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The road to meeting Norway's non-ETS climate goal in 2030

- Is an electric vehicle subsidy the way to go?

Carl Frederik Kontny
Master of Science in Economics

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I take full responsibility for any mistakes and omissions in the thesis.

Oslo, June 2017.

ABSTRACT

As part of Norway's obligations to the Paris agreement, a suggested 40% of greenhouse gas (GHG) emissions must be cut in the non-ETS sectors in 2030, compared to 2005-levels. Flexible mechanisms for non-ETS sectors to complete parts of their required mitigation abroad are currently being discussed, but mitigation activities thus far have had to be completed at home. The greatest source of non-ETS emissions in Norway stem from road traffic. Norwegian authorities provide generous incentives for purchase and use of electric vehicles as a policy to reduce emissions from this sector. While there are positive externalities associated with an immature technology like electric engines, electric vehicles also produce many of the same negative externalities associated with conventional cars.

In this thesis we create a computable general equilibrium (CGE) model of the Norwegian economy in 2030. This model is used to analyse the welfare changes from meeting the non-ETS climate goal in 2030 by subsidising electric vehicles. We then compare this policy to a uniform, non-ETS carbon tax. We find that the electric vehicle subsidy is four times more expensive than the carbon tax, measured in welfare costs for the representative consumer. This result is discussed in light of dynamic effects and factors outside the model.

SAMMENDRAG

Som en del av Norges forpliktelser til Parisavtalen er det foreslått et reduksjonsmål for ikke-kvotepliktig sektor 40 % under utslippsnivået i 2005. Det forhandles om fleksible mekanismer for ikke-kvotepliktig sektor så deler av målet kan nåes ved utslippskutt i utlandet, men foreløpig må utslippsreduksjoner skje hjemme. Den største utslippskilden i ikke-kvotepliktig sektor i Norge er veitrafikk. Norske myndigheter gir store fordeler til kjøp og bruk av elektriske biler som virkemiddel for å redusere utslippene fra denne sektoren. Det er positive, eksterne virkninger i støtte til umodne teknologier som elektriske motorer, men elektriske biler produserer også mange av de negative eksternalitetene forbundet med konvensjonelle biler.

I denne analysen lager vi en computable general equilibrium (CGE) modell for norsk økonomi I 2030. Denne modellen bruker vi til å analysere velferdsendringene som følger av å møte ikke-kvotepliktig sektors klimamål for 2030 ved å subsidiere elbiler. Deretter sammenligner vi dette politikkalternativet med en uniform karbonskatt for ikke-kvotepliktig sektor. Vi finner at et elbil-subsidie genererer et velferdsstap for en representativ konsument som er fire ganger større enn om vi hadde møtt klimamålet med en uniform karbonskatt. Dette resultatet diskuteres i lys av langsiktige virkninger og effekter utenfor modellen.

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1 INTRODUCTION

1.1 SHORT BACKGROUND

The combination of a growing global population and a larger world economy is increasingly putting pressure on scarce, natural resources. The associated greenhouse gas emissions of our production and consumption patterns now outpace the rate at which natural sinks can absorb them, causing them to accumulate in the atmosphere and cause harmful climate change. This poses a direct threat to the livelihood of millions of people, and is widely considered one our time's largest challenges (IPCC 2013).

To address this issue, strong global collaboration is needed. December 2015 saw 195 countries adopt an internationally binding climate agreement for the first time, aiming to limit global warming to a maximum of 2 degrees Celsius and preferably to 1,5 degrees (United Nations 2015). In contrast to previous top-down attempts at reaching a deal, the Paris agreement uses a bottom-up approach, collecting intended nationally determined contributions (INDCs) to share the burden of climate mitigation. This has been praised by many as the key for its successful adoption. Further, a certain degree of flexibility in meeting the INDCs is ensured by allowing countries to implement mitigation activities both at home and abroad. The degree of flexibility has direct consequences for how cost-efficient the countries can be in meeting their climate obligations (Aune & Fæhn 2016).

For EU/EEA countries, this flexibility is operationalized through the EU emissions trading system (EU ETS). The EU ETS is the world's largest cap-and-trade system, covering in excess of 11,000 installations in power and heat generation, energy-intensive sectors, and commercial aviation - in total around 45% of the EU's greenhouse gas emissions (European Commission 2017). Cap-and-trade systems are designed to ensure that mitigation efforts are completed in the least-cost way possible by allowing agents with high marginal abatement costs to purchase quotas from agents that can cut emissions cheaply, lowering the total abatement cost. Allowing emission permits to be traded freely will, given perfect markets, ensure that mitigation activities are done cost-effectively.

Norway's obligation to the Paris agreement is a 40% reduction of total greenhouse gas (GHG) emissions in 2030 compared to 1990-levels (St.meld. nr 13 (2014-2015)). The abatement efforts are split between sectors covered by the EU ETS (the ETS sector) and those outside it (simply referred to as the non-ETS sector). For the ETS sector, the goal is the same as for the EU; 43% below 2005-levels (Erichsen et al. 2014). ETS cuts can be made by allowance trading, taking advantage of opportunities to lower total abatement costs by financing cuts abroad in other EU/EEA countries. Still, about half of Norwegian emissions stem from the non-ETS sector, crudely made up of transportation, agriculture, and buildings. While yet to be decided, the suggested non-ETS reduction target for Norway is set to 40% compared to 2005-levels. The largest potential for reducing non-ETS emissions is found in the transport sector; one fourth of Europe's emissions, and one third of Norway's, stem from this sector alone (MDIR 2016).

Norwegian authorities have so far opted for generous support for electric vehicles (EVs) in both purchase and use to bring down emissions from the transport sector. EV incentives were originally meant to be phased out after 50.000 EVs were on the road, but are now extended until 2020 and possibly longer despite the current count surpassing 100.000 (as of March 2017, Norsk elbilforening 2017). This prompts the question: are electric vehicle subsidies a cost-effective policy to meet Norway's 2030 climate obligation for the non-ETS sector?

1.2 Contribution

The focal point of this thesis is the Norwegian transport sector, and particularly emissions associated with private transportation. To comply with the climate goal for non-ETS in 2030, *greenhouse gas* (GHG) emissions from these sectors must not surpass 16.5 Mtons CO_2 equivalents (CO_2e). However, in our model, we strictly look at CO_2 emissions, not other GHGs, as CO_2 is the most relevant greenhouse gas from transportation. The climate goal for CO_2 emission from non-ETS sectors is found to be 14.0 Mtons.

We analyse two ways of meeting this target. In scenario one (S1), a uniform carbon tax is implemented on the use of fossil energy in non-ETS sectors. This is the approach that economic theory prescribes; a direct tax on the negative externality, set at a uniform rate to ensure the cost-effectiveness of the policy. In scenario two (S2), the goal is met by subsidising electric vehicles. The second scenario is chosen to illustrate the effects of an amplification of current EV policy.

We model the Norwegian economy in 2030 in a computable general equilibrium (CGE) model and analyse the economy-wide, general equilibrium effects of both policies. This gives us estimates for the welfare costs associated with each policy, which I will discuss in the light of potentially beneficial long-term effects of domestic mitigation. In practice, an optimal policy mix is likely achieved by balancing the two policy options, and perhaps combine them with other policy measures. However, we have chosen to analyse two stylised policy tools to meet the 2030 climate target. The purpose of this is to help guide policy and strike a balance between the two suggested alternatives.

1.3 PROBLEM STATEMENT

I will throughout this thesis try to answer the following questions:

- **Should an electric vehicle subsidy be the main policy to meet Norway's non-ETS climate obligation in 2030?**
    - At what rate must the subsidy be set to meet the reduction goal?
    - At what rate must a uniform non-ETS carbon tax be set to meet the goal?
    - What are the policy costs of either alternative?

1.4 STRUCTURE

The remainder of this thesis is structured as follows. In chapter 2, I present the Norwegian obligation to the Paris agreement and the potential to reduce emissions from the transport sector. This chapter also includes a review of both historical and current incentives aimed at cutting emissions from private transportation and accounts for the externalities that might justify government intervention in this market. Chapter 3 proceeds to lay out the relevant economic theory for this research. Building on that foundation, I present Computable General Equilibrium (CGE) modelling as a method in chapter 4. Chapter 5 presents the data and research design before the analysis is conducted in chapter 6. Chapter 7 provides a discussion of the dynamic effects of domestic mitigation activities and of supporting clean technologies, which are not captured by the model. Finally, concluding remarks and suggested future research is presented in chapter 8.

2 BACKGROUND

2.1 THE PARIS AGREEMENT

Norway signed the Paris Agreement in April 2016 along with 174 other countries committed to limiting global warming to a maximum of 2 degrees Celsius, and to '… *pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius'* (United Nations 2015). The agreement entered into force on November 4th 2016, thirty days after the last of 55 countries, accounting in total for at least an estimated 55% of the total global greenhouse gas emissions, deposited their instruments of ratification. For Norway, the climate obligation to the Paris Agreement implies a total cut of greenhouse gas (GHG) emissions of at least 40% below 1990-levels by 2030, the same goal as for the European Union (St.meld. nr 13 (2014-2015)). The intended, nationally determined contributions (INDCs) are ambitious, but currently not enough to meet the stated 2 degree target (Peters et al. 2017). Thus, evaluating the goal effectiveness and cost efficiency of available policy tools is a crucial contribution to meeting the climate challenge with an appropriate response.

2.2 EU ETS

In Europe, the obligations to the Paris Agreement can in part be met by allowance trading in the EU Emission Trading System (EU ETS). The EU ETS is the world's largest cap-and-trade system, a market-based mechanism designed to minimize the total abatement cost of meeting a set reduction target (*see chapter 3*). The EU ETS was established in 2005. Between 2005 and 2007, the system went through a trial trading phase intended to test the infrastructure and rules of trading rather than to achieve large CO_2 reductions (Hood 2010). Since then, the system has developed through a series of trading phases and the rules for trading, how permits are allocated, and the size of the total cap have been adjusted between each phase to ensure the efficiency of the system. The EU ETS is now in its third trading phase (2013-2020) and covers more than 11.000 power stations and industrial plants, offshore industries, and airlines operating between the member states – about 45% of the European Union's GHG emissions (European Commission 2017).

