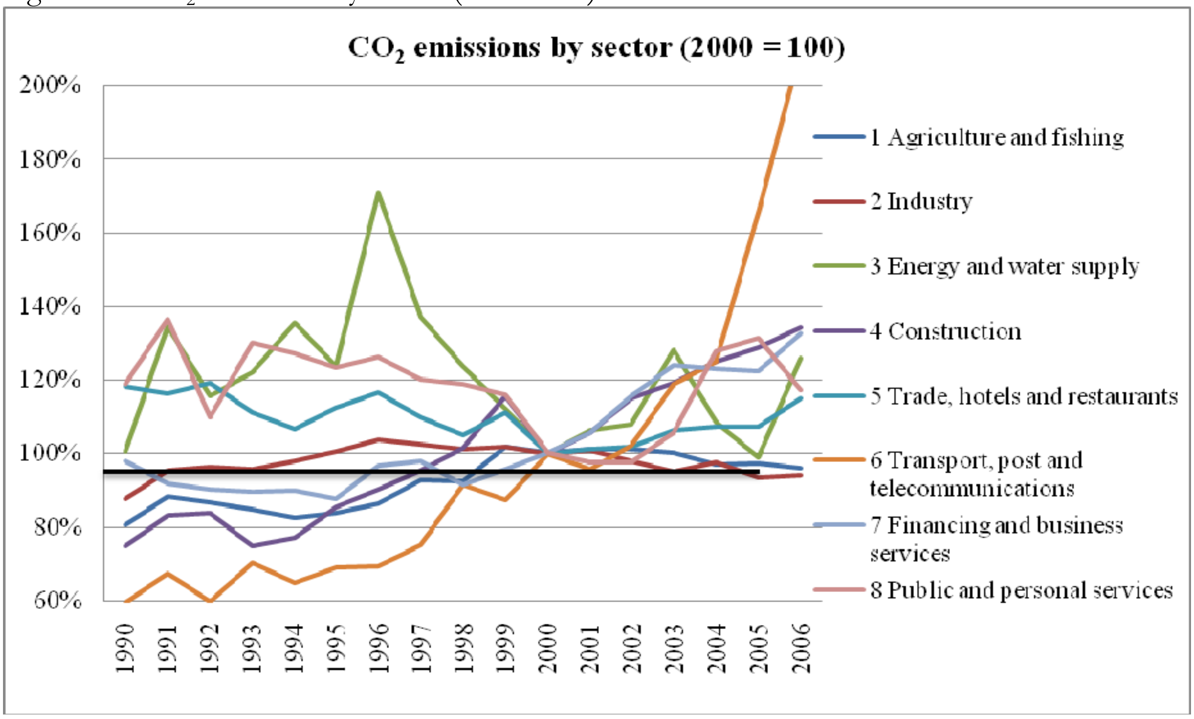
For the past 35 years, Denmark has been able to maintain roughly the same level of energy consumption despite economic growth of over 50 per cent (www.dst.dk). However, contrary to most other sectors, the transportation sector accounts for an increasing share of energy consumption and consequently CO_2 emissions. Fig 3.4.1-1 indicates the relationship between CO_2 emissions and economic growth in Denmark over the past 15 years.

Fig 3.4.1-1 Relative decoupling (1990=100)



Source: Based on Danmarks Statistik

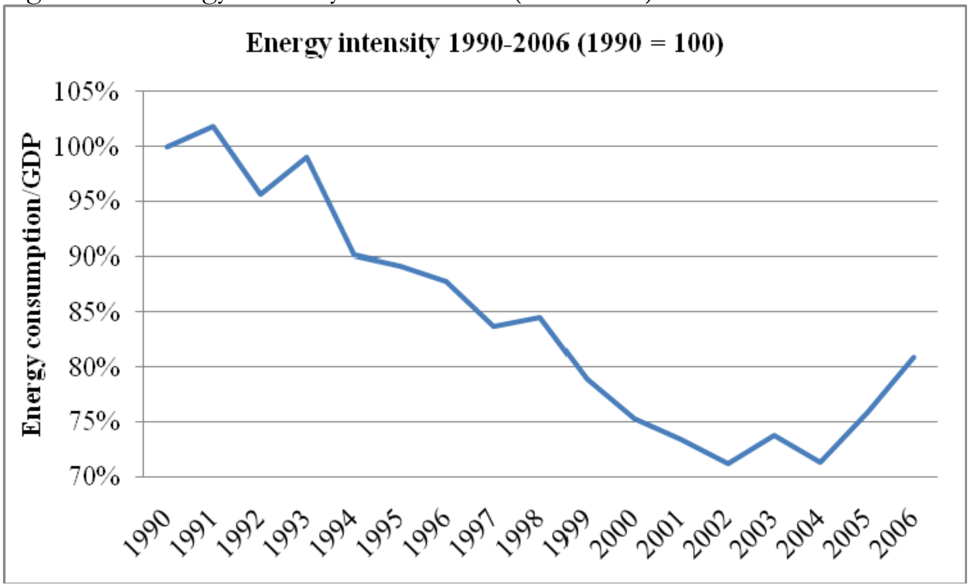
Fig 3.4.1-2 CO_2 emissions by sector (2000=100)



Source: Based on Danmarks Statistik

Overall, the energy intensity has been declining steadily (Fig 3.4.1-3). By 2005, the energy intensity declined to some 70 per cent of 1990 level, however increased again in 2006 (www.dst.dk). The growth in energy intensity has been caused by higher net energy demand from businesses, and particularly increased energy consumption in the transport sector (Fig 3.4.1-2). This consequently affected the levels of CO_2 emissions which grew in line with higher energy consumption.

Fig 3.4.1-3 Energy intensity 1990 – 2006 (1990=100)



Source: Based on Danmarks Statistik

The major objectives of the Danish energy policy are:

1. response to climate change
2. reduction of dependence on external energy supplies, and
3. economic costs.

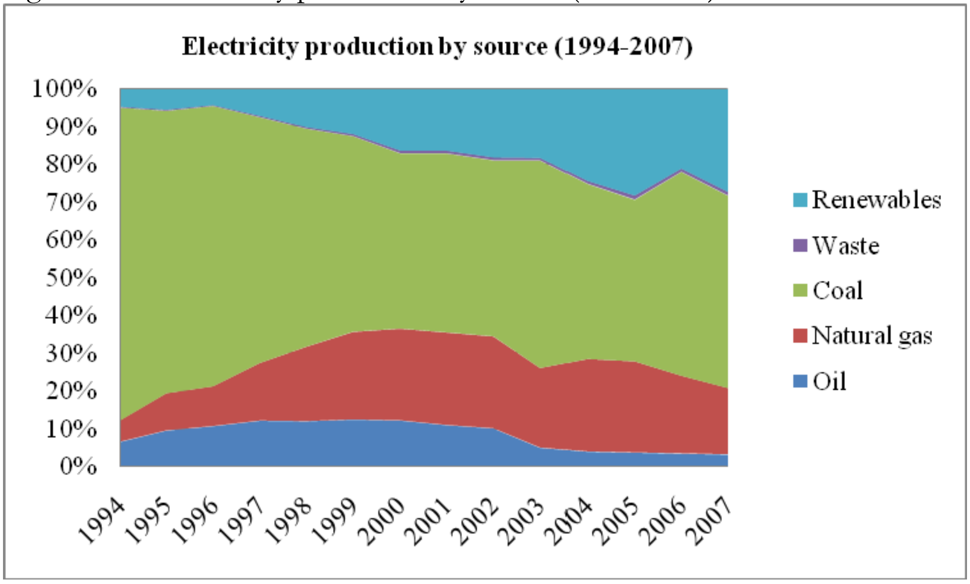
The National Energy Plan (agreed upon in February 2008) states a number of targets for the next coming 4 years, together with longer-term commitments, in part, based on EU Directives. The major targets of the Danish energy plan include:

- To reduce total energy consumption by 2% in 2011and by 4% in 2020 (compared to 2006 levels)
- To increase the share of renewable energy to 20% of gross energy consumption by 2011
- The EU energy and climate proposal includes for Denmark a target of 30% savings in total energy consumption (compared with 1990 levels)
- The government targets 30% of gross energy consumption to come from renewable resources.

3.4.1.1. Electricity infrastructure

Denmark has been one of the forerunners in the EU by including a large share of wind power and CHP in its electricity generation, the development of which started after the oil crisis in 1973. Nevertheless, the largest share of Danish electricity is still produced by coal-fired power plants. The share is however declining, mainly due to the increased use of natural gas (Fig 3.4.1.1-1).

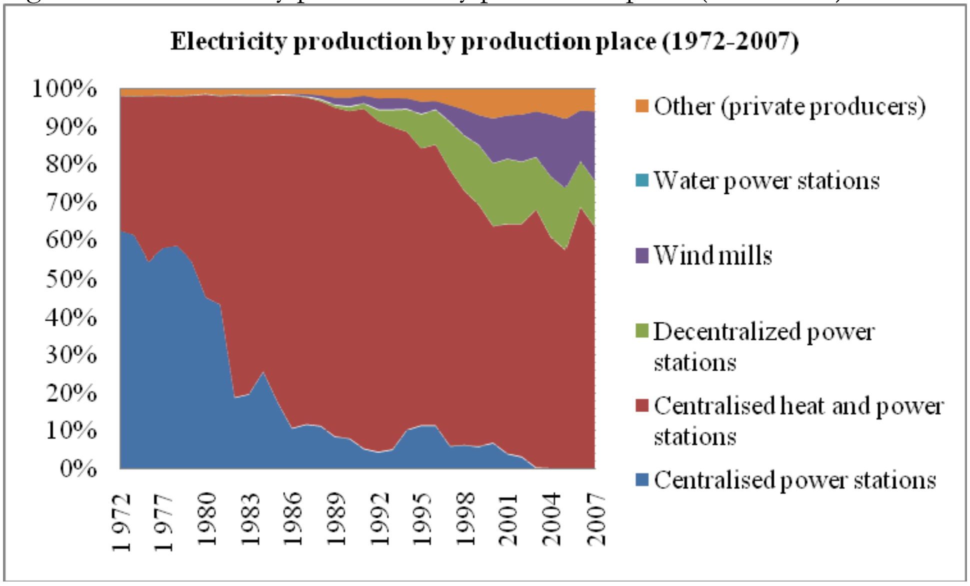
Fig 3.4.1.1-1 Electricity production by source (1994-2007)



Source: Energistyrelsen

The share of renewable sources in the electricity production mix is moderate, but growing. In 2007, 27 per cent of all Danish electricity was generated using 'green sources' and wind power itself accounting for some 18 per cent (Energistyrelsen). The largest share of Danish electricity is produced by centralised heat and power stations (Fig 3.4.1.1-2), followed by windmills and (often) smaller-scale decentralised power stations. Pure electricity generating power stations have ceased to exist by the turn of millenium. (For an overview of electricity production in East and West Denmark see Appendix 25).

Fig 3.4.1.1-2 Electricity production by production place (1972-2007)



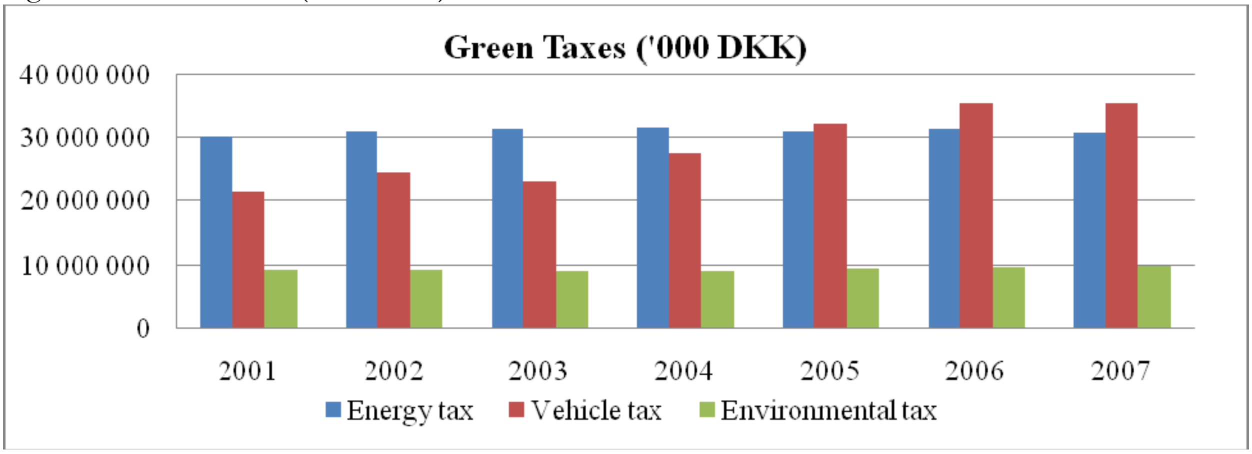
Source: Energistyrelsen

The expansion of wind power is heavily supported by the Danish government through a combination of tax and subsidy policies. Consequently, over the last 30 years, Denmark has become a home to the world's largest wind turbine construction industry generating a turnover of DKK 42.2 billion in 2007 (up from DKK 2.9 billion in 1996) and employed some 23,500 (www.windpower.org). However, Denmark has had problems in balancing the electricity demand and supply and the high share of wind power and CHP is the major contributor to Denmark's excess electricity production. According to Energinet.dk, 84.215 MW/h excess electricity was exported in 2007 free of charge to Norway, Sweden and Germany, which corresponds to an annual electricity consumption of 18,700 Danish households. In order to maximize the economic return of the Danish energy system (return on investments as well as emission reduction), introduction of energy storage capacities should be implemented – vehicle-to-grid (V2G) technology, particularly plug-in EVs. The EVs are therefore believed to provide a long-term solution to one of the major issues in the Danish energy system – the excess electricity production which is expected to even increase in the future as more and more windmill parks are to be installed (estimated 50 per cent of the national electricity production).

3.4.2. Environmental taxes

Total revenues from environmental taxes have been growing steadily over the past 10 years. In 2006, the revenue was some DKK 78 billion (euro 10.5 million), which corresponds to approximately 5 per cent of the Danish GDP.