While not a member state in the European Union, Norway has been included in the EU ETS since 2008. Prior to the EU ETS inclusion, Norway had a national ETS system established in 2005 that covered about 11% of domestic emissions. This national ETS was partly connected to the EU ETS as Norwegian companies could purchase EU permits, but European companies were unable to purchase permits in Norway. Following the inclusion in the EU ETS, more Norwegian sectors were incorporated, including the offshore, petrochemical and wood processing sectors (Stokka 2015). Today, 51.8% of emissions from Norwegian territory are covered by the EU ETS (Statistics Norway 2017), thus allowing for large parts of the obligation to the Paris Agreement to be met through allowance trading. Norway has a common goal with the EU of reducing emissions from the ETS sector by 43% compared to 2005-levels by 2030.

2.3 Non-ETS

The sectors outside of the EU ETS are by convention simply referred to as the non-ETS sectors. The main sources of emissions from non-ETS sectors are transportation, agriculture, buildings, and waste management (Statistics Norway 2017). The EU has set a reduction target for the non-ETS sector at 30% below 2005-levels by 2030. This is translated into individual, binding targets for member states of the European Union. These reduction targets are calculated on the basis of GDP per capita, ranging from 0-40% below 2005-levels by 2030. Norwegian authorities have expressed a wish for a common solution with the EU also for non-ETS sectors. No official target has been set as Norway is not a member of the European Union, but the European Commission has suggested a preliminary emissions reduction target at 40% by 2030. This is the same as given to Sweden and Luxembourg - comparable countries in terms of GDP per capita (Ministry of Climate and Environment 2016).

2.4 Flexibility

2.4.1 Available mechanisms

Norwegian climate policy is based on a principle of cost-effectiveness and promotes policy measures that maximize the carbon abatement for the resources allocated to mitigation activities (St.meld. nr 21 (2011-2012)). Economic theory suggests that this is achieved by allowing for as much flexibility as possible to ensure that mitigation activities undertaken where they are the cheapest. As discussed, flexibility is already fully operationalized through allowance trading for the ETS sector. For the non-ETS sector, however, none such flexible mechanisms are yet confirmed. The EU does not allow countries to meet their reduction targets by paying countries outside of EU/EEA to mitigate. Further, existing systems like the Clean Development Mechanism, a source of flexibility in meeting the abatement targets under the Kyoto Protocol (UNFCCC 2014), are being phased out by 2020 in the EU. However, flexible mechanisms at the EU level are currently being discussed and three mechanisms have been suggested by the European Commission. Firstly, countries with high reduction targets can be allowed to complete a limited purchase of ETS quotas for their non-ETS emissions. Secondly, countries might be allowed to make limited use of credits from mitigation activities in forestry and land use change (St.meld. nr 1 (2016-2017)). Thirdly, and perhaps most importantly, countries can form bilateral agreements to buy and sell non-ETS ‘quotas’ – direct payments for mitigation activities.

Policy cost analyses conclude that a greater level of freedom in meeting non-ETS climate obligations significantly reduces total abatement costs. Aune and Fæhn (2016) estimate the price of an emission permit for a hypothesized, fully flexible system both across ETS and non-ETS sectors and across Norway and the EU (modelled as one entity) to be NOK 450/ton CO_2e. At the other extreme, the domestic uniform emission tax amounts to NOK 4 800/ton CO_2e with no flexibility for the Norwegian non-ETS sectors. This implies a doubling of the welfare costs compared to a fully flexible scenario.

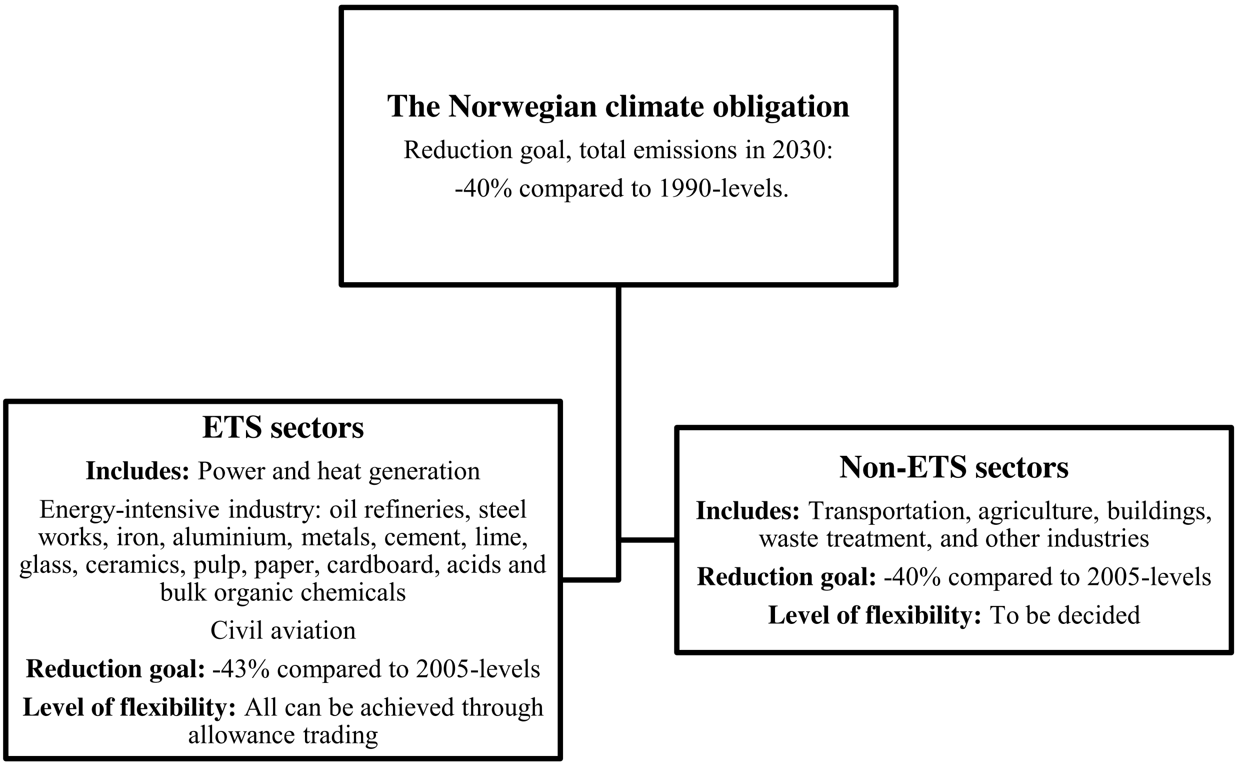

FIGURE 1: THE NORWEGIAN 2030 CLIMATE OBLIGATION.

Figure 1 summarizes Norway's climate obligation to the Paris Agreement. Sector-specific goals are reported along with the degree of flexibility available to meet the suggested reduction targets. Note that the targets are for greenhouse gases (GHGs) measured in CO_2 equivalents (CO_2e). The focus in this thesis will be on CO_2, as this greenhouse gas is the most relevant for the transport sector. We find that the maximum level of CO_2 emissions allowed from non-ETS sectors in 2030 is 14.0 Mtons to meet the climate goal (*see section 6.1.2 for details)*.

2.4.2 Cutting emissions at home or abroad?

While flexibility is essential to meet reduction targets cost-effectively, there are widely different opinions regarding the level of required domestic action among the parties in international climate negotiations. The option to cut emissions abroad through flexible mechanisms in the Kyoto Protocol, the preceding climate agreement to the Paris agreement, is worded to be interpreted as only supplemental to sufficient domestic mitigation. Specifically, Article 6.1(d) states that 'the acquisition of emission reduction units shall be supplemental to domestic actions' (United Nations 1998). However, as the supplementarity requirement was never quantified in the Kyoto Protocol, the reliance on flexible mechanisms has varied greatly between the parties. Some parties argue that the cost-efficiency criteria should form the basis for climate policy and allow maximum flexibility. Other parties point to political, social, and ethical reasons for preferring domestic mitigation activities and that the concept of common, but differentiated responsibility necessitates a ceiling on flexibility (Platjouw 2009).

As previously stated, Norway's climate policy is focused on cost-efficiency and flexible mitigation. This is echoed in Platjouw's study (2009) where she writes that '*Instead of closing the gap on the Kyoto target by a combination of additional domestic measures and use of the flexibility measures, as most Annex I parties intend, Norway aims to acquire a considerable amount of emission reduction units from other countries'*. The level of domestic action Norway should aim for when working towards their 2030 climate target has spurred fierce debate dividing the political landscape (Gullberg & Aakre 2015). While targeted, national policy has cut emissions by an estimated 11 million tonnes CO_2e between 1990 and 2004 compared to a business-as-usual scenario (Norwegian Ministry of the Environment 2005), total emissions have increased by 5% in the period 1990-2013 (Statistics Norway 2017). This has potential detrimental effects on the image and negotiating power for Norway as a climate nation, especially when put next to comparable Nordic countries who have cut theirs significantly - Denmark by 22% and Sweden by 18 % (Eurostat 2017). This further emphasizes the need to evaluate policies that reduce emissions domestically. The development of GHG from these three Nordic countries are compared in figure 2.

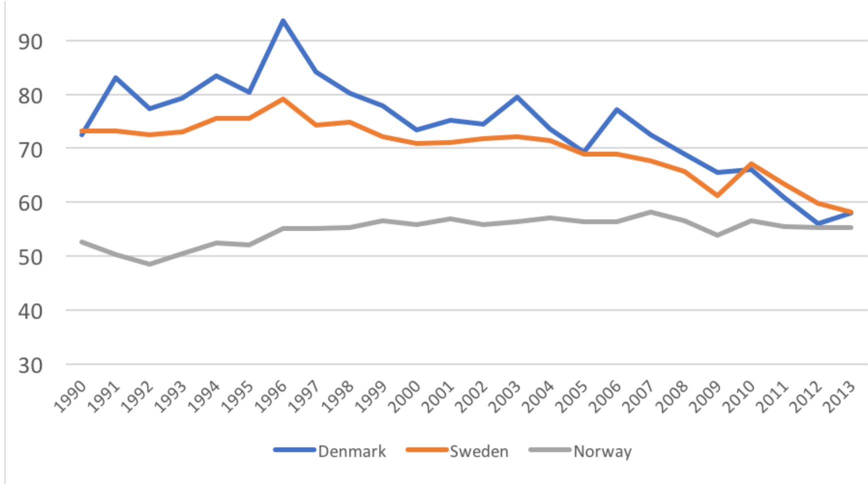

FIGURE 2: DEVELOPMENT OF GHG EMISSIONS BY COUNTRY, 1990-2013. MTONS CO2E.