Fig 3.4.2-1 Green taxes ('000 DKK)



Source: Skatteministeriet

3.4.2.1. Vehicle taxes (see Fig 3.4.2.1-1 for an overview)

Concerning the transport sector, Denmark has some of the highest levels of tax in the world. The largest part is taken up by registration tax (68 per cent of all vehicle related taxes in 2007 - Fig 3.4.2.1-2 and almost 1.5% of the national GDP – Fig 3.4.2.1-3), which is charged at the acquisition of new vehicle. The registration tax is based on the value of the vehicle and this basic value includes a VAT of 25 per cent. High registration tax in Denmark resulted in low car ownership. However, car use compared to GDP remains similar to other EU countries. This is due to the higher average distance driven by cars in Denmark (EC, 2002). The advantage of high registration tax is the tendency to purchase vehicles with higher fuel efficiency (influenced by tax on petrol and diesel and circulation tax); this is however offset by the limited fleet turnover. According to current legislation, EVs are exempt from registration tax until 2012. If retained, this could contribute heavily to the diffusion of Evs.

The annual circulation tax is charged either as green tax (for vehicles registered after 1st July 1997) and based on the fuel efficiency, or as weight tax (for older vehicles) which takes into account only the weight of the vehicle.

Next to vehicle taxes, there are also motoring taxes (taxes on petrol and diesel).

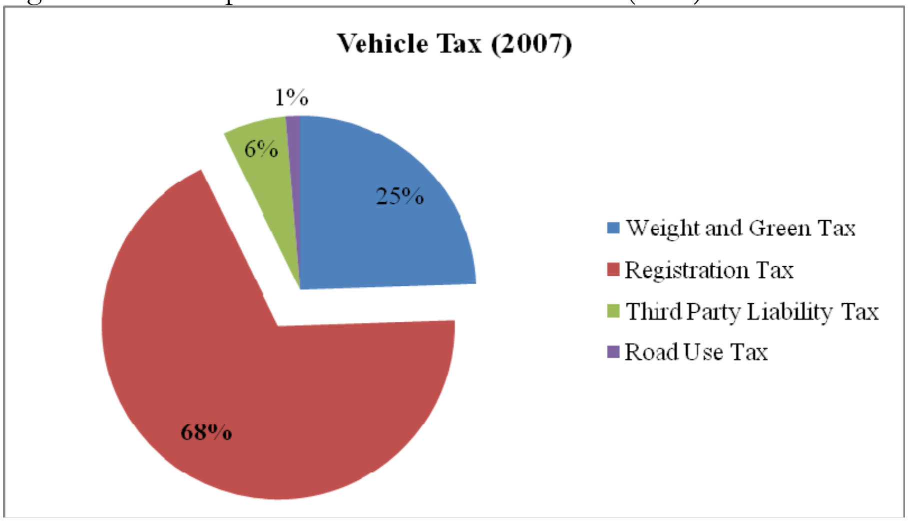
Fig 3.4.2.1-1 An overview of vehicle taxes in Denmark (as of January 2009)

Type of tax	Description	Amount
Green (circulation) tax (Ejerafgift)	Applies to all passenger vehicles registered after 1st July 1997, using petrol or diesel	Semi-annual fee from DKK 260 for petrol driven cars (>20km/l) to DKK 9,230 for petrol driven car (<4.5km/l). Semi-annual fee from DKK 80 for diesel driven cars (>32.1km/l) to DKK 12,530 for petrol driven car (<5.1km/l).
Weight tax (Vægtafgift)	Applies to all passenger cars (registered before 1st July 1997), vans, lorries, buses and taxis.	For passenger cars the amount of semi-annual fee depends upon the weight of the vehicles, ranging from DKK 1,040 (601-800kg) to DKK 3,390 (1,501-2,000kg).

Registration tax (Registreringsafgift)	Applies to all passenger cars, motorbikes, buses, vans and other vehicles to be registered in Denmark.	The amount is based on the retail price of the cars. For passenger cars the tax is 105% for the first DKK 79,000 and 180% on the remaining value of the car.
Road use tax (Vejbenyttelsesafgift)	Tax on trucks over 12 t	
Number plate tax (Nummerpladeafgift)	Basic annual tax on the use of number plate.	Annual fee for passenger cars at DKK 1,180.
Third party liability tax (Ansvarsforsikringsafgift)	Insurance tax, based on third party liability insurance, which is compulsory for all registered vehicles.	42.9% of insurance premium for passenger cars.

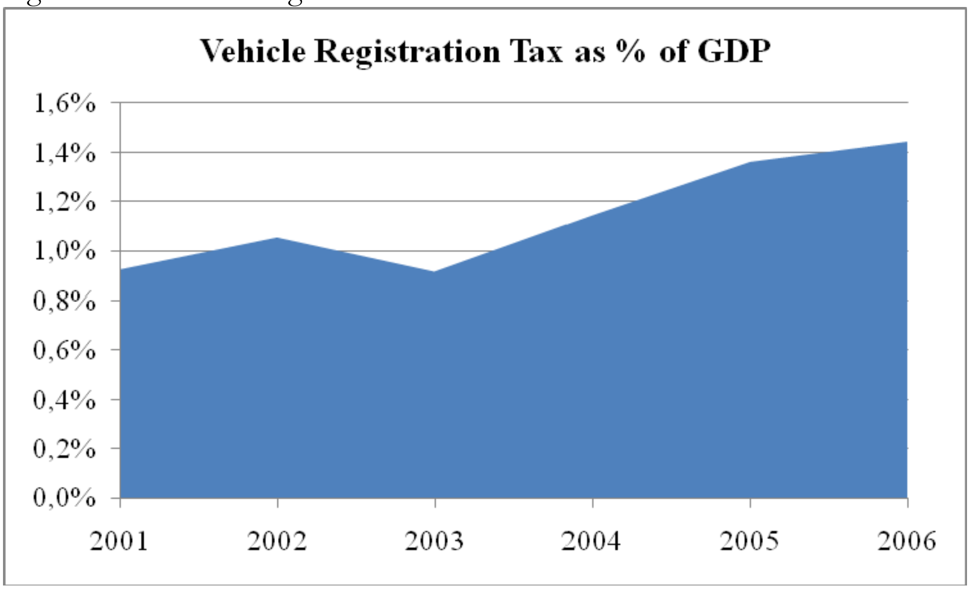
Source: Based on Skatteministeriet (www.skm.dk)

Fig 3.4.2.1-2 Composition of vehicle tax revenues (2007)



Source: Skatteministeriet (www.skm.dk)

Fig 3.4.2.1-3 Vehicle registration tax as % of national GDP

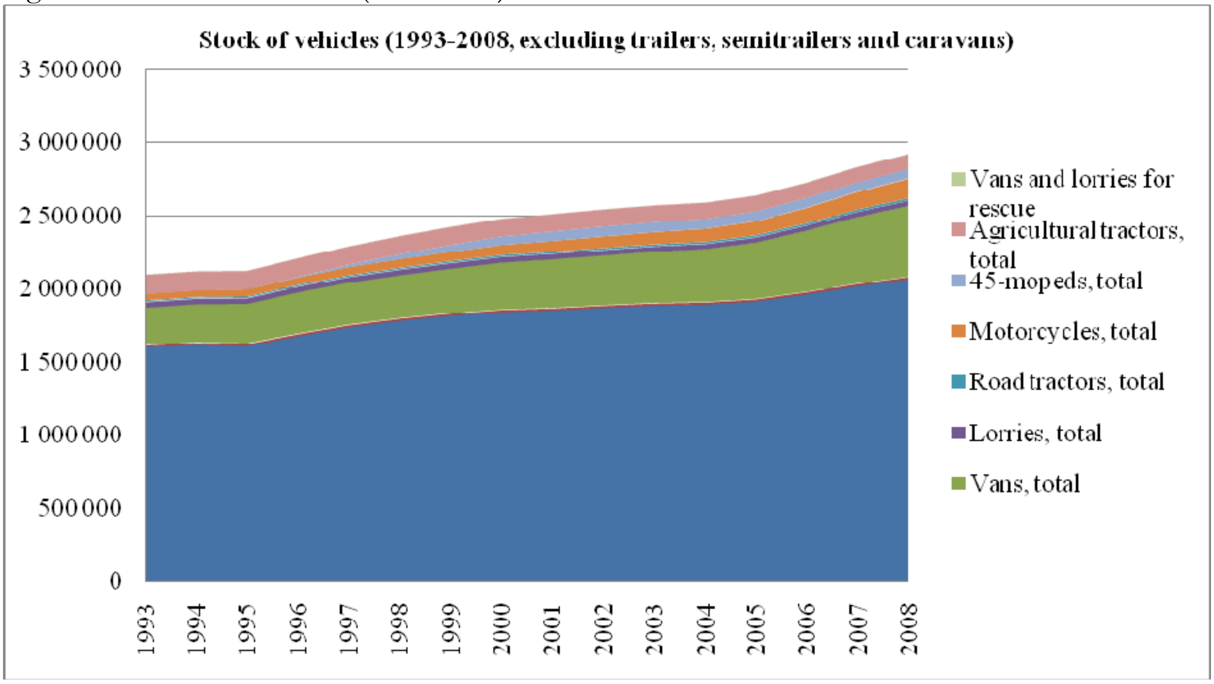


Source: Skatteministeriet (www.skm.dk)

3.4.3. Overview of the Danish transport sector

Overall, the total number of motor vehicles (excluding trailers, semitrailers and caravans) increased significantly from 2.1 million in 1993 to 2.9 million in 2008, of which passenger cars account for some 71 per cent (Fig 3.4.3-1). For more detail see Appendix 1.

Fig 3.4.3-1 Stock of vehicles (1993-2008)



Source: Danmarks statistik (Statistikbanken)

Passenger vehicles, clearly account for the largest share of the Danish vehicle stock. Hence the following statistics will focus only on passenger cars, which is also within the scope of this study. Furthermore, the current level technological development in EVs is primarily focused on passanger vehicles. As a note, the commercial development and diffusion of electric vans is believed to be non-existent prior to 2020.

The number of passenger cars has been rising significantly and the composition of the vehicle fleet by type also recorded many changes (for more detail see Appendix 2). Based on COPERT, the composition of Danish vehicle fleet in 1985, 1995 and 2005 was as follows[4]:

Fig 3.4.3-2 Composition of the vehicle fleet (1985, 1995 and 2005)

Subsector	Technology	1985	1985 (%)	1995	1995 (%)	2005	2005 (%)
Gasoline <1,4 l	PRE ECE	79 252	5,1%	26 640	1,5%	1 196	0,1%
Gasoline <1,4 l	ECE 15/00-01	332 260	21,2%	69 008	4,0%	11 468	0,6%
Gasoline <1,4 l	ECE 15/02	103 426	6,6%	43 214	2,5%	2 708	0,1%
Gasoline <1,4 l	ECE 15/03	343 495	22,0%	254 212	14,7%	25 842	1,3%
Gasoline <1,4 l	ECE 15/04	0	0,0%	266 316	15,4%	138 816	6,9%

[4] There are some marginal differences between the total vehicle fleet according to Danish statistical office and COPERT. These are, however, very low (+/- 5%) and will therefore be ignored, as its impact on the overall calculations remains almost non-existent.

Gasoline <1,4 l	Improved Conventional	0	0,0%	0	0,0%	0	0,0%
Gasoline <1,4 l	Open Loop	0	0,0%	0	0,0%	0	0,0%
Gasoline <1,4 l	PC Euro I - 91/441/EEC	0	0,0%	176 194	10,2%	155 442	7,7%
Gasoline <1,4 l	PC Euro II - 94/12/EEC	0	0,0%	0	0,0%	128 053	6,4%
Gasoline <1,4 l	PC Euro III - 98/69/EC Stage2000	0	0,0%	0	0,0%	134 060	6,7%
Gasoline <1,4 l	PC Euro IV - 98/69/EC Stage2005	0	0,0%	0	0,0%	0	0,0%
Gasoline <1,4 l	PC Euro V (post 2005)	0	0,0%	0	0,0%	0	0,0%
Gasoline <1,4 l	PC Euro VI	0	0,0%	0	0,0%	0	0,0%
Gasoline <1,4 l	All	858 432	54,9%	835 584	48,2%	597 583	29,7%
Gasoline 1,4 - 2,0 l	PRE ECE	60 456	3,9%	18 866	1,1%	930	0,0%
Gasoline 1,4 - 2,0 l	ECE 15/00-01	216 599	13,8%	46 513	2,7%	8 207	0,4%
Gasoline 1,4 - 2,0 l	ECE 15/02	62 809	4,0%	27 607	1,6%	1 746	0,1%
Gasoline 1,4 - 2,0 l	ECE 15/03	208 883	13,4%	143 193	8,3%	14 753	0,7%
Gasoline 1,4 - 2,0 l	ECE 15/04	0	0,0%	182 284	10,5%	89 416	4,4%
Gasoline 1,4 - 2,0 l	Improved Conventional	0	0,0%	0	0,0%	0	0,0%
Gasoline 1,4 - 2,0 l	Open Loop	0	0,0%	0	0,0%	0	0,0%
Gasoline 1,4 - 2,0 l	PC Euro I - 91/441/EEC	0	0,0%	307 673	17,8%	312 796	15,5%
Gasoline 1,4 - 2,0 l	PC Euro II - 94/12/EEC	0	0,0%	0	0,0%	327 368	16,3%
Gasoline 1,4 - 2,0 l	PC Euro III - 98/69/EC Stage2000	0	0,0%	0	0,0%	273 316	13,6%
Gasoline 1,4 - 2,0 l	PC Euro IV - 98/69/EC Stage2005	0	0,0%	0	0,0%	0	0,0%
Gasoline 1,4 - 2,0 l	PC Euro V (post 2005)	0	0,0%	0	0,0%	0	0,0%
Gasoline 1,4 - 2,0 l	PC Euro VI	0	0,0%	0	0,0%	0	0,0%
Gasoline 1,4 - 2,0 l	All	548 747	35,1%	726 136	41,9%	1 028 532	51,1%
Gasoline >2,0 l	PRE ECE	6 140	0,4%	1 464	0,1%	89	0,0%
Gasoline >2,0 l	ECE 15/00-01	18 875	1,2%	3 879	0,2%	753	0,0%
Gasoline >2,0 l	ECE 15/02	9 181	0,6%	2 185	0,1%	137	0,0%
Gasoline >2,0 l	ECE 15/03	30 763	2,0%	19 929	1,2%	2 091	0,1%
Gasoline >2,0 l	ECE 15/04	0	0,0%	24 279	1,4%	12 909	0,6%
Gasoline >2,0 l	PC Euro I - 91/441/EEC	0	0,0%	27 975	1,6%	19 053	0,9%
Gasoline >2,0 l	PC Euro II - 94/12/EEC	0	0,0%	0	0,0%	50 345	2,5%
Gasoline >2,0 l	PC Euro III - 98/69/EC Stage2000	0	0,0%	0	0,0%	84 266	4,2%
Gasoline >2,0 l	PC Euro IV - 98/69/EC Stage2005	0	0,0%	0	0,0%	0	0,0%
Gasoline >2,0 l	PC Euro V (post 2005)	0	0,0%	0	0,0%	0	0,0%
Gasoline >2,0 l	PC Euro VI	0	0,0%	0	0,0%	0	0,0%
Gasoline >2,0 l	All	64 958	4,2%	79 712	4,6%	169 642	8,4%
Gasoline	All	1 472 138	94,1%	1 641 431	94,8%	1 795 758	89,2%
Diesel <2,0 l	Conventional	83 450	5,3%	58 844	3,4%	38 011	1,9%
Diesel <2,0 l	PC Euro I - 91/441/EEC	0	0,0%	24 671	1,4%	49 077	2,4%
Diesel <2,0 l	PC Euro II - 94/12/EEC	0	0,0%	0	0,0%	57 781	2,9%
Diesel <2,0 l	PC Euro III - 98/69/EC Stage2000	0	0,0%	0	0,0%	50 329	2,5%
Diesel <2,0 l	PC Euro IV - 98/69/EC Stage2005	0	0,0%	0	0,0%	0	0,0%
Diesel <2,0 l	PC Euro V (post 2005)	0	0,0%	0	0,0%	0	0,0%
Diesel <2,0 l	PC Euro VI	0	0,0%	0	0,0%	0	0,0%
Diesel <2,0 l	All	83 450	5,3%	83 515	4,8%	195 199	9,7%
Diesel >2,0 l	Conventional	3 481	0,2%	2 893	0,2%	1 994	0,1%
Diesel >2,0 l	PC Euro I - 91/441/EEC	0	0,0%	1 499	0,1%	2 627	0,1%
Diesel >2,0 l	PC Euro II - 94/12/EEC	0	0,0%	0	0,0%	6 025	0,3%
Diesel >2,0 l	PC Euro III - 98/69/EC Stage2000	0	0,0%	0	0,0%	11 434	0,6%
Diesel >2,0 l	PC Euro IV - 98/69/EC Stage2005	0	0,0%	0	0,0%	0	0,0%
Diesel >2,0 l	PC Euro V (post 2005)	0	0,0%	0	0,0%	0	0,0%
Diesel >2,0 l	PC Euro VI	0	0,0%	0	0,0%	0	0,0%
Diesel >2,0 l	All	3 481	0,2%	4 392	0,3%	22 081	1,1%
Diesel	All	86 932	5,6%	87 907	5,1%	217 280	10,8%

LPG	Conventional	285	0,0%	272	0,0%	14	0,0%
LPG	PC Euro I - 91/441/EEC	0	0,0%	0	0,0%	0	0,0%
LPG	PC Euro II - 94/12/EEC	0	0,0%	0	0,0%	0	0,0%
LPG	PC Euro III - 98/69/EC Stage2000	0	0,0%	0	0,0%	0	0,0%
LPG	PC Euro IV - 98/69/EC Stage2005	0	0,0%	0	0,0%	0	0,0%
LPG	PC Euro V (post 2005)	0	0,0%	0	0,0%	0	0,0%
LPG	PC Euro VI	0	0,0%	0	0,0%	0	0,0%
LPG	All	285	0,0%	272	0,0%	14	0,0%
2-Stroke	Conventional	4 877	0,3%	2 442	0,1%	0	0,0%
Hybrid Gasoline <1,4 l	PC Euro IV - 98/69/EC Stage2005	0	0,0%	0	0,0%	0	0,0%
Hybrid Gasoline 1,4 - 2,0 l	PC Euro IV - 98/69/EC Stage2005	0	0,0%	0	0,0%	0	0,0%
Hybrid Gasoline >2,0 l	PC Euro IV - 98/69/EC Stage2005	0	0,0%	0	0,0%	0	0,0%
Other	All	4 877	0,3%	2 442	0,1%	0	0,0%
	All	**1 564 231**	**100,0%**	**1 732 052**	**100,0%**	**2 013 051**	**100,0%**

Source: COPERT

3.4.3.1. Emissions from passenger cars

In general, passenger cars account for a relatively small share of emissions in the road transport sector (Fig 3.4.3.1-1), most of which are released by light duty vehicles, heavy duty trucks and buses (detailed calculations on emissions from passenger cars are to be found in Appendix 4).

Fig 3.4.3.1-1 Development in emissions from passenger cars (1990 vs. 2005)

	CO	NMVOC	NO_x	CO_2	PM (exhaust)	N_2O	CH_4	NO	NO_2	NH_3
2005										
TOTAL emissions passenger cars	**48 451,8**	**5 303,7**	**15 806,4**	**5 837 652,0**	**421,0**	**231,8**	**652,5**	**14 600,6**	**1 205,8**	**2 304,7**
TOTAL emissions road transport	192 000,0	25 900,0	68 500,0	12 229 000,0	4 800,0	380,0	2 184,0	na	na	na
% share passenger cars/road transport	25,2%	20,5%	23,1%	47,7%	8,8%	61,0%	29,9%	na	na	na
TOTAL emissions transport	201 100,0	27 700,0	80 300,0	13 056 500,0	5 200,0	400,0	na	na	na	na
% share passenger cars/all transport	24,1%	19,1%	19,7%	44,7%	8,1%	58,0%	na	na	na	na
TOTAL emissions DK (GHG)	na	na	na	**49 000 000,0**	na	**7 800,0**	**5 600,0**	na	na	na
% share passenger cars/total DK	na	na	na	**11,9%**	na	**3,0%**	**11,7%**	na	na	na
1990										
TOTAL emissions passenger cars	**201 608,3**	**23 104,2**	**41 052,9**	**3 170 606,3**	**331,4**	**134,7**	**1 669,0**	**39 349,5**	**1 703,4**	**36,6**
TOTAL emissions road transport	459 500,0	81 800,0	105 900,0	9 275 200,0	na	300,0	2 547,0	na	na	na
% share passenger cars/road transport	43,9%	28,2%	38,8%	34,2%	na	44,9%	65,5%	na	na	na
TOTAL emissions transport	467 500,0	83 900,0	124 000,0	10 528 100,0	na	400,0	na	na	na	na
% share passenger cars/all transport	43,1%	27,5%	33,1%	30,1%	na	33,7%	na	na	na	na
TOTAL emissions DK (GHG)	na	na	na	**51 700 000,0**	na	**10 800,0**	**5 800,0**	na	na	na
% share passenger cars/total DK	na	na	na	**6,1%**	na	**1,2%**	**28,8%**	na	na	na
	CO	**NMVOC**	**NO_x**	**CO_2**	**PM (exhaust)**	**N_2O**	**CH_4**	**NO**	**NO_2**	**NH_3**

Source: Own calculations based on COPERT and CAIT

As indicated in the table above, it is mainly CO_2 and N_2O emissions from passenger cars which contribute the most significantly to total transport emissions (44.7 per cent and 58 per cent respectively). Moreover, emissions of these two gases increased significantly between 1990 and 2005, while other emissions declined. CO_2 emissions from passenger cars increased significantly by over 84 per cent between 1990 and 2005 while number of passenger cars in the Danish vehicle fleet grew by some 22 per cent in the same period. Emissions of particle matter and NH_3 from passenger cars also recorded an increase.

3.4.3.2. Driving patterns and behavior

Average annual mileage driven depends upon the type of passenger car and is approximately 19,000 km a year, which can be split between highways (19 per cent), rural (46 per cent) and urban areas (35 per cent) (Fig 3.4.3.2-1).

Fig 3.4.3.2-1 Driving patterns (for a detailed split and other important driving assumptions see Appendix 5 and 6)

	Share (%)	Average speed (km/h)
Highway	19	100
Rural	46	70
Urban	35	40

Source: COPERT

3.4.3.3. Danish EV market

Denmark has a relatively long tradition of domestic production of small neighborhood EVs, with first model "Ellert" produced in 1987 followed by the KEWET El-Jet model in 1991. Growing sales of these models were aided by the exclusion from registration and green taxes. Ellert and KEWET El-Jet were the only models available in the Danish market until 1997, since then

Citroen introduced its first model, followed by Norwegian Think in 2000. The market as evident in Fig. 3.4.3.3-1 has remained niche. The Ellert is, however, excluded from this table as the vehicle is registered as a 3-wheeler motorcycle (not a 4-wheeler). It is estimated, that the park of Ellerts in Denmark is currently 325 registered vehicles, most of which have been produced in 1987 and 1988.

Majority of EVs currently registered in Denmark are used by municipalities or private companies and only a small share is driven by private persons.

Fig. 3.4.33-1 Danish EV market

Model	1997	2002
EVs (passenger vehicles)		
KEWET	158	126
SAXO	0	60
AX	2	3
Think	0	20
Others	1	2
Total	161	211
EVs (light-duty vehicles)		
Berlingo	0	75
KEWET	15	10
Elcat	3	3
Others	10	10
Total	28	98
EVs (All)		
Passenger EVs	161	211
Light-duty EVs	28	98
Total	189	309

Source: Elbiler i Danmark

The Danish market for pure EVs clearly remains very small, mainly due to limited supply of vehicles considered alternative to conventional models. At the same time, the actual large scale introduction of hybrid vehicles is hampered by high registration tax (to illustrate this, a Honda Civic Hybrid costs on average DKK 370,000, while regular Honda Civic with gas engine is more than DKK 100,000 cheaper, www.danskelbilkomite.dk). To conclude, currently the market for both EVs and HVs in Denmark is almost non-existent.

3.4.3.4. Danish EV plan

Currently, there is no specific policy on EVs, except for their exclusion from registration tax. However, in 2008 Danish Ministry of Environment has published an initiative stating that the first EVs for commercial use should appear on Danish roads by latest 2009.By 2012 up to 100,000 EVs should be on the roads. To help promote these targets, the Ministry of Environment has reserved a financial incentive of DKK 35 million for research into the EV and charging technology (www.mim.dk), a figure rather absurd considering the high targets to be achieved.

Denmark has an ambition of becoming a leading country in respect to electric vehicles and aims to incorporate a large fleet of electric vehicles into the existing energy system which will be increasingly dominated by wind power. According to Dansk Energi (www.danskenergi.dk), a target of 400,000 electric vehicles (a minimum of 20 per cent of the Danish car fleet) is to be achieved by 2020.

3.4.3.5. Global market for EVs

According to Global Insight (in Deutsche Bank, 2008:11) the global market for passenger vehicles will remain dominated by ICEVs, with the rest being taken up by various forms of hybrid vehicles (micro hybrids to plug-in hybrids). The article is rather cautious in its predictions on the penetration of pure EVs due to uncertainties concerning the battery market. It predicts penetration of no more than 2-3 percent in Europe and the USA by 2020 (penetration in other parts of the world is likely to remain significantly below European and US levels, ibid:28).

Contrary to hybrid vehicles using predominantly NiMH batteries, EVs will to a large extent utilize lithium ion batteries due to its higher power density. The share of lithium ion batteries is, however, expected to increase also for hybrid vehicles in the future and on the whole lithium ion batteries will account for 70% of the global market for automotive batteries in 2020 (for both hybrids and pure EVs), up from some 30% in 2015 (ibid:29). According to Deutsche Bank report (2008:28) the growing demand for lithium ion batteries will consequently result in batteries' cost reduction. The report states that a premium of approximately euro 8,000 (DKK 60,000) for pure EVs is forecasted in 2020 when compared to retail price of a conventional model (in other words if the price of conventional vehicle is euro 20,000, the retail price for the same model driving solely on electricity is to be euro 28,000).

4. Methodology

As mentioned in section 1.3., the major objective of this paper is to evaluate the immediate social costs/benefits of nation-wide diffusion of EVs faced by the Danish society. On the whole, causal link within this paper examines to what extent the increased penetration of EVs will affect the social costs/benefits in 2020, holding everything else constant. Furthermore, the link between the impact of EVs on national CO_2 emissions, air pollutants and the long-term economic growth is studied. The magnitude of the social impact will be calculated for each scenario. Furthermore, sensitivity analysis of the social costs/benefits is conducted by incorporating various estimations of environmental costs. In the end, the results of analysis will be critically evaluated and discussed within the theoretical frameworks of induced technological change and its impact on long-term economic growth.

Time unit for this analysis is set in the year 2020, with some references made to 2005 and a general discussion of long-term implications. The study is an example of policy research carried out for a number of scenarios and requiring multi-level analysis by researching the immediate impacts of green legislation on social costs/benefits and future long-term economic growth.

The study supplements earlier studies conducted in the area of economics of climate change by focusing on the impacts of one particular sector of the national economy – the transport – and one particular country - Denmark. The approach can, however, be replicated also for other countries by inserting the corresponding data inputs. The major drawback of the methodology applied is the assumption of everything else staying constant, thus isolation from other side effects which the high penetration of EVs may produce indirectly.

4.1. Social costs/benefits analysis

First, in order to evaluate the impact analysis, taking into account, various policy options and consequently various penetration levels of EVs in the passenger cars fleet by 2020, four major scenarios will be assessed. Scenarios with some share of electric vehicles in the fleet (scenario 2,3 and 4 as summarized below) will each be further split into three sub-scenarios indicating the share of green electricity in the national electricity grid (assumed to be predominantly wind power in case of Denmark) to be used for vehicles' charging.