2.5 NORWEGIAN EMISSIONS

The climate goal in the Paris Agreement sets specific reduction targets for GHG emissions measured in CO_2 equivalents (CO_2e). In 2015, Norway's total GHG emissions amounted to 53.9 Mtons CO_2e, 26.6 Mtons from ETS sectors and 27.3 Mtons from non-ETS sectors (Meld.St.29 (2016-2017)). Total emissions are capped in the EU ETS, but policy is needed also for the non-ETS sectors to meet their separate climate goal discussed in section 2.3.

Emissions from non-ETS sectors are mainly from buildings, agriculture and transport (*see figure 3*). Emissions from oil and gas are large, but covered by the EU ETS. So are most emissions from industry, which show a steady decline. The largest emissions from the non-ETS sector stem from transportation which are exhibiting an upward trend, supporting the argument that this is where climate policies should be directed.

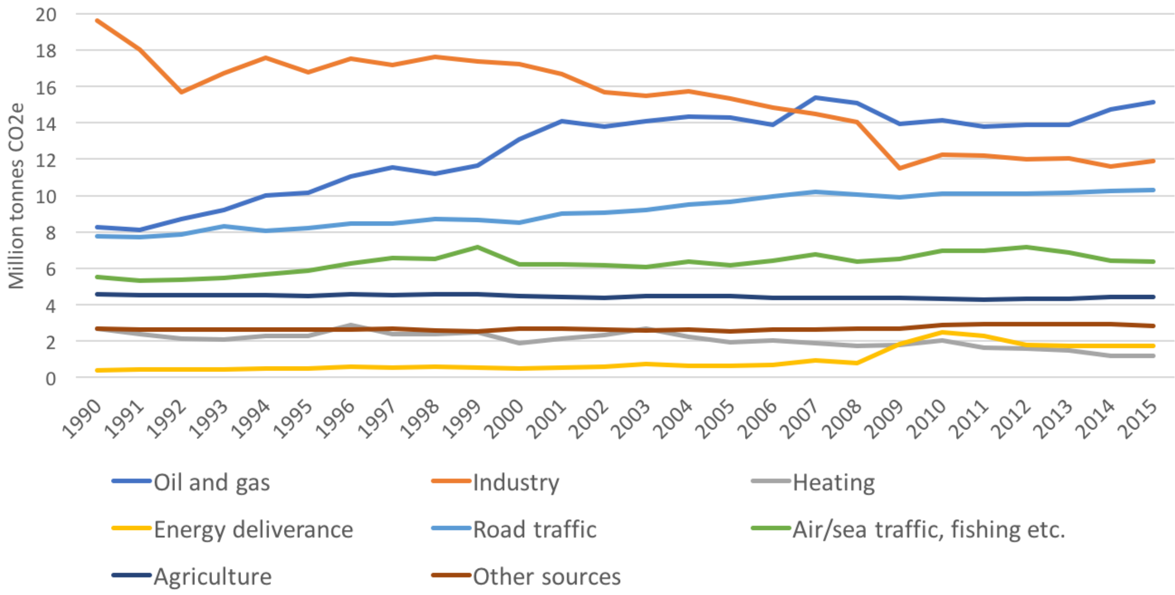

FIGURE 3: NORWEGIAN GHG EMISSIONS BY SOURCE, 1990-2015. MTONS CO2E (STATISTICS NORWAY 2017).

The four graphs in figure 4 below lets us take a closer look at the development of greenhouse gas emissions from the major non-ETS sectors, and it reveals a few critical insights. Firstly, emissions from agriculture have remained close to constant over the period at 4.5 million tonnes CO_2e. Technological advances to cut GHG emissions from agriculture are inherently hard as the majority consists of methane from livestock. Secondly, emissions related to buildings have been halved over the relevant period. While other European countries have much to gain by switching to cleaner energy when heating buildings, most of this potential is already harnessed in Norway as buildings are primarily heated by electricity from a hydropower dominant energy mix (IEA 2013). Strict policies are already in effect to phase out oil heating by 2020. Thirdly, emissions from transportation show an opposite trend to that of buildings; transport-related emissions have grown steadily since 1990. Finally, the fourth graph in figure 4 shows that increasing emissions from transportation are mainly from road traffic, which accounts for about 60% of the total. Consequently, the largest potential to reduce non-ETS emissions is likely found in policies geared towards road traffic, and its main source of emissions, private cars (MDIR 2015). This is a sector which is emitting increasing amounts of greenhouse gases, but also one in which clean technologies are on the rise. Policy options to cut emissions from private cars are therefore the natural focal point of this thesis.

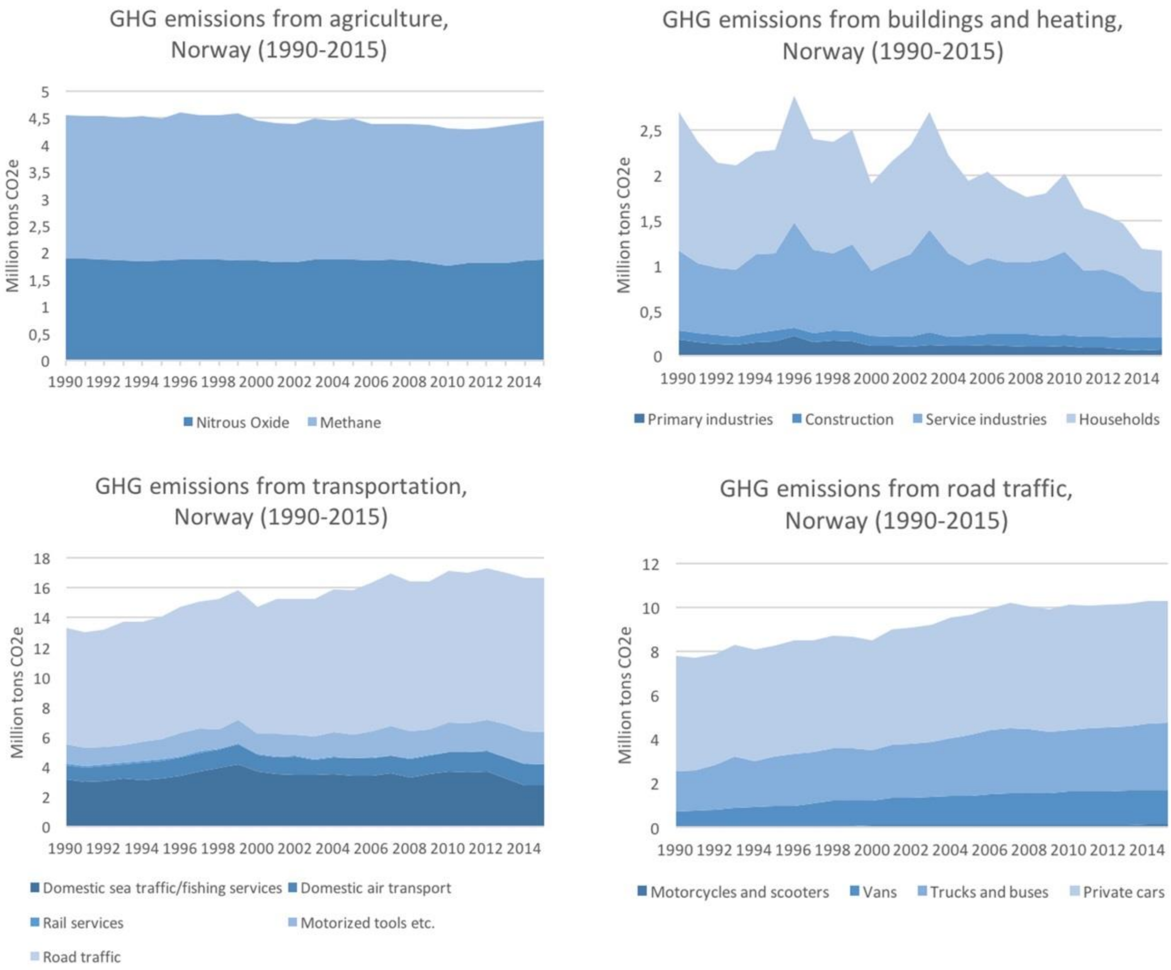

FIGURE 4: GHG EMISSIONS FROM NORWEGIAN NON-ETS SECTORS.

2.6 ROAD TRAFFIC EXTERNALITIES AND POLICIES

Road traffic is the source of a range of external effects (*see discussion of externalities in section 3.5*). The most prominent negative externalities include noise, congestion, road wear, local pollution from exhaust and particles, and global pollution from CO_2 emissions. Petrol and diesel have been subject to a national carbon tax since 1991 (Larsen & Nesbakken 1995). To further address the issue of GHG emissions from road traffic, Norwegian authorities have since 1996 given substantial incentives to purchase and to use electric vehicles (EVs) (Figenbaum & Kolbenstvedt 2013). EVs have several benefits compared to fossil fuel vehicles (FVs). They produce less noise pollution, have no on-road emissions, and upstream emissions from producing their fuel can be far less severe than their fossil fuel counterparts, depending on the source of electricity (e.g. hydropower or coal). Further, the production of the electricity used can be greatly diversified (Mersky et al. 2016).

Since the exemption from the registration tax introduced in 1996, incentives for electric vehicles have been added successively until the market responded sufficiently. Figenbaum & Kolbenstvedt (2013) summarized the benefits and investigated the importance of the various incentives (*see table 1*).

TABLE 1: ELECTRIC VEHICLE INCENTIVES AND THEIR IMPORTANCE FOR CONSUMERS.

Incentive	*Introduced*	*Importance*
Exemption from registration tax	1996	+
Reduced annual vehicle license fee	1996/2004	+
Free toll roads	1997	++
Free public parking (often with free charging)	1999	+
VAT exemption	2001	++
Access to bus lanes	2003/2005	++
Reduces rate on ferries	2009	0

Source: Figenbaum & Kolbenstvedt (2013).