The calculation of socio-economic impact analysis used within this paper adopts the form of social net marginal

4.1.1. Scenarios overview

1. Business As Usual Scenario (BAU), implying 0% penetration of electric vehicles and reflecting current situation in the Danish passenger vehicles fleet
2. Electric Vehicles with Low (5%) Penetration (EVLOW)
    a. Green Electricity Share in electricity supply for EVs (20%)
    b. Green Electricity Share in electricity supply for EVs (30%)
    c. Green Electricity Share in electricity supply for EVs (50%)

3. Electric Vehicles with Medium (20%) Penetration (EVMED)
    a. Green Electricity Share in electricity supply for EVs (20%)
    b. Green Electricity Share in electricity supply for EVs (30%)
    c. Green Electricity Share in electricity supply for EVs (50%)
4. Electric Vehicles with High (40%) Penetration (EVHIGH)
    a. Green Electricity Share in electricity supply for EVs (20%)
    b. Green Electricity Share in electricity supply for EVs (30%)
    c. Green Electricity Share in electricity supply for EVs (50%)

Fig 4.1.1-1 Summary of scenarios analyzed

Scenario option		**EV penetration in the vehicle stock**	**Share of green power in electricity supply**
BAU	Business As Usual	0%	na
EVLOW1	Electric Vehicles with Low Penetration	5%	20%
EVLOW2			30%
EVLOW3			50%
EVMED1	Electric Vehicles with Medium Penetration	20%	20%
EVMED2			30%
EVMED3			50%
EVHIGH1	Electric Vehicles with High Penetration	40%	20%
EVHIGH2			30%
EVHIGH3			50%

4.1.2. Methodology steps

For each scenario, a quantitative analysis is carried out, following the same methodology steps:

a. Modelling of the composition of the passenger car fleet
b. Estimate average values of traffic activity for each vehicle group (annual mileage, fuel consumption, ...)
c. Estimate average emission values for each vehicle group (air pollutants, CO_2 emissions, noise)
d. Calculate environmental costs for each scenario
e. Estimate average fiscal impacts for each vehicle group (tax reduction effects)

f. Calculate economic costs for each scenario

g. Calculate social net benefit/cost for each scenario based on calculations of marginal damage (environmental damage) and reduced tax revenues.

Social Marginal Net Benefit (MNB) = Δ MD - Δ TR; where

Δ MD is a Decrease in Marginal Damage, Δ MD = MD^{CV} - MD^{EV}[5],

Δ TR is a Decrease in Tax Revenues, Δ TR = TR^{CV} - TR^{EV}[6].

h. Summarize results for each vehicle group and compare scenarios

i. Sensitivity analysis for each scenario based on different valuation of environmental costs.

4.2. Overall impact on future economic growth

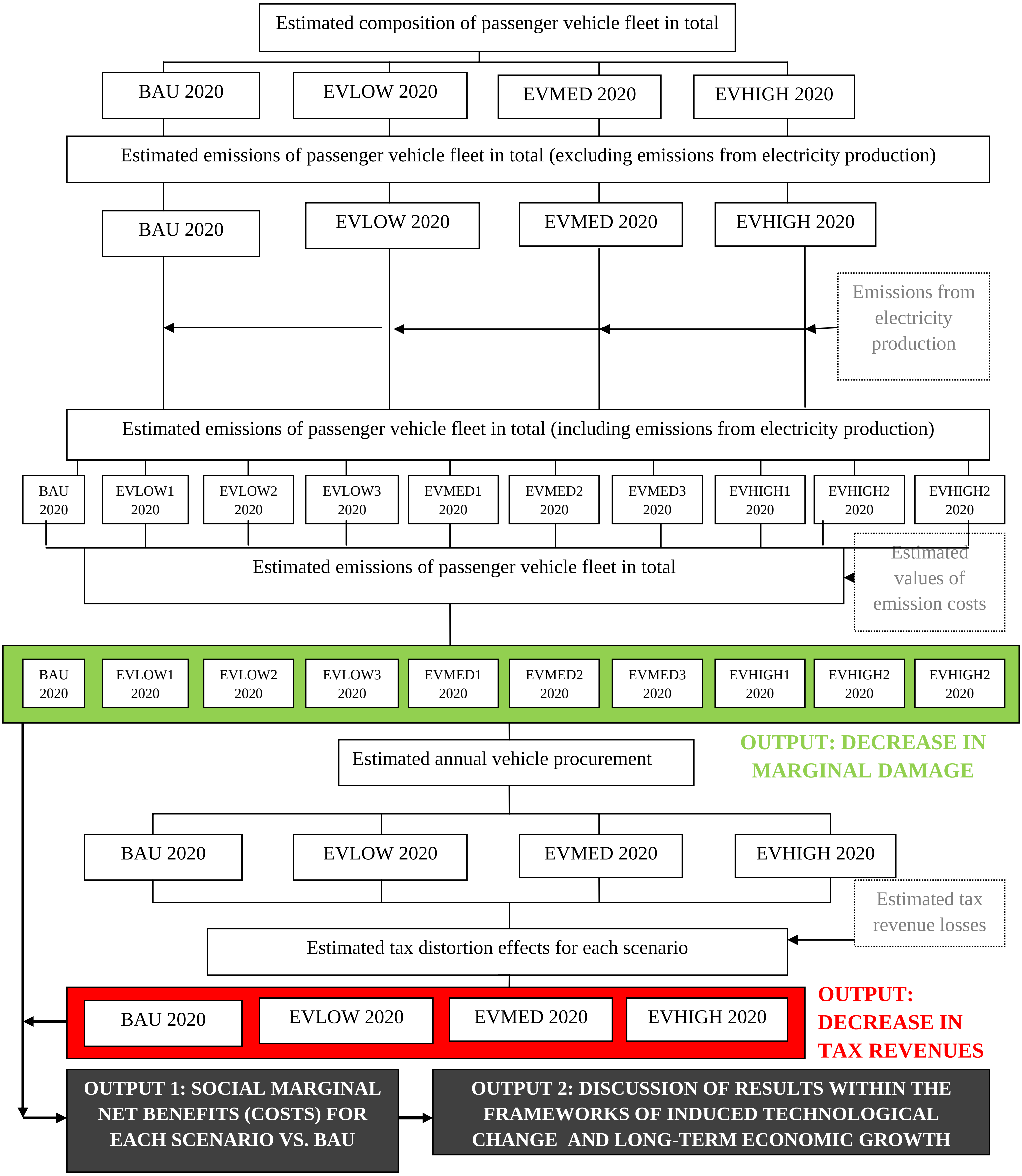
Having established the magnitude of social costs/benefits for each scenario, the results will be critically analyzed together with their impact on long-term economic growth. The theoretical framework applied within this section will be based on the theories of induced technological change and its impact on long-term economic growth.

4.3. Structure outline of overall methodology for scenarios comparison

[5] MD^{CV} = Marginal Damage of Conventional Vehicles, MD^{EV} = Marginal Damage of Electric Vehicles

[6] TR^{CV} = Tax Revenues from Conventional Vehicles, TR^{EV} = Tax Revenues from Electric Vehicles

Fig 4.3-1 Structure outline



4.4. Social costs/benefits analysis

4.4.1. Modeling future passenger car park and emissions (BAU scenario)

As presented in Fig 4.4.1-1, no EVs are included within the BAU scenario. Although it is rational to assume a certain number of EHVs to penetrate the market by 2020, based on current sales trends, the overall penetration, in this scenario, is believed to remain very limited.

Fig 4.4.1-1 The stock of passenger vehicles 2005-2020 (BAU)

BAU: The stock of passenger vehicles (2005-2020)				
Subsector	2005	2010	2015	2020
Gasoline <1,4 l	597 583	478 498	420 332	394 483
Gasoline 1,4 - 2,0 l	1 028 532	1 110 537	1 132 747	1 121 420
Gasoline >2,0 l	169 642	173 471	183 359	205 728
Gasoline	1 795 758	1 762 507	1 736 439	1 721 630
Diesel <2,0 l	195 199	265 176	340 476	393 916
Diesel >2,0 l	22 081	32 004	46 178	58 020
Diesel	217 280	297 181	386 654	451 936
	2 013 051	2 059 698	2 123 102	2 173 576

Source: Own calculations based on COPERT and TREMOVE (see Appendix 7 for more detail)

As for emissions and consumption factors of vehicle technologies, EC program COPERT was used (a complete overview of assumptions and input data is to be found in Appendix 6 and 8). The emissions model takes into account both larger vehicle fleet as well as increased annual mileage (as forecasted by both EC and Transportrådet) and improved fuel efficiency ((including also the newest Euro V and Euro VI standards).

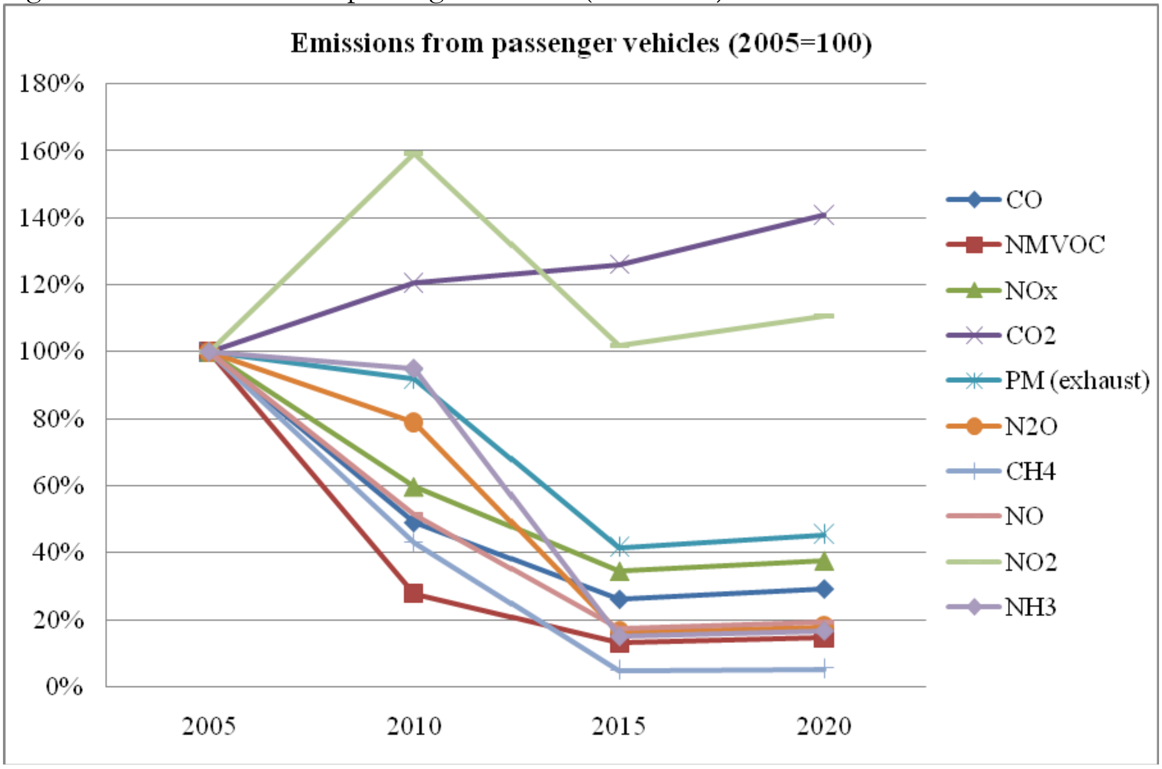
Fig 4.4.1-2 Continual development in major emissions (BAU scenario)

	CO	NMVOC	NO_x	CO_2	PM (exhaust)	N_2O	CH_4	NO	NO_2	NH_3
2005	48 451,8	5 303,7	15 806,4	5 837 652,0	421,0	231,8	652,5	14 600,6	1 205,8	2 304,7
2010	23 712,0	1 472,7	9 438,7	7 046 990,8	386,7	182,8	281,1	7 519,3	1 919,4	2 190,2
2015	12 588,6	691,0	5 459,8	7 366 576,4	175,1	38,0	31,8	2 523,6	1 228,7	347,6
2020	14 094,7	771,8	5 953,7	8 225 913,2	191,6	41,5	35,2	2 781,9	1 336,6	386,1

Source: Own calculations based on COPERT and TREMOVE (see Appendix 9 for more detail)

From the emissions calculations presented in Fig 4.4.1-2 and illustrated in Fig 4.4.1-3 it is clear, that even in case when no policies supporting AFVs are to be introduced on a large scale by 2020, the most common emissions from passenger vehicles are set to decline significantly. This is mainly due to increased efficiency of new vehicles.

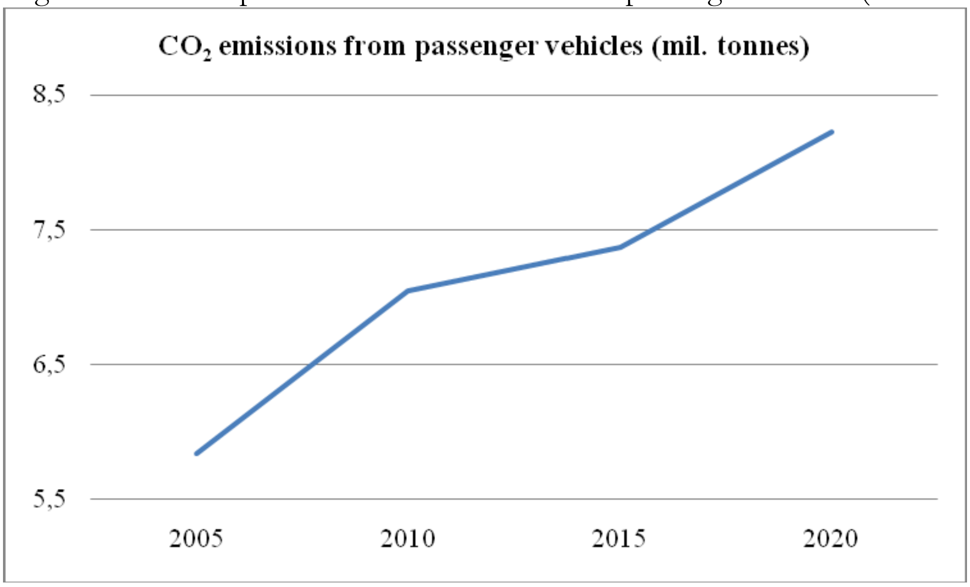
Fig 4.4.1-3 Emissions from passenger vehicles (2005=100)



Source: Own calculations (based on preceding table)

Despite the seemingly favorable developments, CO_2 emissions are to increase significantly in the same period, up by nearly 41 per cent while the total vehicle stock increases by some 8 per cent (Fig 4.4.1-4).

Fig 4.4.1-4 Development in CO2 emissions from passenger vehicles (mil. tones)



Source: Own calculations

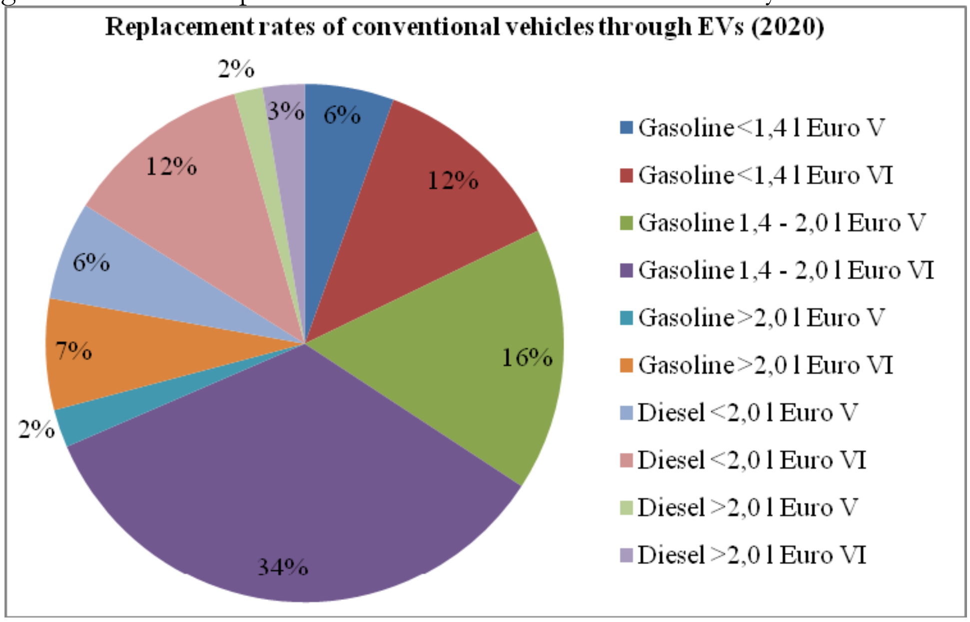
4.4.2. Analysis of emissions of proposed scenario options

4.4.2.1. General Assumptions

1. For every EV sold, the sales of conventional vehicles are to be reduced by one unit. This implies that the introduction of EVs does not affect the size of the total vehicle stock. Similarly, the annual distance driven by EVs is assumed to be identical with the mileage of conventional vehicles which these EVs replace.

2. EVs will gradually replace sales of all types of both gasoline and diesel passenger vehicles complying with the Euro V and Euro VI standards, as consumers buying an EV are assumed to possess a certain degree of environmental consciousness, thus purchasing an electric vehicle instead of other efficient car category available in the market (first Euro V vehicles and later Euro VI vehicles). Although majority of sales will still replace smaller conventional gasoline vehicles, sales are to be recorded also in larger categories and among diesel sales. This is based on the assumption that consumers will tend to replace their existing vehicle with a vehicle of similar category. The split of sales to be applied to all scenarios is as indicated in Fig 4.4.2.1-1:

Fig 4.4.2.1-1 2020 Replacement rates of conventional vehicles by EVs



Source: Own assumptions

3. The composition of the Danish vehicle fleet based on above mentioned assumptions is to be found in Appendix 10.

4. Highest penetration of EVs in the vehicle stock was set at 40 per cent. This is close to the maximum possible to be achieved by 2020, as considerable time lag is required for a vehicle stock replacement in such a degree by 2020.

5. Emissions from electricity generation have the same impact on the environment as emissions from vehicles.

6. Other policies (such as road pricing) which have not been agreed upon prior to spring 2009 are not to be included, as their impact on the 2020 is likely to remain insignificant.

7. EVs average driving range is assumed to be 200 km per charge.

8. Energy consumption (electricity) for EVs is set at 0.15 kWh_{el}/km for all calculations (current technology development), which may possibly overestimate the total energy consumption as there are signs that a gradual improvement in efficiency could be expected after 2015 (down to even 0.10 kWh_{el}/km).

9. The estimations of emissions from electricity generation are based on the 2008 splits of fuel supply for combined heat and power. Although, it is likely, that the use of natural gas will to some extent grow on the account of coal, this is not considered in the analysis as the share of electricity demand from EVs of the total electricity production is relatively low.

10. Costs of infrastructure for EVs are not included, as private companies are likely to bear the bulk of these costs (e.g. charging stations).

11. Although this paper is based on current legislation, it is very likely, that if a sudden mass shift towards EVs occurs, the Government will pass on new fiscal laws (for example new registration or ownership taxes on EVs).

4.4.2.2. Emissions analysis

Primarily, in order to assess the costs of each scenario, it is necessary to establish the levels of emissions. This is done in two steps:

1. Basic calculation of emissions for future scenarios EVLOW, EVMED and EVHIGH (excluding emissions from electricity production)

Detailed calculations of emissions from passenger vehicles for each scenario (2020) can be seen in Appendix 11, 12 and 13. These calculations are based on the vehicle stock as previously highlighted in Appendix 10, incorporating 5 per cent, 20 per cent and 40 per cent penetration of EVs respectively. The summary of basic findings is demonstrated in Fig 4.4.2.2-1. These calculations, however, serve only as a basis for further calculations, as emissions from electricity supply to EVs are excluded.

Fig 4.4.2.2-1 Emissions in tonnes (excluding emissions from electricity generation for EVs)

	CO	NMVOC	NO_x	CO_2	PM (exhaust)	N_2O	CH_4	NO	NO_2	NH_3
BAU	14 094,7	771,8	5 953,7	8 225 913,2	191,6	41,5	35,2	2 781,9	1 336,6	386,1
EVLOW	13 510,9	735,8	5 785,2	7 835 888,0	189,0	41,5	35,2	2 733,3	1 335,4	386,1
EVMED	11 759,3	627,7	5 279,8	6 665 815,8	181,3	41,5	35,2	2 587,6	1 332,0	386,1
EVHIGH	9 423,9	483,6	4 606,0	5 105 718,4	171,0	41,5	35,2	2 393,3	1 327,4	386,1
	% Savings vs. BAU									

	CO	NMVOC	NO_x	CO_2	PM (exhaust)	N_2O	CH_4	NO	NO_2	NH_3
EVLOW	4,14%	4,67%	2,83%	4,74%	1,34%	0,00%	0,00%	1,75%	0,09%	0,00%
EVMED	16,57%	18,67%	11,32%	18,97%	5,37%	0,00%	0,00%	6,98%	0,34%	0,00%
EVHIGH	33,14%	37,35%	22,64%	37,93%	10,74%	0,00%	0,00%	13,97%	0,69%	0,00%

Source: Own calculations based on COPERT.

Based on the calculations above, it is clear that a 5 per cent replacement of passenger vehicles by EVs would lead to a CO_2 saving of 4.74 per cent. Similarly, in case of high penetration of 40 per cent (EVHIGH), the savings in CO_2 would climb to nearly 38 per cent. This is, however, only the case if all electricity fed to EVs is to be marked as CO_2-neutral, which is an unlikely situation in 2020 (based on previous developments in the Danish electricity generation presented in section 3.4.1.1.).

2. Adding emissions from electricity production to total emissions from the passenger vehicle sector

Although EVs do not emit any tailpipe emissions, emissions from electricity production need to be taken into consideration in order to critically assess their environmental impact. To illustrate with the EVLOW scenario, EVs would strain the Danish electricity grid demand by almost 345 GWh annually. This corresponds to 1.2 per cent of Danish electricity use in 2007 (for detailed calculation see Appendix 14)[7]. However, slightly different results were generated for the same scenario when using other methods of measurement: 382.9 GWh according to Lund & Kempton methodology (2008) and 344 GWh using ratios from US DOE (Energy Efficiency and Renewable Energy)[8]. For the purposes of this study, however, the values of 345 GWh are to be included as these are in between the two extremities calculated from other academic sources.

Fig 4.4.2.2-2 Additional annual electricity demand per scenario

	Annual electricity feed per fleet EVLOW	Annual electricity feed per fleet EVMED	Annual electricity feed per fleet EVHIGH
TOTAL (MJ)	1 240 615 734	4 962 451 519	9 924 903 038
TOTAL (GWh)	345	1 378	2 757

As indicated in Fig 4.4.2.2-2, it is clear that a shift to EVs will increase Danish electricity demand within a range of 345-2,757 GWh (at varying levels depending on the scenario). In order to calculate emissions from electricity feed for EVs, this paper will assume that the total increase in use will be equal to the increased national demand for electricity (marginal electricity). This is likely to overestimate the actual emissions from EVs, as benefits of night charging are not included. As described in section 3.4.1.1. EVs could take advantage of night charging when excess electricity is produced (often windmills) and therefore contribute to even increased efficiency of the current Danish electricity grid. However, for simplicity this paper will assume

[7] Based on an average fuel consumption of EVs at 67.2MJ/100 km (Granovskii et al, 2005:1187), average mileage corresponding to that of conventional vehicles replaced by EVs but higher share of urban driving (55 per cent as opposed to 35 per cent applied to previous calculations of conventional vehicles).
[8] http://www.afdc.energy.gov/afdc/data/fuels.html (accessed 28th February 2009)

that adding one EV to the grid proportionately increases the national electricity demand[9]. Various marginal electricity scenarios were evaluated – starting from the current electricity mix and extrapolating this to 2020 to increasing the share of wind power (Appendix 15).

Fig 4.4.2.2-3 compares the various emission levels for each scenario in absolute terms and Fig 4.4.2.2-4 shows a percentage change for each scenario compared to BAU. A reduction in GHGs (CO_2 emissions) and other air pollutants (NMVOC and CO) is recorded for all scenarios. On the other hand, the tables indicate a rise in NO_x, N_2O and PM which is likely to reflect the emissions from electricity generation in fossil-fueled power plants. The tremendous increase in emissions of CH_4 is also believed to originate from high level of CH_4 emissions from coal and natural gas fired power stations[10].

Fig 4.4.2.2-3 Emissions in tonnes (including emissions from electricity generation for EVs)

	Unit	2020 EVLOW			2020 EVMED			2020 EVHIGH			BAU
		1	2	3	1	2	3	1	2	3	
CO2 (from electricity)	mil. tonnes	8,006	7,985	7,942	7,347	7,262	7,092	6,468	6,298	5,957	8,226
NOx	tonnes	6 113	6 072	5 990	6 591	6 427	6 099	7 228	6 900	6 244	5 954
CH4	tonnes	144	130	103	469	415	306	903	795	578	35
N2O	tonnes	45	45	44	56	54	50	69	66	59	42
NMVOC	tonnes	762	759	752	733	720	693	694	667	615	772
CO	tonnes	13 584	13 575	13 556	12 050	12 014	11 941	10 006	9 933	9 787	14 095
PM	tonnes	198	197	194	216	212	203	240	232	214	192

Source: Own calculations based on COPERT (Appendix 16 and 17)

Fig 4.4.2.2-4 Emission savings for each scenario in % compared to BAU

	2020 EVLOW			2020 EVMED			2020 EVHIGH		
	1	2	3	1	2	3	1	2	3
CO2 (from electricity)	-2,7%	-2,9%	-3,4%	-10,7%	-11,7%	-13,8%	-21,4%	-23,4%	-27,6%
NOx	2,7%	2,0%	0,6%	10,7%	7,9%	2,4%	21,4%	15,9%	4,9%
CH4	308%	270%	193%	1233%	1079%	771%	2466%	2158%	1541%
N2O	8,4%	7,4%	5,3%	33,7%	29,5%	21,0%	67,3%	58,9%	42,1%
NMVOC	-1,3%	-1,7%	-2,5%	-5,1%	-6,8%	-10,2%	-10,1%	-13,5%	-20,3%
CO	-3,6%	-3,7%	-3,8%	-14,5%	-14,8%	-15,3%	-29,0%	-29,5%	-30,6%
Particulate matter	3,2%	2,6%	1,5%	12,7%	10,4%	5,9%	25,4%	20,9%	11,9%

Source: Own calculations based on COPERT (Appendix 16 and 17)

From Fig 4.4.2.2-4 it is clear that even when emissions from electricity production are to be considered, a diffusion of EVs for all penetration levels results in reductions of CO_2 emissions (a reduction ranging between 2.7 per cent and 27.6 per cent), one of the major GHG. However,

[9] The issue related to the possible overestimation of the actual impact of EV's integration into the electricity grid is the increased share of wind power. As Lund argues (EnergyPlan 2008) the share of wind power raised from current levels to some 30 per cent results in over 10 per cent annual excess electricity production (respectively 50 per cent share of wind power leads to over 17 per cent annual excess electricity production). This would imply that in virtually all scenarios, the integration of EVs into the vehicle grid leads to increased system efficiency and not necessarily marginal electricity production.

[10] CH_4 emissions are not core to the analysis conducted within this study; however, future investigation into the reasons of such a significant increase should be undertaken.

interestingly when comparing CO_2 emissions from passenger cars of EVHIGH3 scenario at 5.96 mil. tonnes to the passenger car emissions recorded in 2005 (5.84 mil. tones as shown in Fig 4.4.1-2), an actual increase in emissions of 2 per cent is recorded. This is due to the anticipated increase in the size of the Danish passenger vehicle fleet as well as increased car ownership and mileage. Holding everything else constant, CO_2 emissions of the sector would increase by almost 41 per cent (Fig 4.4.2-1 from 5.84 to 8.23 mil. tones). However, a significant diffusion of EVs at a penetration level of 40 per cent together with a 50 per cent share of green electricity generation leads to a rise in CO_2 emissions of "only" some 2 per cent, thus significantly lower than the anticipated rise of 41 per cent if no other regulatory measures are to be made in the sector.