When the incentives were first introduced, electric cars were a niche market with high production costs and less than a percent of total new car sale. However, in 2016, the market share for electric vehicles in Norway hit 15.7%, the highest in the world (European Alternative Fuels Observatory 2017). In the policy package 'Klimaforliket' (St.meld. nr 21 (2011-2012)) launched in 2012, owners of EVs were granted an extension of the existing, generous benefits until 2016 or 50.000 cars sold. The 50.000 mark was reached in April 2015 (Norsk elbilforening 2017), but the VAT exemption and exemption from registration tax are extended until 2020. Other incentives are to be decided locally (St.meld. nr 1 (2016-2017)).

In December 2016, the sitting government also enforced a requirement that by 2020, 20% bio-fuel should be mixed in with conventional petrol. While national emissions might be reduced as a result, experts disagree whether it will reduce, or in fact increase, global emissions. This has led the government to open for a retraction of the policy (Strand et al. 2017). The bio-fuel requirement will be omitted from this analysis because of the uncertainty surrounding its enforcement. Also, the requirement is more relevant for heavy-duty transport, air travel and shipping where electrification is more challenging. Finally, if the electric car market keeps up the current pace, demand for fuels, and by extension biofuels, will be less relevant.

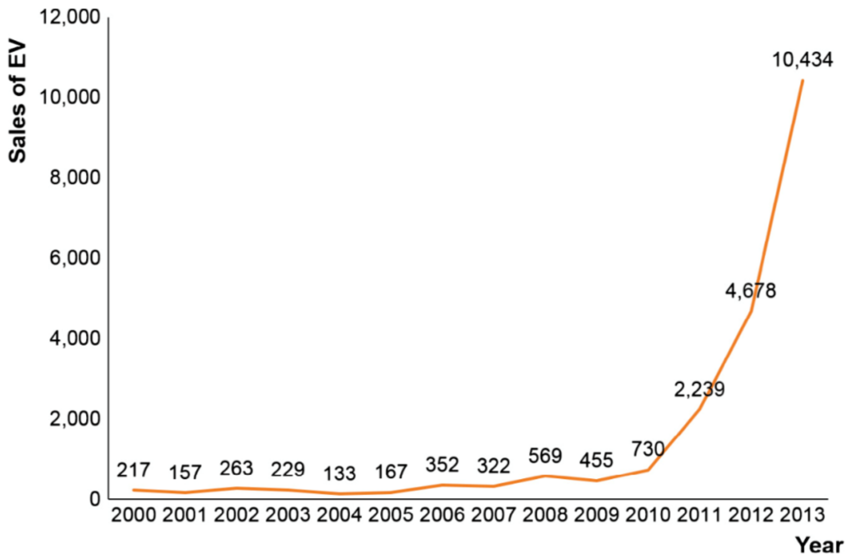

FIGURE 5: ELECTRIC VEHICLE SALES (2000-2013).

Source: Norsk elbilforening (Norsk elbilforening 2017).

Figure 5 shows the explosive growth in electric vehicle (EV) sales since 2000. The fact that EVs now account for 18% of the new car sale (Norsk elbilforening 2017) suggests that incentives for electric vehicles has been a goal-effective policy to increase the market share of electric vehicles. However, goal effectiveness – that is to what extent the policy achieves its intended purpose – can be a problematic metric, as it says nothing about whether the goal itself is desirable. It is not straight-forward to conclude that having as many electric vehicles on the road as possible is a desired goal. If the goal instead is to reduce GHG emissions, economic theory suggests that we should tax GHG emissions directly, not subsidize an alternative technology that is associated with lower emissions (Tinbergen 1959). By subsidizing electric vehicles, we also subsidize the negative externalities that they produce e.g. congestion, noise, and air particles, contrary to what economic theory prescribes.

Another important question is whether using EV incentives as the primary policy to reduce GHG emissions is a cost-effective way to meet Norwegian climate obligations to the Paris agreement. Some have voiced strong critique against this policy suggesting the policy cost is in the area of NOK 80.000 per reduced ton of CO_2 (Holtsmark 2012). Institute for Transport Economics, however, estimate the cost to be NOK 400-2500/ton CO_2 reduced and support the policy on the grounds that this must be compared to other domestic mitigation options, not the prevailing ETS quota price as some suggest, as there are no flexible mechanisms available to the non-ETS sector yet (Fridstrøm 2014). Finally, the Norwegian Environment Agency calculate the policy cost of ensuring that EVs make up 100% of the new car sale in 2030 to be NOK 1035/tCO_2e (MDIR 2016). This estimate is, unfortunately, based an outdated reference scenario. The reference scenario used predicts 80.000 EVs on the road in 2030. In March 2017 there were already 110.002 (Norsk elbilforening 2017). Hence, this report grossly overstates the number of fossil fuels replaced by electric vehicles in their scenarios, and as a result obtains a lower policy cost per reduced ton CO_2e.

While there have been many attempts at estimating the policy cost of electric vehicle incentives, there has, to our knowledge, not been a study of the general equilibrium effects and associated welfare losses in 2030. In this context, this research hopes to shed light on economy-wide effects on consumption and production, and their associated changes in welfare, from two different policy options available to meet Norway's climate target in 2030 – electric vehicle support or a uniform non-ETS carbon tax.

3 Relevant economic theory

3.1 The theoretical foundation for the model

Before presenting the methodology and data used in this research, this section will map out the relevant theory that underpins an Arrow-Debreu-style general equilibrium framework. This is the basis for our computable general equilibrium model and provides a micro-theoretical foundation that will later be complemented with empirical data. We will also discuss relevant climate economic theory in relation to externalities and the social cost of carbon.

3.2 Consumer theory

3.2.1 The representative agent

Standard consumer theory assumes one representative, rational consumer who maximizes utility subject to a linear budget constraint.

Utility function:
$$u = v(\boldsymbol{q}) = v(\ldots q_j) \tag{1}$$

Linear budget constraint:
$$\sum_{j \in J} p_j q_j = M \tag{2}$$

Here, utility u is obtained from consumption of the vector of goods, $\boldsymbol{q}$**.** The set of commodities is given by J, and q_j and p_j represent the quantity and price of commodity j respectively. Total income, equal to total expenditure by assumption is represented by M. In the context of this research, the representative consumer has income from renting out labour and capital as factors of production, as well as a net transfer of tax revenue collected by the public sector. This income is, by assumption, spent in its entirety on consumer goods produced domestically or imported to the economy.

The representative consumer has preferences over the various goods in the economy. Of particular interest here are his preferences for transportation modes given a designated budget share to spend on travel. His preferences are formalized using the utility function $v(\boldsymbol{q})$ that describes the utility obtained from a certain combination of goods. We assume well-behaved indifference curves where more is better (monotonicity), and where averages are preferred to extremes (convexity) (Varian 1992).

General utility functions are ordinal, meaning that they do not provide quantitative information about the level of utility, only that if $v_1(\boldsymbol{q}) < v_2(\boldsymbol{q})$ then the consumer prefers bundle 2 to bundle 1. However, when working with homothetic preferences - a class of utility functions that are homogenous of degree one – utility can be cardinalised (*see section 3.2.3*). Further, if we assume that all consumers have homothetic preferences, we can represent aggregate demand as that of one representative agent. This is a key assumption in our analysis, as we abstract away from heterogeneous preferences in households. However, and as pointed out by Aurland-Bredesen (2016), the 'representative agent'-approach does not rule out heterogeneous preferences, it merely assumes that the sum of all consumers behave as if it was only one consumer. Heterogeneity can then be thought of as an aggregated preference for diversity, which is captured in the parameters of the utility function.

3.2.2 CES Utility and the elasticity of substitution

To model consumer preferences over various consumption bundles and the utility obtained from these, we need to assume something about the form of the utility function. For the type of computable general equilibrium (CGE) modelling used in this research, it is common to use a special class of utility functions with homothetic preferences called *constant elasticity of substitution* (CES). As implied by its name, CES functions have the property that the elasticity of substitution, meaning the percent change in relative demand from a percent change in the relative prices, is constant.

CES functions are widely accepted by economists for CGE modelling as they provide an attractive trade-off between realism and simplicity, making them the work-horse functions of this type of applied work. Also, CES functions can be defined by their zeroth, first, and second order properties. This means that underlying technology or set of preferences is fully described by its location (price and quantity), slope (marginal rate of substitution), and curvature (elasticity of substitution). The modelling tool MPSGE (*see chapter 4*) recognizes these three arguments and generates the appropriate CES functions for the model automatically (Markusen & Rutherford 2004).

Of particular interest in our thesis is the elasticity of substitution between electric and fossil fuel vehicles in 2030. This can be interpreted as the inclination to increase the 2030 relative use of electric vehicles (EVs) to fossil fuel vehicles (FVs) for each percent increase in the relative user-cost of FVs to that of EVs. The elasticity of substitution is visually represented as the curvature of the indifference curve ranging from no substitutability ($\sigma = 0$) to perfect substitutability ($\sigma \to \infty$). The implications on the indifference curve are shown visually in figure 6.

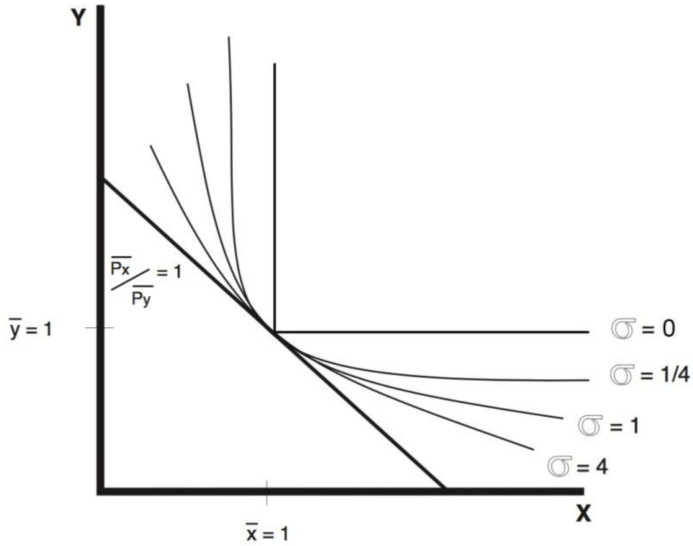

FIGURE 6: INCREASING LEVELS OF SUBSTITUTABILITY.

Constant elasticity of substitution (CES) utility functions for two goods are on the form

$$U(x, y) = (\alpha x^{\rho} + (1 - \alpha) y^{\rho})^{1/\rho} \tag{3}$$

where x, y are the commodity quantities and α is the share parameter. Further, ρ is a preference parameter between the goods. By applying a monotonic transformation, we can write $\sigma = \frac{1}{1-\rho}$ where σ is the elasticity of substitution. This ranges from zero (Leontief/no substitution) where goods are used in a fixed relationship and cannot be substituted, to infinity where the goods are perfect substitutes (ten Raa 2015).

3.2.3 Demand functions

From the direct utility function we get the Marshallian demand functions:

$$x(p_x, p_y, M) = \left(\frac{\alpha}{p_x}\right)^{\sigma} \frac{M}{\alpha^{\sigma} {p_x}^{1-\sigma} + (1-\alpha)^{\sigma} p_y^{1-\sigma}} \tag{4}$$

and

$$y(p_x, p_y, M) = \left(\frac{\alpha}{p_y}\right)^{\sigma} \frac{M}{\alpha^{\sigma} {p_x}^{1-\sigma} + (1-\alpha)^{\sigma} p_y^{1-\sigma}} \tag{5}$$

The corresponding indirect utility function is:

$$V\left(p_x, p_y, M\right) = M(\alpha^\sigma p_x^{1-\sigma} + (1-\alpha)^\sigma p_y^{1-\sigma})^{\frac{1}{\sigma-1}} \tag{6}$$

The utility function is linearly homogenous which means that V is homogenous of degree one in income M. This allows us to perform a convenient cardinalisation of the ordinal utility function, as percentage changes in U are equivalent to percentage Hicksian equivalent variations in income. The linear homogeneity lets us create an expenditure function which gives a price index we can interpret as the cost of one unit of utility.

$$e\left(p_x, p_y\right) = \ (\alpha^\sigma p_x^{1-\sigma} + (1-\alpha)^\sigma p_y^{1-\sigma})^{\frac{1}{1-\sigma}} \tag{7}$$

This allows us to rewrite the indirect utility function as:

$$V\left(p_x, p_y, M\right) = \frac{M}{e\left(p_x, p_y\right)} \tag{8}$$

Equation (8) states that the utility we can get given income M and prices p_x and p_y is equal to the income divided by the unit cost of utility. As pointed out by Markusen & Rutherford (2004), the homothetic preferences given by the linear homogeneity of the underlying utility function lets us represent utility like any other good in the economy. Specifically, and without loss of generality, we can interpret this as the consumer demanding only one good, utility.

3.2.4 Nested CES Utility for multiple goods

Multiple consumption goods can be modelled in subutility functions to the original utility function, a preference structure often referred to as a utility tree (see figure 14 in section 5.2.2). Aasness and Holtsmark (1993) describe how this is done by dividing the set J of commodities in (3) and (4) into r exhaustive and mutually exclusive groups of goods in the following way:

$$j \in J_r, \quad r \in R, \ \ J = \cup_r J_r, \ \ J_r \cap J_s = \phi, \ \ r \neq s, \ \ r, s \in R$$

In words, there are r groups of commodities each containing J_r commodities. The expenditure on group r is then given by:

$$y_r = \sum_{j \in J_r} p_j q_j \,, \ \ r \in R \tag{9}$$

The Marshallian group expenditure functions can be defined as:

$$y_r = g_{yr}(y, p) \equiv \sum_{j \in J_r} p_j g_j(y, p), \;\; r \in R \,. \tag{10}$$

In its most stringent form, the utility tree preference structure assumes that the direct utility function is weakly separable in the set R of commodity groups. Formally, this is given by:

$$u = f(\ldots, v_r(q_r), \ldots) \tag{11}$$

Here, q_r is a vector of the commodities consumed in nest r. The subutility function for this nest is given by $v_r(q_r)$. From this we get the conditional demand functions

$$q_j = g_{jr}(y_r, p_r), \qquad r \in R, \;\; j \in J_r \tag{12}$$

This implies that the demand for commodity j as a function of group expenditure and prices in that group or 'nest' in the utility tree is not affected by the total expenditure on (or the utility from) a separate nest (Deaton & Muellbauer 1980). This can add realism to the analysis by restricting the opportunities for substitution to compensate for welfare changes as a result of price changes for certain goods. For instance, it is reasonable to assume that a price change for public transportation will not affect consumer demand for meat products. However, and as pointed out by Aasness and Holtsmark (1993), weak separability is only an acceptable assumption for the initial division of the direct utility function. For nests at lower levels, price changes must be assumed to impact demand for more closely goods. One must, for instance, account for the substitution effect that a price change in public transportation might generate for the use of private cars. These substitution effects are captured in the elasticities of substitution between each nest on the same level and are crucial parameters for our analysis (see figure below). In particular, the elasticity of substitution between electric vehicles and fossil fuel vehicles will be given much attention in subsequent chapters. The policy cost of the two proposed policy alternatives depends critically on the ease of substitution between electric and fossil fuel vehicles, which again is a direct result of the consumer perception of differences in attributes between the two options captured by the elasticity of substitution.

3.3 Production theory

3.3.1 Profit maximization

In neoclassical economic theory, the firm is typically assumed to be a rational, profit-maximizing entity. It operates in a perfectly competitive market characterized by 1) symmetric information, 2) many firms so that the market price is outside their control, 3) homogenous products sold by the firms, and 4) that firms can freely enter and exit the market (Frank 2010).

Given a market that meets the above assumptions, the profit maximizing solution for a company $Comp1$ that produces one output x can be described by looking at its profit function. The firm maximizes profits with respect to x:

$$\pi_{Comp1} = px - c(x) \tag{13}$$

Here, π is the firm's profit, p is the price per unit sold of output x and $c(x)$ is the cost function for the firm. The profit maximizing solution is thus given by:

$$p = c'(x) \tag{14}$$

In words; the profit is maximized when the marginal revenue (equal to the price of x) equals the marginal cost of producing that unit. This makes intuitive sense when imagining an allocation outside of the profit maximizing solution. If $p > c'(x)$, then clearly producing another unit would increase total profits. The opposite is true if the marginal revenue of producing another unit is lower than the marginal cost.

3.3.2 CES AND CET PRODUCTION FUNCTIONS

Similarly to the utility function, we also need to assume something about the technology used in production which determines functional form of the production function. Here, we use assume constant elasticity of substitution in production. This implies that the relative increase in the use of one factor of production for a relative decrease in the price of this factor is constant. The nested CES production function is visualised in figure 7.

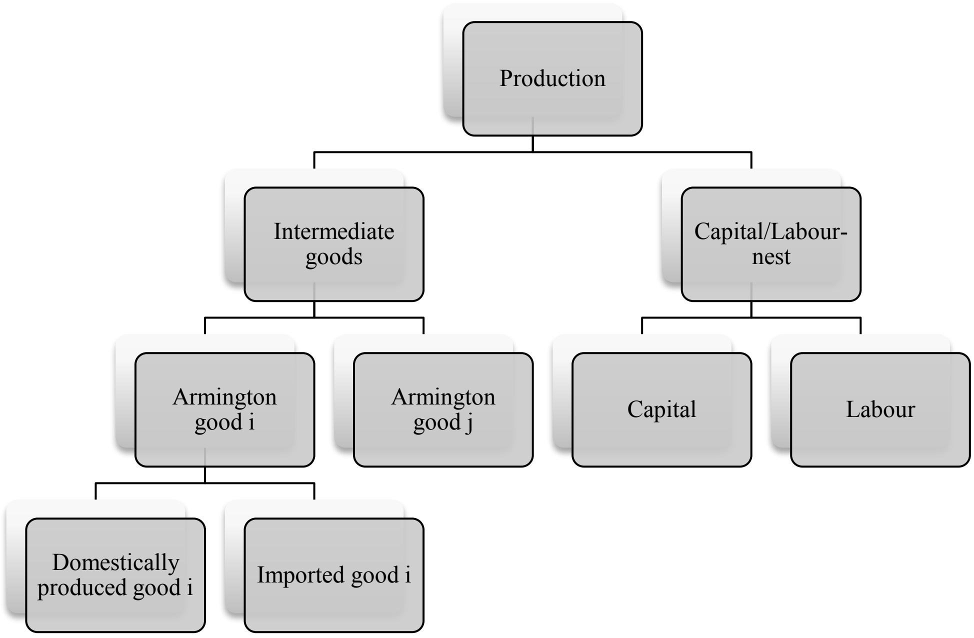

FIGURE 7: NESTED CES PRODUCTION FUNCTION.

Nested CES production functions combine primary factors and intermediate goods in production as shown in figure 7. Similarly to the CES utility function, groups in each nest can, by assumption, be substituted with each other. The level of substitution is constant and given by the associated elasticity of substitution. The intermediate goods used in production are combinations of imported and domestically produced goods, so-called Armington goods (Armington 1969). These are combined with capital and labour to produce the consumer good. Armington (1969) suggested that imported goods and domestically produced goods are imperfect substitutes. The *Armington elasticity* describes the level of substitutability between the imported and domestically produced goods.

Domestic consumers can choose between domestically produced or imported goods, and producers can choose to produce for the domestic market or for exports to the world market. This necessitates an assumption regarding the substitutability between domestic and foreign products. We use the standard assumption that Norway is a small, open economy, implying that domestic production does not alter world prices. To account for the substitutability between goods produced for the domestic market and for exports, we use a constant elasticity of *transformation* (CET) production function (*see figure 8*).

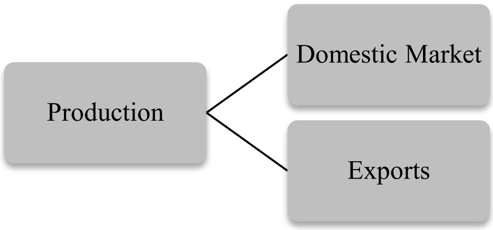

FIGURE 8: CONSTANT ELASTICITY OF TRANSFORMATION (CET) FUNCTION.

Figure 8 shows the CET production function for exports and the domestic market. The elasticity of transformation between these goods is constant by assumption.