To conclude, even high penetration of EVs in the national vehicle fleet is not likely to bring CO_2 emissions of the sector below 2005 levels, however it does to a certain extent, prevent a further massive growth in emissions.

4.4.3. Analysis of social marginal net benefit of proposed scenario options

4.4.3.1. Marginal Damage (Environmental damage)

Environmental costs are considered to represent one form of external costs in the transport sector (Fig 4.4.3.1-1). Other external costs include infrastructure costs (congestion and scarcity costs) and accident costs; however, these will not be assessed within this paper, as the diffusion of EVs is not believed to have any major effect in this respect.

Fig 4.4.3.1-1 Components of external costs

External cost components and level of externality		
Cost component	**Private and social costs**	**External part in general**
Costs of scarce infrastructure (Congestion and scarcity costs)	All costs for traffic users and society (time, reliability, operation, missed economic activities).	Extra costs imposed on all other users and society exceeding own additional costs.
Accident costs	All direct and indirect costs of an accident (material costs, medical costs, production losses, suffer and grief caused by fatalities).	Part of social costs which is not considered in own and collective risk anticipation and not covered by (third party) insurance.
Environmental costs	All damages of environmental nuisances (health costs, material damages, biosphere damages, long term risks).	Part of social costs which is not considered (paid for).

Source: Handbook on estimation of external costs in the transport sector (2008:14)

Moreover, although arguments about increased accident costs of EVs (due to its silent operation not warning pedestrians enough about its approach and thus resulting in higher accident rates) appeared, these will not be considered within the study due to missing scientific evidence.

Fig 4.4.3.1-2 Overview of major environmental costs

Overview of main issues of environmental costs	
Cost component	**Cost elements**
Air pollution	Health costs Crop losses Building damages Costs for nature and biosphere

Noise costs	Rent losses Health costs Annoyance costs
Climate change	Prevention costs to reduce risk of climate change Damage costs of increasing temperature

Source: Handbook on estimation of external costs in the transport sector (2008:21-22)

Following unit external costs for air pollution, GHG and noise are to be used:

Fig 4.4.3.1-3 External costs

Air pollution costs in euro/tonne of pollutant				
Pollutant	NOx	NMVOC	PM urban	PM rural
	4 400	700	386 800	45 500
Air pollution costs in euro/tonne of pollutant for electricity generation				
Pollutant	NOx	NMVOC	PM	
	4 400	700	7 700	
Climate change costs in euro/tonne of CO2				
Pollutant	CO2			
	40			

Noise costs in euro cent/vkm	
Urban areas	Rural areas
0,823	0,13

Source: Handbook on estimation of external costs in the transport sector (2008)

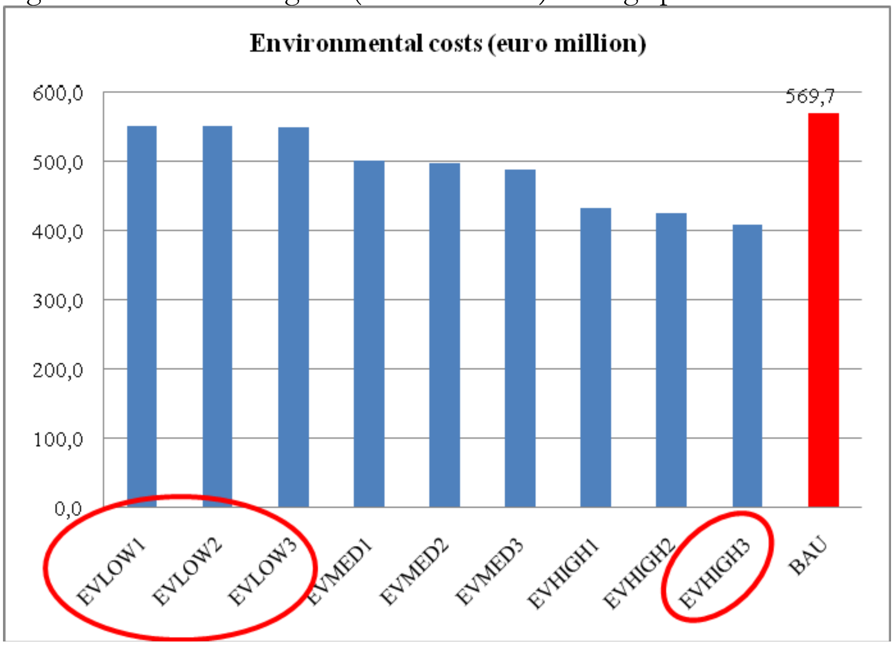
Based on assumptions given above, the environmental costs for each scenario are summarized in Fig 4.4.3.1-4 and illustrated in Fig 4.4.3.1-5 (for detailed calculations see Appendix 18). Fig 4.4.3.1-6 presents the comparison of marginal damage of all scenarios with the BAU scenario. It is obvious, that reductions in monetary terms associated with the lowest penetration (5 per cent, EVLOW) of EVs in the Danish vehicle fleet are minimal (around 3 per cent reductions for all three sub-scenarios). On the other hand, a high penetration of EVs is likely to bring significant environmental costs reductions (up to 28 per cent reduction if the share of green electricity is set at 50 per cent).

Fig 4.4.3.1-4 Total marginal (environmental) damage per scenario (absolute values in mil. euro)

Total Marginal Damage per scenario (in mil. euro)										
	Unit	Denmark 2020 EVLOW			Denmark 2020 EVMED			Denmark 2020 EVHIGH		
		EVLOW1	EVLOW2	EVLOW3	EVMED1	EVMED2	EVMED3	EVHIGH1	EVHIGH2	EVHIGH3
NOx	mil. euro	26,897	26,717	26,356	28,999	28,278	26,836	31,801	30,360	27,476
NMVOC	mil. euro	0,533	0,531	0,527	0,513	0,504	0,485	0,486	0,467	0,430
Particulate matter	mil. euro	31,243	31,235	31,218	30,170	30,137	30,070	28,740	28,674	28,540
CO2	mil. euro	320,248	319,397	317,693	293,883	290,477	283,664	258,730	251,917	238,292
Noise	mil. euro	173,792	173,792	173,792	148,114	148,114	148,114	113,878	113,878	113,878
TOTAL	mil. euro	552,713	551,671	549,586	501,680	497,510	489,171	433,636	425,296	408,617

Source: Own calculations

Fig 4.4.3.1-5 Total marginal (environmental) damage per scenario



Source: Illustration based on preceding table

Fig 4.4.3.1-6 Comparison of total marginal damage per scenario (BAU=100)

Comparison of total Marginal Damage per scenario (BAU = 100)										
	Denmark 2020 EVLOW			Denmark 2020 EVMED			Denmark 2020 EVHIGH			BAU
	EVLOW1	EVLOW2	EVLOW3	EVMED1	EVMED2	EVMED3	EVHIGH1	EVHIGH2	EVHIGH3	
NOx	103%	102%	101%	111%	108%	102%	121%	116%	105%	100%
NMVOC	99%	98%	97%	95%	93%	90%	90%	86%	80%	100%
Particulate matter	99%	99%	99%	95%	95%	95%	91%	91%	90%	100%
CO2	97%	97%	97%	89%	88%	86%	79%	77%	72%	100%
Noise	95%	95%	95%	81%	81%	81%	62%	62%	62%	100%
TOTAL	97%	97%	96%	88%	87%	86%	76%	75%	72%	100%

Source: Own calculations

Fig 4.4.3.1-7 summarizes final results of Δ Marginal Damage (reduction in environmental damage caused by increase in number of EVs). According to the calculations, environmental benefits in monetary terms are most significant in the reduction of CO_2 emissions and the reduction of noise. On the other hand, scenarios with low and medium share of EVs (EVLOW and EVMED) do not contribute to reductions in air pollutants, but on the contrary represent increased environmental costs to the society due to its increase in NO_x emissions.

Fig 4.4.3.1-7 Δ MARGINAL DAMAGE per scenario ($MD^{CV} – MD^{EV}$)

Δ MARGINAL DAMAGE per scenario (environmental benefits, absolute values in mil. euro)										
	Unit	Denmark 2020 EVLOW			Denmark 2020 EVMED			Denmark 2020 EVHIGH		
		EVLOW1	EVLOW2	EVLOW3	EVMED1	EVMED2	EVMED3	EVHIGH1	EVHIGH2	EVHIGH3
NOx	mil. euro	-0,7	-0,5	-0,2	-2,8	-2,1	-0,6	-5,6	-4,2	-1,3
NMVOC	mil. euro	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1
Particulate matter	mil. euro	0,4	0,4	0,4	1,4	1,5	1,5	2,9	2,9	3,1
CO2	mil. euro	8,8	9,6	11,3	35,2	38,6	45,4	70,3	77,1	90,7
Noise	mil. euro	8,6	8,6	8,6	34,2	34,2	34,2	68,5	68,5	68,5
TOTAL	mil. euro	**17,0**	**18,1**	**20,1**	**68,0**	**72,2**	**80,6**	**136,1**	**144,4**	**161,1**

Source: Own calculations

4.4.3.2. Decrease in Tax Revenues

The widespread diffusion of EVs is believed to have a significant impact on the Danish tax revenues. As mentioned it chapter 3.2.2., revenues from environmental taxes account for some 5 per cent of the Danish GDP. It is clear, that a trend towards EVs, in case of current legislation, will lead to significant losses in tax revenues. The fiscal impact of EVs is to be mirrored in changes in following taxes:

- Energy tax: Loss in tax revenues from excise duties, while increased tax generation from electricity consumption.

- Vehicle tax: Loss in both registration tax and annual ownership tax (green circulation tax), as this concerns only conventional vehicles on gasoline or diesel.

- VAT: Increased tax revenues from higher retail selling price of EVs as compared to their conventional alternatives.

Assumptions:

1. Average fuel consumption in 2020 is set to 6l/100 km for gasoline driven vehicles and 5.5l/100 km diesel vehicles (based on projections from Nielsen&Jørgensen and Carlsson&Johansson-Stenmann).

2. Excise duties on fuels applied in calculations are based on 2008 values of 508 euro/1,000 litres for unleaded petrol and 404 euro/1,000 litres of diesel (detailed calculations in Appendix 19).

3. The duties on electricity consumption are for households and include electricity tax, electricity distribution tax, electricity savings contribution and CO_2 tax and are set at 67.50 øre/kWh (9 euro cent/kWh) (danskenegi.dk).

4. Values of green circulation tax used in calculations are highlighted in Appendix 20.

5. Although the amount of vehicle registration tax depends on the value of the car (chapter 3.2.2.), an average of 130 per cent was used for calculations (as indicated by ACEA statistics).

6. Estimated additional battery costs for EVs to be euro 8,000 (DKK 60,000) in 2020 (Deutsche Bank, 2008:29) and current VAT rate of 25 per cent is estimated to remain by 2020.

7. Importantly, the analysis is based on current state of legislation which excludes EVs from the duty to pay vehicle registration and ownership tax. It has been announced in March 2009, that a parliament vote concerning this issue will take place during 2010. Although some MPs argue for further 10-year exemption (following the expiry in 2012), it remains questionable to what extent is the Government willing to disregard such a significant tax element (representing 1.4 per cent of GDP in 2007).

8. 2020 vehicle procurement is based on an average of 150,000 new registrations (Nielsen&Jørgensen) and progressive development in sales of EVs between 2010 and 2020 (Appendix 21), which corresponds realistically with the ongoing technological development of EVs and a path of gradual adoption of a new technology. The annual procurement of EVs therefore starts at low levels and gradually increases its share among new registrations by 2020.

As indicated in Fig 4.4.3.2-1 the most significant losses in tax revenues are expected due to the omission of vehicle registration tax which is currently applied to EVs according to the Danish legislation. On the other hand, tax revenue losses incurred as a result of decline in excise duties on fuel and annual vehicle ownership taxes are to be partly offset by additional revenues from duties on electricity consumption and VAT. Overall, however, the decrease in tax revenues is expected to be significant ranging from euro 255.6 million to almost euro 1.9 billion.

Fig 4.4.3.2-1 Final calculations of decreases in tax revenues (TR^{CV}-TR^{EV})

Final calculations of decreases in TAX REVENUES (Δ TR)				
	Unit	**EVLOW**	**EVMED**	**EVHIGH**
Excise duties on fuel	Total (mil. DKK)	-489,4	-1 957,7	-3 915,4
	Total (mil. euro)	-65,7	-262,7	-525,4
Duties on electricity consumption	Total (mil. DKK)	232,6	930,5	1 860,9
	Total (mil. euro)	31,2	124,9	249,7
Additional VAT revenues	Total (mil. DKK)	270,0	1 057,5	1 912,5
	Total (mil. euro)	36,2	141,9	256,6
Vehicle ownership tax	Total (mil. DKK)	-172,3	-689,1	-1 378,2
	Total (mil. euro)	-23,1	-92,5	-184,9
Vehicle registration tax	Total (mil. DKK)	-1 746,0	-6 838,5	-12 367,5
	Total (mil. euro)	-234,3	-917,7	-1 659,6
TOTAL	**TOTAL(mil. DKK)**	**-1 905,1**	**-7 497,3**	**-13 887,7**
	TOTAL (mil. euro)	**-255,6**	**-1 006,1**	**-1 863,6**

Source: Own calculations (for detail see Appendix 19, 20 and 22)

4.4.3.3. Presentation of final results social net benefit/costs of EVs

The following table (Fig 4.4.3.3-1) summarizes the benefits of reduced environmental damage with the costs associated with losses in tax revenues for each scenario in 2020. All values are expressed in absolute terms (monetary terms - mil. euro or euro as indicated) and reflect the costs associated with various levels of penetration of EVs to the Government of Denmark (the social costs/benefits).

Fig 4.4.3.3-1 Total social marginal net benefits

2020 TOTAL SOCIAL MARGINAL NET BENEFITS (MNB)									
		BENEFITS (Marginal Damage)				COSTS			
Scenario	Unit	Pollution	GHG emissions (CO2)	Noise	Total	Tax revenue loss	**Total social marginal net benefit (MNB)**	**Total social MNB per EV (€)**
EVLOW1	mil. euro	-0,3	8,8	8,6	17,0	-255,6	**-238,6**	**-2 195,8**
EVLOW2	mil. euro	-0,1	9,6	8,6	18,1	-255,6	**-237,6**	**-2 186,2**
EVLOW3	mil. euro	0,2	11,3	8,6	20,1	-255,6	**-235,5**	**-2 167,0**
EVMED1	mil. euro	-1,3	35,2	34,2	68,0	-1 006,1	**-938,0**	**-2 157,8**
EVMED2	mil. euro	-0,6	38,6	34,2	72,2	-1 006,1	**-933,9**	**-2 148,2**
EVMED3	mil. euro	0,9	45,4	34,2	80,6	-1 006,1	**-925,5**	**-2 129,1**
EVHIGH1	mil. euro	-2,7	70,3	68,5	136,1	-1 863,6	**-1 727,5**	**-1 987,0**
EVHIGH2	mil. euro	-1,2	77,1	68,5	144,4	-1 863,6	**-1 719,2**	**-1 977,4**
EVHIGH3	mil. euro	1,9	90,7	68,5	161,1	-1 863,6	**-1 702,5**	**-1 958,2**

Source: Own calculations

From Fig 4.4.3.3-1 it is clear, that although the increased penetration of EVs leads to net benefits in environmental costs, these are considerably offset by the expected tax revenue losses of the Danish state. This is a rather country specific characteristic, as Denmark has one of the highest vehicle taxes in the world, and a similar analysis applied to other countries could lead to very different results. However, in the case of Denmark, the diffusion of EVs is therefore not believed to be socio-economically beneficial. At least not taking into account the current state of legislation, according to which EVs would be “subsidized” through tax exemptions and low electricity taxes.

However, when calculating the level of “subsidy” per one EV on the Danish roads in 2020, is actually only some euro 2,000 (social MNB per EV). Moreover, the amount of this annual “subsidy” declines with the rising penetration of EVs on the Danish roads, reflecting the increase in environmental benefits (from euro 2,196 per each EV in case of EVLOW1 down to euro 1,958 in case of EVHIGH3).

4.4.3.4. Impact of emission savings in the transport sector on total emissions in Denmark

In order to understand the total impact of diffusion of EVs in Denmark, it is necessary to consider their environmental impact overall. As analyzed in preceding chapter, the major benefit of EVs replacing conventional gasoline vehicles is the reduction in CO_2 emissions. This is an important feature, as CO_2 emissions are the major contributor to global warming and in

Denmark the passenger vehicle fleet contributes some 12 per cent to total CO_2 emissions (up from 6 per cent in 1990).

According to the report on Projection of Greenhouse Gas Emissions 2007-2025, Denmark's total emissions of CO_2 peaked in 2008 at a level of 57,316,000 tons. They are however projected to decline to 43,213,000 tons by 2020. This is mainly due to the increased efficiency in energy industries, which is however forecasted to be partly offset by rising emissions from the transport sector (an anticipated rise from 5.84 to 8.26 mil. tonnes between 2005 and 2020). However, additional savings can be made if EVs are introduced (as shown in section 4.4.2.2. even a 40 per cent diffusion of EVs is unlikely to bring CO_2 emission levels of the transport sector below 2005 levels, however, it does significantly reduce the anticipated growth in CO_2 emissions from 41 per cent down to some 2 per cent) .

Fig 4.4.3.4-1 below summarizes potential savings in CO_2 emissions based on projected efficiency improvements. The EVHIGH3 scenario illustrates that; ceteris paribus, a 40 per cent penetration of EVs among passenger vehicles would lead to an additional 5.25 per cent reduction in total Danish CO_2 emissions. Moreover, this figure, however, is still largely underestimated as it does not include the contribution of high green electricity share on other sectors as well as utilization of excess electricity from windmills. The purpose of following table is therefore only to illustrate the actual minimal impact of EVs on the state of Danish CO_2 emissions, not taking into account the benefits of replacing other energy sources with wind power.

Fig 4.4.3.4-1 Potential savings in CO_2 emissions in total per scenario

Scenario	2020 Total CO2 emissions according to Danish projections (excluding introduction of EVs)	- of which: 2020 CO2 emissions from passenger vehicles ('000)	2020 Total CO2 emissions ('000) including EVs	Total reduction in CO2 emissions (%)
BAU	43 213,0	8 225,9	43 213,0	**0,00%**
EVLOW1	43 213,0	8 006,2	42 993,3	**-0,51%**
EVLOW2	43 213,0	7 984,9	42 972,0	**-0,56%**
EVLOW3	43 213,0	7 942,3	42 929,4	**-0,66%**
EVMED1	43 213,0	7 347,1	42 334,2	**-2,03%**
EVMED2	43 213,0	7 261,9	42 249,0	**-2,23%**
EVMED3	43 213,0	7 091,6	42 078,7	**-2,62%**
EVHIGH1	43 213,0	6 468,3	41 455,3	**-4,07%**
EVHIGH2	43 213,0	6 297,9	41 285,0	**-4,46%**
EVHIGH3	43 213,0	5 957,3	40 944,4	**-5,25%**

Source: Own calculations (based on Projection of Greenhouse Gas Emissions 2007-2025)

4.4.3.5. Summary of results per scenario

Despite the fact that large scale introduction of EVs is associated with immediate social costs, the environmental benefits of each scenario should not be overlooked. In case of the EVLOW scenario, it is clear that environmental savings in monetary terms are very limited with savings achieved only due to reduction of noise (5 per cent) and GHGs (3 per cent), while costing the Danish Government additionally some 240 million euro. On the other hand, the environmental benefits for EVHIGH scenarios are easily documented and include significant reductions in the emission of GHGs (up to 28 per cent in monetary values compared to BAU scenario – Fig 4.4.3.1-6) as well as noise (38 per cent). In addition, EVHIGH scenarios allow for a reduction of total Danish CO_2 emissions within a range of 4-5.25 percent, significantly helping to meet Denmark's obligations of the Kyoto Protocol while at the same time reducing the national dependence on external energy supplies (one of three major targets of the Danish Energy Policy). Moreover, given the EU target of 10 percent of biofuel vehicles (also including EVs) by 2020, it is clear that the Government of Denmark will need to sacrifice part of its tax revenue in order to push forward EVs on such a commercial basis.

On the other hand, environmental benefits of EVs mentioned above are to remain significantly offset by lack of improvements in the efficiency of other means of transportation. As indicated in 3.4.3.1., the major contributors to GHG emissions and air pollutants in the Danish road transport remain light duty vehicles, heavy duty trucks and buses. This further highlights the limited impact on environment even when Denmark manages to reach a high share of EVs in the passenger car park, as other motor vehicles will continue emitting significant levels of emissions (unless significant efficiency improvements are to take place).

4.4.3.6. Limitations of CBA

"Cost-benefit analysis is a very important tool for support of rational decision making. But in the context of climate change it is faced with some difficulties" (Nestle, in Hansjurgens & Antes, 2008:24). The major issues concerning the use of this approach include the estimation of parameters such as the damage costs. Therefore comparison of current costs to future uncertain impacts of climate change has many disadvantages which may lead to a spectrum of diverse results when comparing various cost-benefit analyses. Within this study, the monetary values for environmental damages (for an overview of major damages associated with climate change see Appendix 26) have been taken from the EC Handbook on estimation of external costs in the transport sector (2008). According to the Stern Report as well as other authors, however, the monetary costs of environmental pollution and climate change are far higher than as suggested by previous studies.

The social costs/benefits analysis of EVs presented above proved to be socially unprofitable. Nevertheless, it has to be taken into account that the analysis concerns only immediate impacts of various scenarios at one point in time – the year 2020. Thus, this rather static model does not include the benefits of low carbon emissions for the future generations and the study of immediate impact on social welfare in a given period is in this respect restricting. This is another drawback of the approach, as one can assume as Stern does, that major benefits of lower emissions policies are to be recorded in the second half of the 21st century. Hence there is a significant time lag between the year when costs occur and the benefits appear. Moreover, the social cost of carbon[11] (and other pollutants) is likely to be different in various points in time (in

[11] There are different approaches to carbon pricing. Within this paper, the "social cost of carbon" approach (more precisely, the societal cost of tonne of emission) is used as it measures the costs to society of a tonne of additional carbon emissions. The major advantage is the fact that it measures actual costs, which can then be compared to other costs/benefits, but on the other hand, the approach is linked with a high degree of uncertainties (for example how to value damage to the next generations) (www.foe.co.uk).

our case costs are based on 2001 values, but applied to the year 2020) as increased concentration of air pollutants and GHG leads to higher marginal damage (Stern, 2006). Within this study a cost of 40 euro per ton of carbon has been applied (a figure indicated by the EC), however as one can see in Fig 4.4.3.6-1 "monetary values of the same climate impact vary" significantly (Hohmeyer 2005, p. 164)

Fig 4.4.3.6-1 Examples of different carbon prices (2005 US dollars per ton of carbon)

Examples of different carbon prices (2005 US dollars per ton of carbon)											
Policy	**2005**	**2015**	**2025**	**2035**	**2045**	**2055**	**2065**	**2075**	**2085**	**2095**	**2105**
Stern	248.98	336.38	408.68	480.24	554.59	633.89	719.59	812.89	915.08	958.01	939.82
Gore	24.99	94.14	264.73	501.28	794.11	948.82	928.56	909.29	890.96	873.52	856.93
Kyoto with US	0.08	15.02	15.72	14.74	13.70	12.95	12.40	11.99	11.67	11.43	11.25
Kyoto w/o US	0.08	1.56	1.08	0.95	0.93	0.95	0.23	0.35	0.53	0.79	1.18
Kyoto strengthened	0.08	19.82	53.15	114.51	181.34	223.05	251.54	275.48	296.34	314.21	329.30

Source: Nordhaus (2008:93)

Given the number of difficulties associated with the cost estimations, researchers have been questioning the usefulness of CBA while assessing the benefits of particular climate change policies. On the other hand, as illustrated above the analysis of various levels of penetration of EVs on Denmark's emission levels serves as in ideal tool in assessing and comparing number of scenarios. The cost-benefit analysis therefore still represents a useful assessment tool for an evaluation of environmental impact of alternative policy initiatives.

4.4.3.7. Sensitivity analysis

As highlighted in 4.4.3.6. the monetary valuation of carbon emissions differs significantly from author to author. Carbon price of 40 euro per ton of CO_2 used within the social cost analysis is a value indicated and commonly used by the EC. Naturally, if other carbon values are used for calculation, the results of the identical analysis are strikingly different. Fig 4.4.3.7-1 and Fig 4.4.3.7-2 below present the total social MNB using Stern's and Gore's estimation of future carbon prices (in this case 2025 values have been used).

Fig 4.4.3.7-1 GORE: Total social MNB per scenario

2020 Total social Marginal Net Benefit (MNB) using GORE's carbon price of 264.73 US dollars per ton of carbon									
		BENEFITS (Marginal Damage)				COSTS			
Scenario	Unit	Pollution	GHG emissions (CO2)	Noise	Total	Tax revenue loss	**Total social marginal net benefit (MNB)**	**Total social MNB per EV (euro)**
EVLOW1	mil. euro	-0,3	42,7	8,6	50,9	-255,6	**-204,7**	**-1 883,9**
EVLOW2	mil. euro	-0,1	46,8	8,6	55,2	-255,6	**-200,4**	**-1 844,1**
EVLOW3	mil. euro	0,2	55,1	8,6	63,9	-255,6	**-191,8**	**-1 764,5**
EVMED1	mil. euro	-1,3	170,7	34,2	203,6	-1 006,1	**-802,5**	**-1 846,0**
EVMED2	mil. euro	-0,6	187,3	34,2	220,9	-1 006,1	**-785,2**	**-1 806,2**
EVMED3	mil. euro	0,9	220,3	34,2	255,5	-1 006,1	**-750,6**	**-1 726,6**
EVHIGH1	mil. euro	-2,7	341,4	68,5	407,2	-1 863,6	**-1 456,4**	**-1 675,1**
EVHIGH2	mil. euro	-1,2	374,5	68,5	441,8	-1 863,6	**-1 421,8**	**-1 635,3**
EVHIGH3	mil. euro	1,9	440,7	68,5	511,1	-1 863,6	**-1 352,6**	**-1 555,7**

Source: Own calculations

Fig 4.4.3.7-2 STERN: Total social MNB per scenario

2020 Total social Marginal Net Benefit (MNB) using STERN's carbon price of 408.68 US dollars per ton of carbon								
		BENEFITS (Marginal Damage)				COSTS		
Scenario	Unit	Pollution	GHG emissions (CO2)	Noise	Total	Tax revenue loss	**Total social marginal net benefit (MNB)**	**Total social MNB per EV (euro)**
EVLOW1	mil. euro	-0,3	65,9	8,6	74,1	-255,6	**-181,5**	**-1 670,4**
EVLOW2	mil. euro	-0,1	72,3	8,6	80,7	-255,6	**-175,0**	**-1 609,9**
EVLOW3	mil. euro	0,2	85,0	8,6	93,8	-255,6	**-161,8**	**-1 488,9**
EVMED1	mil. euro	-1,3	263,5	34,2	296,4	-1 006,1	**-709,6**	**-1 632,4**
EVMED2	mil. euro	-0,6	289,1	34,2	322,7	-1 006,1	**-683,3**	**-1 571,9**
EVMED3	mil. euro	0,9	340,2	34,2	375,3	-1 006,1	**-630,7**	**-1 450,9**
EVHIGH1	mil. euro	-2,7	527,1	68,5	592,9	-1 863,6	**-1 270,7**	**-1 127,0**
EVHIGH2	mil. euro	-1,2	578,2	68,5	645,5	-1 863,6	**-1 218,1**	**-1 080,4**
EVHIGH3	mil. euro	1,9	680,3	68,5	750,7	-1 863,6	**-1 112,9**	**-987,1**

Source: Own calculations

As documented in the calculations above, the use of different monetary values of carbon prices has significant impact on the final results of the social costs analysis. A summary of possible results is presented in Fig 4.4.3.7-3 by using recommendations on carbon prices from three various sources: the EC (values used within this study), Gore and Stern. The table clearly shows that the level of "subsidy" per each EV differs significantly when using various levels of carbon valuation (EVHIGH3 scenario shows the most striking differences ranging between 1,958 euro and 987 euro).