3.4 General Equilibrium in a small, open economy

The description of the perfectly competitive economy at the beginning of this chapter is characterized by consumers maximizing utility subject to a budget constraint and producers maximizing profits subject to available technology. The French mathematical economist, Leon Walras, famously introduced the concept describing the state of such an economy at any given point in time as the solution to a set of simultaneous equations. These equations describe the supply of goods by producers, the demand of goods by consumers, and the equilibrium condition that supply must equal demand for the commodity market to clear (Walras 1900). Walras' work was further developed by economists Kenneth J. Arrow and Gerald Debreu (1954) to a theoretical framework for general equilibria. This equilibrium framework serves as the theoretical foundation for much applied work even today, and indeed also for this research.

Assuming constant return to scale in production and non-satiable utility, Arrow and Debreu (1954) showed that, with the assumptions that producers maximize profits and consumer maximize utility subject to constraints, we can characterize a general equilibrium by three critical conditions:

Market clearance

$$Production_i + Import_i \geq Intermediate\ good\ demand_i + Exports_i + Total\ consumption_i \qquad (15)$$

This condition states that, in equilibrium, the sum of domestic production and imports from sector i must be greater than, or equal to, the sum of intermediate use, exports, and total consumption of the goods produced by this sector.

Zero Profits

$$Cost_i(\boldsymbol{p}) \geq Revenue_i(\boldsymbol{p}) \tag{16}$$

This condition is based on the competitive market assumption which eliminates the possibility for a firm to earn positive profits without being undercut by a rival producer. Thus, the costs of input to production must be greater than, or equal to, the revenue earned from production at a given set of prices $\boldsymbol{p}$.

Income balance

$$\sum_i p_i Production_i \geq wL + p_k K \tag{17}$$

By assumption, all income earned by consumers from renting out labour and capital as factors of production, is spent on the consumer good. As we abstract from savings and investment, the sum of the expenditure on the good from industry i at price p_i must be greater than, or equal to, the income earned from supplying labour L at wage w, capital K at rate p_k.

3.5 EXTERNALITIES

According to the first theorem of welfare economics, the theoretical, perfectly competitive market described in section 3.3.1 only leads to a Pareto efficient equilibrium in the absence of externalities (Cowell 2006). Externalities are unaccounted for effects of an action, positive or negative, imposed on another agent (Varian 1992). In the context of transportation, there are a plethora of externalities to address; cars and buses contribute to both local and global pollution, road wear, congestion and noise. Supporting electric vehicles can lead to positive effects in the form of knowledge spill-overs and lowered production costs. Investing in public transportation can relieve congestion. The socially optimal solution, therefore, requires that external effects associated with transportation services and their associated inputs (e.g. type of vehicle and the required fuel) are accounted for.

We can illustrate the example of a negative externality by returning to $Comp1$ used as an example in section 3.3.1 and by defining the profit function of another company, $Comp2$ that is affected by the production of the first firm. Specifically, $Comp1$ produces just one output x, which imposes a cost $e(x)$ on $Comp2$. Again, letting p be the output price and $\pi(y)$ denote the profit $Comp2$ earns from producing output y, which we for simplicity assume is not affected by the externality, we have:

$$\pi_{Comp1} = px - c(x) \tag{18}$$

$$\pi_{Comp2} = \pi(y) - e(x) \tag{19}$$

Using (14), we know that the equilibrium output for $Comp1$ is given by $p = c'(x)$, but the socially optimal solution now requires that $Comp1$ also considers the marginal external cost it imposes on the other agent. Consequently, equation (14) only describes the *privately* optimal solution, not the *socially* optimal. To determine the socially efficient amount of output, we can merge the two companies, thus internalizing the external cost $e(x)$.

$$\pi_{merged} = \pi(y) + px - c(x) - e(x) \tag{15'}$$

The first order condition with respect to x becomes:

$$p = c'(x) + e'(x) \tag{20}$$

which states that the socially efficient allocation is found by equating the marginal revenue and the marginal *social* cost of production. This is illustrated in figure 9, showing how the merged firm will produce $X1 < X2$ amount of output when considering the external cost $e(x)$. This way, a negative (positive) externality no longer results in too much (too little) output being produced from a social point of view – the externality is internalized.

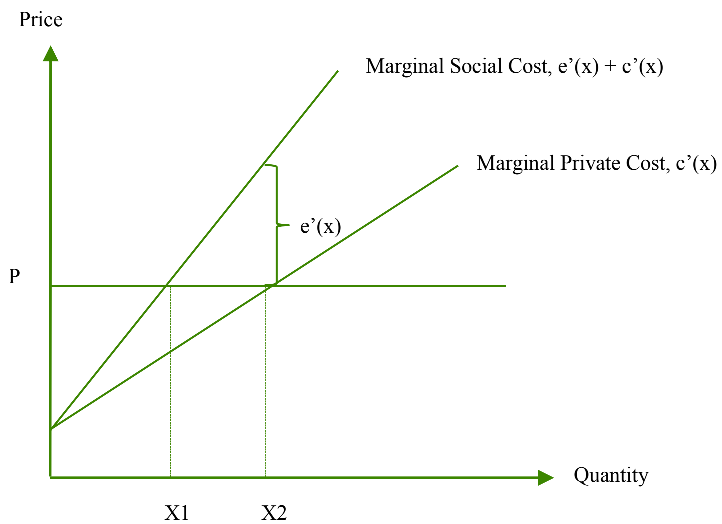

FIGURE 9: THE SOCIALLY OPTIMAL LEVEL OF OUTPUT WHEN FACED WITH A NEGATIVE EXTERNALITY.

3.6 Social Cost of Carbon

The key externality that electric vehicle incentives have been put in place to address is the one associated with CO_2 emissions. As the rate of CO_2 emissions outpace the rate at which natural sinks can absorb it, the scientific consensus is that this will trap more heat in the atmosphere and lead to potentially destructive climate change (IPCC 2013). Losses to human welfare are hard to quantify, but crucial to estimate and include in carbon-related policy decisions. Consumers who do not face the socially optimal price of consumer goods are likely to choose inefficiently large quantities of goods and services that are carbon-intensive. They may, for instance, opt for a fossil fuel vehicle rather than an electric vehicle or public transportation. Similarly, firms are incentivized to produce inefficiently large quantities of carbon-intensive goods and services to the detriment of social welfare. They would do this because, while there are clear costs of emitting carbon, there are also clear benefits; the power and products that modern societies rely on are not yet cost competitive to produce without creating CO_2 emissions. The result is that the optimal solution cannot be zero emissions, which begs the question - what *is* the optimal level?

This question lies at the very core of climate economics. While we in this research focus on Norwegian climate policy, this global pollutant forces us to look at the globally optimal solution. We can formalize the problem by letting $B(E_t)$ be the benefits of emitting E_t and $D(S_t)$ denote the damages from the stock S_t of carbon in the atmosphere. The net present value of emitting carbon is then given by the following optimization problem:

$$\max_{E_t} NPV = \int_0^\infty (B(E_t) - D(S_t))e^{-rt}dt \qquad s.t. \qquad \dot{S}_t = f(E_t, S_t) \tag{21}$$

We assume that the benefits of emitting are immediate, while the costs come later when the carbon is added to the atmospheric stock, increasing future damages of climate change. The first order condition becomes with respect to emissions is given by:

$$B'(E_0) = \int_0^\infty D'(S_t)\frac{\partial S_t}{\partial E_0}e^{-rt}\ dt. \tag{22}$$

The first order condition states that we should emit to the point where the marginal benefits of emitting today equal the total discounted marginal damages in perpetuity. In a static framework, this can be illustrated as in figure 10 where the optimal solution is defined by the intersection of the marginal benefits and marginal damage curves.

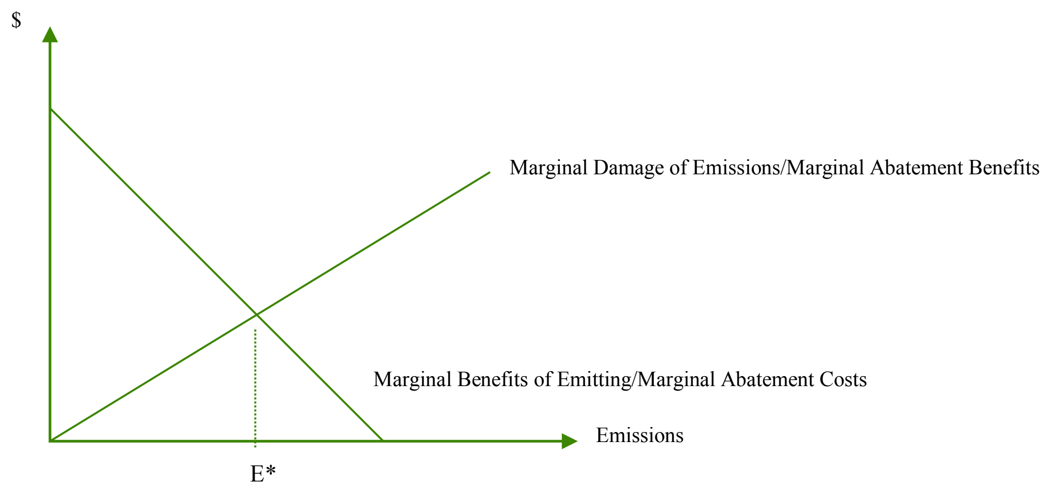

FIGURE10: THE OPTIMAL LEVEL OF EMISSIONS IS GIVEN BY THE INTERSECTION OF THE MARGINAL DAMAGE AND MARGINAL BENEFITS CURVES , E*.

To fully answer the question of what the optimal level of emissions is, we need to estimate the two curves presented in figure 10 – the hardest one arguably being the marginal damages of CO_2 emissions. To do this, researchers often use Integrated Assessment Models (IAMs). In these models, the costs of a warming climate are modelled using an aggregate damage function (Hackett & Moxnes 2015). The models combine the science and economics of climate change to produce estimates of the so-called social cost of carbon (SC-CO_2)[1]. We can define the SC-CO_2 formally by letting *D* depict damages incurred from carbon emissions, *E* be the level of emissions, *r* be the interest rate and *t* represent time. This gives us:

$$SC{-}CO_2 = \int_0^\infty ({\partial Dt}/{\partial E_0}) e^{-rt} dt \tag{23}$$

In words, the SC-CO_2 is the discounted, marginal damage of carbon emissions, equivalent to the right-hand side of equation (21). The marginal benefits of emitting carbon today should equal the marginal social cost of carbon in perpetuity in the optimal solution.

To get estimates for the SC-CO_2, the IAMs use economic- and population growth forecasts and project associated increases in emissions. These projections form the basis for expected future climate change and the damages this will lead to. Then, the models produce a monetary estimate for these damages, adjusted for discount rate. This is often decided based on the so-called Ramsey rule, an equation that gives the discount rate as a function of a pure time preference parameter, risk aversion, and an equity factor. Alternatively, the prevailing market rate can be used for discounting (Hepburn 2006).

Because of the number of parameters and the uncertainty surrounding them, IAMs are somewhat controversial. Strong criticism has been voiced by, for instance, Robert Pindyck when he wrote paper entitled ‘Climate Change Policy; What do the models tell us?’ and concluded that they told us ‘very little’ (Pindyck 2013). Despite the criticism, IAMs are frequently used to estimate the marginal damage of CO_2 emissions. Many such models exists, and SC-CO_2 estimates differ greatly, but to serve as a point of reference, the US Interagency Working Group (IWG) on the social cost of carbon state that the SC-CO_2 given a discount rate of 3% is $42 in 2020 (Interagency Working Group on Social Cost of Greenhouse Gases 2016).

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[1] The monetized damages associated with an incremental increase in carbon emissions in a given year. (Interagency Working

3.7 Pigouvian taxes

Returning to our discussion about externalities, the estimate of the social cost of carbon is important to serve as a policy guide when developing market-based mechanisms to internalise external costs and benefits. In theory, a corrective tax equal to the marginal damage (known as a Pigouvian tax) could lead a profit-maximizing actor to choose the socially optimal level of production without direct regulation. For instance, a carbon tax set to the same level as the social cost of carbon, assuming we could estimate this correctly, would internalize the negative externality of CO_2 emissions. Varian (1992) put it well when he wrote that '*achieving an efficient allocation in the presence of externalities essentially involves making sure that agents face the correct price for their actions*'.

3.8 Cost-effectiveness of uniform taxation

In policy scenario S1, we implement a uniform carbon tax on the use of fossil energy in non-ETS sectors. The fact that it is uniform is what makes this a cost-effective policy. To see this, we can illustrate the marginal abatement cost (MAC) curves of two firms or sectors as in figure 11. We assume linear MAC curves which increase with increased abatement, i.e. the cheapest abatement options are applied first.

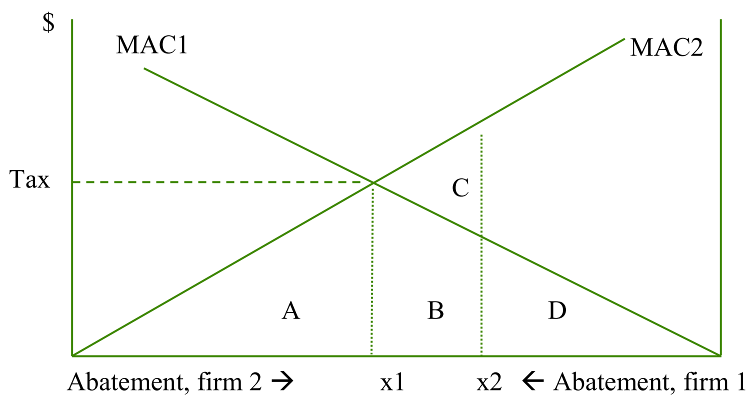


FIGURE 11: COST-EFFECTIVENESS WITH EQUALIZES MARGINAL ABATEMENT COSTS.

Figure 11 illustrates the costs associated with two different divisions of abatement between the two firms in the figure. In division x1, the abatement effort is divided such that marginal abatement costs are the same for both firms. This means that total abatement costs are given by the sum of areas A, B, and D. In the alternative division of abatement effort, x2, firm 2 is required to abate more than before, despite having higher marginal costs than firm 1 in the new allocation. The result is that total costs of abatement increase, in this example by area C. Clearly, no other allocation than x1 can produce lower total costs of abatement, and situation x1 is thus said to be cost-effective.

Figure 11 also illustrates why a tax set at the level where marginal abatement costs are equal leads to a cost-effective solution. For all abatement cheaper than the tax, both firms will choose to clean instead of paying the tax. This leads both firms to clean until they arrive at the same level of marginal abatement costs, which is equal to the tax. Hence, the tax incentivizes the firms to reach the cost-effective division of abatement effort.

3.9 Double Dividends

The non-market costs of pollution, noise, congestion, and environmental damages that are caused by conventional private transportation can theoretically be corrected for by an appropriate Pigouvian tax. Further, the resulting tax revenue can be used to reduce distorting taxes elsewhere in the economy and thereby improve overall economic performance. This use of Pigouvian taxes in tandem with reduced burden of the overall tax system generates double dividends.

Further, the income generated from this tax could generate double dividends if used to alleviate distorting taxes or subsidies elsewhere in the economy, typically income taxes or taxes on capital, generating increased welfare (Jorgenson et al. 2013).

3.10 Measuring welfare changes

The assumption of one representative agent discussed in section 3.2.1 entails that all economic costs and gains eventually make their way to this representative agent and affects its welfare. Therefore, we can measure welfare as the representative agent's total consumption and the welfare change as a change in total consumption.

Equation 7 gave us the expenditure function, that is the minimum expenditure required to obtain a given utility level for a given set of current prices $\boldsymbol{p}$ and goods $\boldsymbol{x}$. By applying the direct money metric utility function (*see Varian (1992), p.109 for details*), we can answer how much money a given consumer would need at prices $\boldsymbol{p}$ to be as well off as by consuming the bundle of goods $\boldsymbol{x}$**.** Closely related is the money metric *indirect* utility function, a measure for how much income one would need at a new set of prices, $\boldsymbol{p'}$, to be as well off as when facing original prices $\boldsymbol{p}$ and having income m. The utility level μ is given by:

The money metric indirect utility function $\mu(\boldsymbol{p}; \boldsymbol{p'}, m)$ (24)

This provides a convenient basis for measuring welfare changes from, in our case, two proposed policy changes. Introducing taxes (either positive or negative) will alter the prices facing the consumer and hence induce a welfare change. To measure this welfare change, we use equivalent variation. Equivalent variation is a measure for the income change at current prices $\boldsymbol{p}$ equivalent to the impact on utility from the proposed price change. Mathematically we have:

Equivalent variation $= \mu(\boldsymbol{p}; \boldsymbol{p}', m') - \mu(\boldsymbol{p}; \boldsymbol{p}, m) = \mu(\boldsymbol{p}; \boldsymbol{p}', m') - m$ (25)

Simply choosing new prices as the base and ask what income change would be necessary to compensate the consumer for the price change leads to a very closely related measure for welfare change called compensating variation. This is perhaps a preferred option if one plans a compensation scheme. We have opted for equivalent variation to measure the welfare change as it measures the income change at observable current prices. Further, and perhaps even more importantly, when comparing several proposed policy options, compensating variation uses the new prices resulting from each policy as the basis. Equivalent variation instead keeps the base prices fixed. Hence, Varian (Varian 1992) explicitly recommends equivalent variation to compare the effects of a variety of projects.

4 METHOD

The purpose of this thesis is to model the economy-wide effects of using incentives for EV owners as the main policy to meet Norway's 2030 climate goal for the non-ETS sector. This policy is compared to a uniform non-ETS carbon tax set to a level high enough to achieve the same level of emission reductions. The analysis is based on computable general equilibrium (CGE) modelling of the Norwegian economy using an aggregated MPSGE model constructed from official data from Norwegian national accounts. The model is calibrated to the base year 2013 before alternative policies are introduced.

4.1 COMPUTABLE GENERAL EQUILIBRIUM MODELS

Computable general equilibrium (CGE) models are used for simulations that combine the theoretical, Arrow-Debreu framework for general equilibria *(see chapter 3)* with empirical data to solve numerically for the levels of supply, demand and price that support an equilibrium across a specified set of markets (Wing 2004). Theoretical models in traditional economic literature are often fairly limited as they typically assume two goods, two factors, two countries, and that consumers everywhere have the same, homogenous preferences over goods (Markusen & Rutherford 2004). CGE modelling, however, allows for any number of goods, factors, household types and countries. This is a necessary feature as we model the entire economy, albeit in very aggregated sectors. We can model the effects of sector-specific taxes and subsidies on a large set of production activities and a number of transportation alternatives along with other consumption options. In general, CGE models are frequently used for evaluating the effects of policy changes ex ante. In a paper on CGE models of trade, the World Trade Organization notes that this method *'... preserves the optimizing assumptions and links between markets that are the hallmarks of the standard general equilibrium model. The attraction to analysts of a CGE trade model is that it arrives at a numerically precise answer while ensuring that the results are theoretically consistent"* (Piermartini & Teh 2005).

As discussed in the previous chapter, the theoretical framework formulated by Arrow & Debreu (1954) aims to explain the entire economy by a set of equations that represent the economic flow of goods, services, financial transfers, and factor payments. The agents and their market interactions can be visualized as in figure 12.