Likewise, different valuation of other variables of the model, for example noise or other air pollutants, would have similar effects.

Fig 4.4.3.7-3 Comparison of differences between social MNB per EV

Comparison of total social MNB per EV (euro) using various estimations on carbon price			
	EC	**Gore**	**Stern**
EVLOW1	-2 196	-1 884	-1 670
EVLOW2	-2 186	-1 844	-1 610
EVLOW3	-2 167	-1 765	-1 489
EVMED1	-2 158	-1 846	-1 632
EVMED2	-2 148	-1 806	-1 572
EVMED3	-2 129	-1 727	-1 451
EVHIGH1	-1 987	-1 675	-1 127
EVHIGH2	-1 977	-1 635	-1 080
EVHIGH3	-1 958	-1 556	-987

Source: Own calculations

However, although the social costs decline with higher values for carbon emissions (for example Stern's values), the analysis still shows that an introduction of EVs (in any degree of penetration) is socially unprofitable. What would then have to be the price of carbon emission for EVs to be beneficially in Denmark in 2020, thus yielding a final result of social MNB equal to zero for all scenarios? Fig 4.4.3.7-4 summarizes these values with the lowest value documented for the EVHIGH3 scenario at a level of some euro 790, thus still running at nearly double the value of Stern's recommendations. Nevertheless, one should keep in mind that the values below are heavily dependent on the peculiarities of the Danish market with its profound system of taxation.

Fig 4.4.3.7-4 Recommended monetary values of carbon emissions

Monetary values (in euro) of carbon emissions for each scenario to be socially profitable (MNB = 0)								
Denmark 2020 EVLOW			Denmark 2020 EVMED			Denmark 2020 EVHIGH		
EVLOW1	EVLOW2	EVLOW3	EVMED1	EVMED2	EVMED3	EVHIGH1	EVHIGH2	EVHIGH3
1 126,2	1 025,9	870,5	1 107,4	1 008,8	855,9	1 022,9	931,7	790,5

Source: Own calculations

To conclude, the use of different monetary values of carbon emissions is indicative of the limitations faced by environmental economists when assessing the economic impact of climate change policies.

5. Discussion of results

The major purpose of this paper was to calculate the immediate social costs/benefits in the year 2020 associated with Denmark's plans to become a world leader in the share of EVs among passenger vehicles and if the Government of Denmark should support this plan by various forms of subsidies or tax incentives. The social CBA conducted above proved that the decrease in marginal damage in a form of environmental benefits is rather low in comparison with the loss in tax revenue that the Government would face in 2020. This is, of course, depending on a number of assumptions and unknowns considered within the analysis (such as highlighted in section

4.4.2.1.) as well as the limitations of the social CBA approach (see 4.4.3.6.). Nevertheless, the negative results of the analysis failed to refute the general belief that climate change policies are growth restricting, at least in the short-term (the previously mentioned time lag between the year when costs occur and the benefits appear, in this case social costs faced by the Danish public in 2020 could have hindering effects on the economic growth at that point in time which, however, in turn is met by reductions in negative impacts of climate change in the second half of the century)[12]. Taking into account a long-term global perspective allows for a better understanding of other potential costs and benefits initially not considered within the traditional concept of social CBA. As critics often complain, economists count what they can count, and not necessarily what counts (Manne, 1995:18). To help understand this issue, theory of induced technological change is to be applied.

5.1.1. EVs as induced innovation in climate change policy

The theory of induced technological change is usually referred to, in connection with the new growth theory (Lucas (1986) and Romer (1990)) and builds upon the assumption of endogenous technological change. To link this to the case of EVs, one could assume that increased investments (in our case for example in a form of tax incentives or "subsidies") in this particular vehicle technology will lead to improved productivity of the sector and eventually to higher long-run growth rate of the economy. According to Nordhaus (2002:275) induced innovation strategy leads to reductions in carbon emissions, however, the reduction is rather limited in the early decades while increasing significantly in the long-term. This notion could partly be explained by balancing other costs and benefits of EVs within the framework of induced technological change.

5.1.2. The costs of mitigation policies – speculating about the case of EVs

In the analysis of Denmark, the costs associated with the nation-wide introduction of EVs included the social marginal net costs originating from reduced tax revenues (although partly offset by environmental benefits), ceteris paribus. These are the direct social costs faced by the Danish society in 2020 unless other corrective measures are adopted in the meantime. Nevertheless, by taking into consideration the global perspective, there are additional costs associated with the commercial introduction of radically new vehicle type in the market:

1. Direct engineering costs (Edenhofer et al, 2006:70) which include costs of research and development into new technology development, particularly research in batteries, vehicle materials and charging stations

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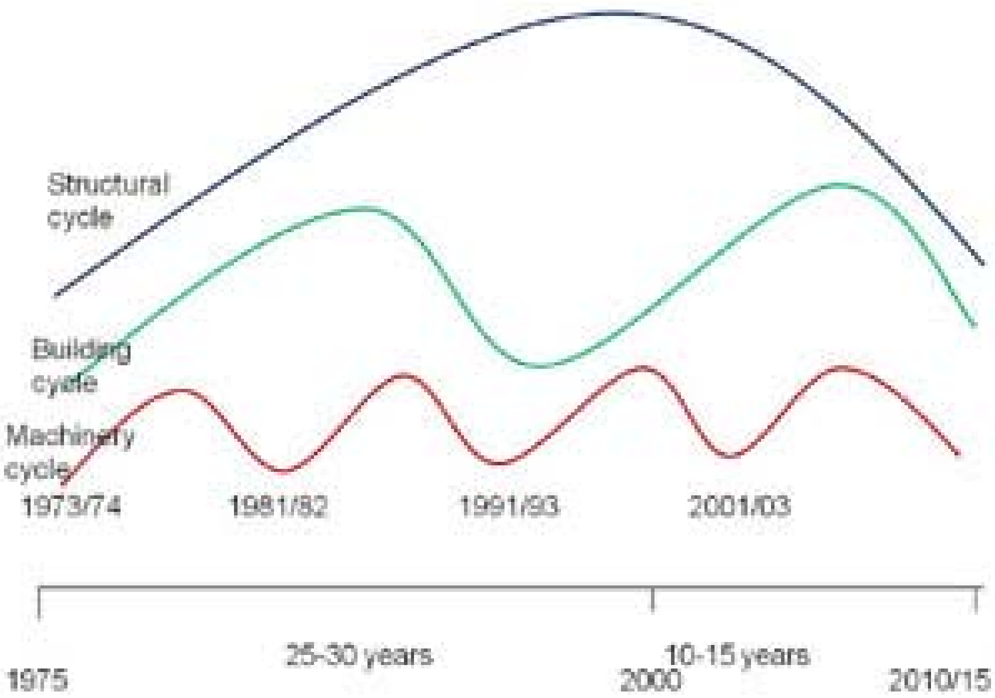
[12] This is supported by the results of the Stern report (2006). According to Stern, if no action is taken to reduce the global CO_2 emissions, the total costs of climate change caused by rising emission levels, will be 5 per cent of global GDP at the very minimum from now and forever (and other less conservative estimates forecast a GDP reduction of up to 20 per cent). However, despite these gloomy expectations Stern at the same time stresses out that there is still time to avoid the worst impacts of climate change, if immediate action is taken. Therefore, the investments made in the following 10-20 years will have a significant impact on the global climate in the second half of 21st century and consequently on its economic development.

2. The costs associated with the reduction of investment in other areas, such as hydrogen or biofuel vehicles. Although at a moment research is concentrated in various areas of AFVs, it is likely that if there is a signal that EV research is to be profitable, a share of investment funds will be poured over into this area, while R&D in other technologies might be put on hold (Popp, 2006:608).

3. Economic costs for a specific sector of the industry - the costs of the structural change as obsolete industries are pushed out of the market. This concerns the car manufacturing industry in particular, which is believed to be severely hit by the current financial/economic crisis. According to Schon's (1998) theory on industrial crises, the global economy is approaching a structural crisis at a moment (Fig 5.1.2-1). Structural crisis is often preceded by a process of rationalization as resources and investments are used in order to increase efficiency in existing production branches, while at the same time an early development of particular innovation takes place. Many industries, often profitable decades ago and consuming vast amounts of investments, gradually become obsolete and the sudden breakthrough in new technologies leads to a structural crisis causing demise of these industries. Following this, resources start to pour to new knowledge which creates blocks with new competencies slowly diverging from the leading centers to peripheries. Moreover, the investments into new areas increase gradually since the start of the crisis and result into a new market technology about a decade after with slow, but increasing profitability. This theory, often referred to as endogenous growth theory, could clearly be linked to the current situation in the automobile industry. Pressured by high fuel prices and the ongoing discussion about the impacts of global warming, which cars of nowadays are rather significant contributors to, many policy makers are calling for immediate action in the industry. A structural crisis, which we are facing at the moment, could eventually give way to increasing investments in EVs that after some 10 years result in new development blocks having a fundamental impact on the future industry growth rates (Schon, 1998:408). The research in AFVs, in our case EVs, slowly progresses and if clear policies are established supporting further diffusion of this technology, it is likely that investments within this field will grow exponentially while making current automobile industry obsolete. The victims of this crisis are then believed to be primarily large multi-national car corporation (US and European car producers), having secondary effects also on other geographical regions, where car production is concentrated. On the other hand, battery manufacturers or car producers committing resources in R&D of EVs are likely to be the winners, together with other supporting industries, such as electricity suppliers. It is difficult to estimate, what actual costs the structural crisis of the automobile industry is likely to have in case of Denmark. Denmark does not have any car production facilities but is a supplier of various car parts. However, all economies undergo some form of structural change and only economies, which are flexible enough to accommodate change and innovation, are to be successful (Stern, 2006).

   Similarly, costs associated with further expansion of the Danish wind system (together with the whole structural change in the Danish energy system) are to be mentioned.

Fig 5.1.2-1 Structural cycles



Source: www.ekh.lu.se

5.1.3. The benefits of mitigation policies – speculating about the case of EVs

Much has been talked about the costs of mitigation policies and the benefits often remain overlooked, except for the fact that major benefits stem from avoiding the potential negative consequences of climate change. But abatement costs can actually facilitate growth if new technological knowledge is created and realized. The major benefits of new induced technology on economic growth could then be summarized as follows:

1. Increased efficiency in the particular sector where new knowledge is implemented (Golub et al, 2006:527). In case of EVs, investments into research and development could fuel further efficiency improvements of the technology, resulting in higher driving ranges and increased engine and battery efficiencies. This assumption is supported by a scientific evidence of the existence of mathematical relationship between the use of new technology and its efficiency; implying that efficiency increases by 70-90 per cent "for each doubling of the cumulative use of a particular energy technology" (ibid:526). Similarly, the utilization of batteries in other road vehicles - light duty vehicles, heavy duty trucks and buses – could prove beneficial, leading to further significant emission savings.

2. Spillover effects onto other sectors which in case of EVs could lead to increased efficiency in for example batteries but also in wind turbine industry which could create a large business opportunity for Denmark. Section 3.4.1.1. highlighted the issues concerning the increasing amounts of excess electricity produced by Danish windmills and the need for energy storage capacities in order to maximize the economic returns of the investments in the Danish energy system. EVs do represent a suitable technology in

this respect. Moreover, as indicated in section 4.4.2.2. 50 per cent share of wind in the national electricity grid will lead to an excess electricity production of 17 per cent, which is more than enough to fully charge a passenger vehicle fleet consisting of 40 per cent EVs.

3. Generally increase in productivity growth, however likely with a significant time lag of 20-30 years as experienced with the diffusion of other technologies in the past. Nation-wide diffusion of EVs may in a longer term lead to higher total factor productivity as a result of improvements in the use of resources (wind energy) and reduced depletion of natural resources.

6. Conclusion

The major purpose of this paper was to critically assess the Danish Government's plans to implement a program for a nation-wide diffusion of EVs. With the recent revival of interest in Denmark, EVs are often thought of as profitable not only for the end consumer, but also on a socio-economic scale given that improvements to the environment can be, to some extent, measured in monetary value. However, this study shows that the reductions of environmental costs are by far offset by the decrease in tax revenues faced by the Danish Government, given a sudden rise in sales of EVs (Fig 4.4.3.3-1). In the case of Denmark the tax revenue losses are of such a magnitude that any potential reductions in costs related environmental damages seem insignificant.

Evidently, replacing conventional ICEVs with EVs will reduce GHGs, (some) air pollutants and noise. However, one should keep in mind that even with high replacement rates, EVs potential contribution to environmental savings are rather small in the overall picture (Fig 4.4.3.1-1). Furthermore, high replacement rates are associated with high implementation costs. The technology of EVs does aid combat the growing emissions in the transport sector; however, it is clearly only one of many possible solutions available. Thus, only a combination of technologies (HVs, biofuel, hydrogen as well as improved efficiency of ICEVs) and a variety of regulatory measures (for example road pricing or taxation based on vehicle's efficiency) is the solution to the environmental challenges of the transport sector. No single technology is capable of doing the entire task.

The question is to what degree the Danish Government should focus its research and public financial resources on EVs, whose environmental impact is so limited. However, there are other potential benefits linked to the diffusion of this technology which in the future are likely to foster growth and increased efficiency in other sectors, such as wind energy. Further research is, however, needed in order to quantify these potential benefits, such as increased sector efficiency or spillover effects. Moreover, as Stern notes, investments in efficient and green technology made in the coming 10-20 years are crucial to limit the worst impacts of climate change in the second half of the 21st century and consequently also its negative impact on economic growth. Hence, such investments in green technology, albeit linked to high immediate costs (as shown by this paper), can be accompanied by other benefits of induced innovation (section 5.1.3.) having a positive impact on the long-term economic development. Perhaps in the end, green tech could even represent such a radical innovation to become the driving force behind the next industrial revolution.

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