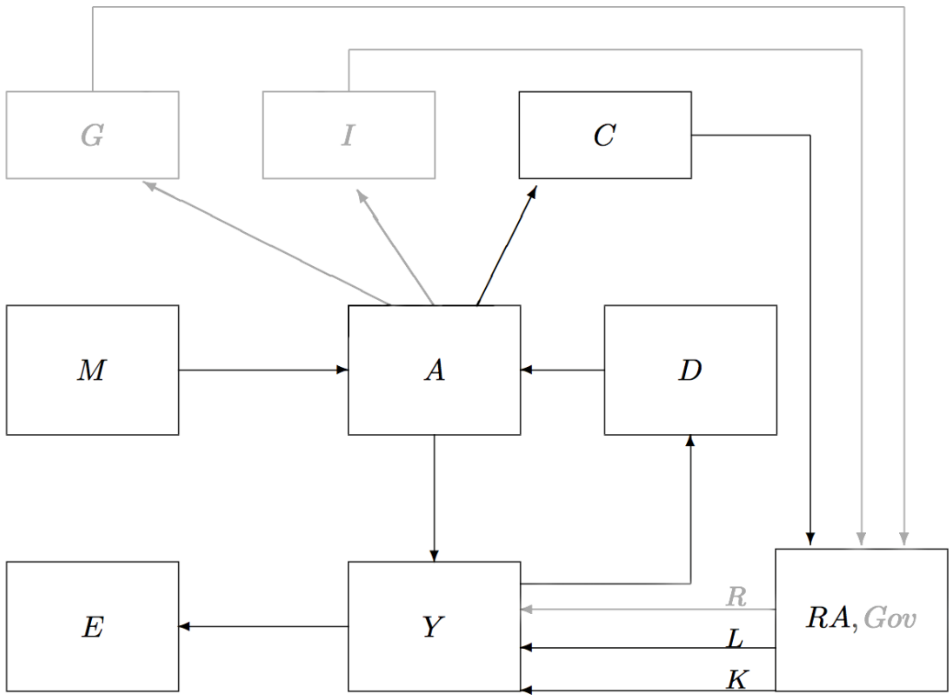


FIGURE 12: A VISUAL REPRESENTATION OF THE ECONOMIC FLOWS IN A SIMPLE ECONOMY.

Figure 12 describes the framework for the economic flow in a CGE model. The production sectors *Y* combine resources *R*, labour *L*, and capital *K* with intermediate goods to produce for the domestic market *D* and for exports *E*. The Armington composite good *A (see section 3.3.2)* is the combination of domestically produced goods and imports, *M* and is the basic commodity in the economy. It is demanded by industry as an intermediate good in production, and used to create goods for final use by the representative agent *RA* and government *Gov* as either investments *I,* our as household goods *C* or government goods *G* (Markusen & Rutherford 2004). In our model we will abstract away from investment and a public sector by simply assuming one representative agent. Finally, we will also assume that goods are produced using only labour, capital, and intermediate goods, thus *R* is not explicitly included.

Mathiesen (1985) showed how this economy can be formulated and solved as a complementarity problem - a square system of weak inequalities each associated with a complementary variable. The three conditions for a general equilibrium discussed in chapter 3 - market clearing, zero profit, and income balance – each apply to one of three classes of variables:

- A non-negative vector of activity levels in the production of the commodities in the economy.
- A non-negative vector of the associated commodity prices.
- A vector of income levels for each consumer in the economy, wherein the public sector is interpreted as a consumer.

Solving a system of weak inequalities rather than strict equalities has the virtue of allowing some goods not to be produced or some possible trade links to be inactive. If a particular inequality, e.g. that input costs must be greater than, or equal to, the output value (zero profit condition) holds as an equation, the complementary variable, here activity level, is strictly positive. If, on the other hand, it holds as a strict inequality, the activity level would be zero (otherwise the production would generate negative profits) (Markusen & Rutherford 2004).

This theoretical framework serves the purpose of translating an economy into a well-defined mathematical problem. Next, we proceed to complement the theoretical framework laid out above with empirical data.

4.2 SOCIAL ACCOUNTING MATRIX

Our model, like many of its kind, is based on a social accounting matrix (SAM) from an appropriate base year in which the economy is assumed to be in equilibrium and uses this as a starting point for policy evaluation. A social accounting matrix is a snapshot of the economy – a tabular representation of how different industries, consumers and government agents produce, purchase, and sell goods in the economy (*see figure 13*). It describes how the value added in production accrues to production factors, and by extension (and assumption) to the households that rent them out. The SAM also illustrates how these incomes are spent on goods, yielding consumer utility (Keuning & De Rutter 1988).

	INTERMEDIATE USE by Production Sectors 1 2 …j… n	FINAL USE Private consum. Gov't consum. Invest. Export
Domestic Production by sector 1 2 : i : n	A	B
Import	C	D
Value added: -labor -capital	E	F
Transfers -taxes -margins	G	H

FIGURE 13: THE SOCIAL ACCOUNTING MATRIX LAYOUT OF PRODUCING UNITS, INTERMEDIATES, AND FINAL USE SECTORS.

The general social accounting matrix in figure 13 presents the economic flows discussed in the previous section in a way that makes it easier to combine the theory and data of CGE modelling. The left-hand side of the matrix is the production side of the economy (areas A, C, E, and G). It gives detailed information about input costs from using primary factors of production with intermediate goods in production, and the taxes that apply to each sector along with any imported goods. The right-hand side of the matrix (areas B, D, F, and H) describes the final use sectors of the economy. In the general framework illustrated in figure 13, final use sectors include government consumption and investment in addition to private consumption and exports. In our model, however, we will consider government and private households to be one representative agent and assume that all income is spent on consumption (i.e. no investment).

The empirical data introduced in the SAM is meant to complement the theoretical framework for an Arrow-Debreu general equilibrium. This implies that the data needs to be balanced or *micro-consistent*, meaning that it complies with the general equilibrium conditions discussed in chapter 3. Making sure the social accounting matrix is micro-consistent is a first, critical step in computable general equilibrium modelling. Presenting the data in a social accounting matrix lets us check the conditions in the following way:

- The market-clearing condition is checked by making sure the sum in each column (the total output value) in the production-side of the matrix (Area A, C, E, and G) is equal to the row sum for the same sectors (A and B, equal to total final use). This means that the supply of domestic and imported goods equal the demand from final use in the economy and exports, and the market clears.
- We assume constant return to scale in production and impose the zero-profit condition such that total output value is lower, or equal to, total input costs in production. This implies that there should be no positive profit margins in the matrix.
- Finally, all income from taxes and renting out capital and labour must, by assumption, be spent on consumer goods in the economy. This is checked by comparing the sum of the rows associated with primary factors and taxes (which is the total income for the representative agent) with the final use column associated with the representative agent.

4.3 GAMS/MPSGE

Once we have a micro-consistent SAM, the economic flows put in system by the Arrow-Debreu framework can be coded using a General Algebraic Modelling System, or GAMS for short. GAMS is a high-level modelling system for mathematical programming and optimization. This coding system, and its subsystem MPSGE (Mathematical Programming System for General Equilibrium), provides a compacted way of describing the agents in an economy and how they interact in markets.

GAMS/MPSGE can read data from a micro-consistent social accounting matrix prepared by the researcher. The next step is then a calibration process in which the researcher defines sets of sectors, endogenous variables to be solved (e.g prices, activity levels, trade volumes) and exogenous parameters (e.g. technologies, preferences, factor endowments). Finally, production functions, market demand for final use and utility functions must be specified along with elasticities of substitution/transformation and assignments of any taxes and their associated revenues.

As discussed in chapter 3, GAMS/MPSGE accepts benchmark price/quantity, marginal rate of substitution/transformation, and the elasticity of substitution/transformation as sufficient information to automatically write the underlying (nested if specified) CES utility and CET production functions. It also specifies their associated expenditure and cost functions which is practical especially for the large, nested utility tree preference structure used in this research. Coding the expenditure functions for a multi-level CES utility function and subutility functions is a tedious and error-prone task. MPSGE does that job in the background, letting the researcher focus on high-level analysis and structures in the economy. However, as economics has trained us to realise, there is no such thing as a free lunch. Researchers must still assume something about the functional forms in the model and their critical parameters.

When the data set is balanced and micro-consistent, and the model is properly specified to the wanted level of detail, the calibration will return the original benchmark data as an equilibrium, assuming that the details of various levels of intricacy are included correctly. From this starting point, a reference scenario can be made by altering exogenous parameters, typically labour endowment and the access to capital based on expected economic growth. This allows for policy analysis through a series of counterfactual experiments, for instance by introducing sector-specific taxes and subsidies. GAMS/MPSGE will list the effects on activity levels for each sector, the prices of goods and factors in the economy relative to a numeraire good for which the price is fixed, and the levels of income for consumers and the public sector.

5 DATA AND RESEARCH DESIGN

This section will describe the empirical data used for this analysis. Additionally, any assumptions, abstractions, and/or simplifications necessary to arrive at a complete model of the Norwegian economy in 2030 are reported.

5.1 PRODUCTION SECTORS AND LEVEL OF AGGREGATION

To study the effects that are most relevant for the research questions, we have aggregated the production sectors and consumption options in the economy into the sectors presented in table 2 and 3. As our focus is on transportation, transport-relevant sectors are kept as disaggregated as possible. Remaining production sectors are aggregated into rest non-ETS and rest ETS. Table 2 lists the production sectors in the model along with the corresponding sectors in the Norwegian National Accounts (Statistics Norway 2015).

TABLE 2: TABLE OF PRODUCTION SECTORS AND SHORT-HAND NAMES.

Production sector	Short-hand	Sector code	Description
Motor vehicles and parts	mvh	R29	Motor vehicles and parts: cars, lorries, trailers and semi-trailers.
Refined petroleum products	oil	R19	Refined petroleum products, coke oven products, processing of nuclear fuel.
Electricity	ele	R35	Production and distribution of electricity.
Water transport	wtp	R50	Water transport services, goods/passengers.
Land transport	otp	R49	Other transport services: road and rail.
Air transport	atp	R51	Air transport and related services.
Rest of ETS sectors	ets	R06, R09, R23, R29	Oil and gas extraction, chemicals, minerals, iron and steel, and paper production.
Rest of non-ETS sectors	non	Remaining sectors	

5.2 CONSUMPTION GOODS

In the aggregation process of the consumption goods, the following assumptions were made:

- The economy features one representative agent whose consumption expenditure includes public spending. Hence, there is only one consumer in our model, and public spending is just a consumption option for this consumer, i.e. government is not treated as a different economic agent.
- Government consumption, gross fixed capital formation, stock changes, and consumption by non-governmental organisations are aggregated to 'govt'. Hence, we abstract from investment in our model.
- In the base year 2013, electric vehicles accounted for less than 1% of the car fleet[2]. For simplicity, we therefore assume no electric vehicles in the base year and so all expenditure on motor vehicle capital equipment in 2013 is attributed to *fossil fuel* vehicle capital equipment.

The resulting consumption goods are listed with descriptions in table 3.

TABLE 3: CONSUMPTION GOODS AND OTHER FINAL USE SECTORS.

Consumption	Short-hand	Description
Electric vehicle capital equipment	evcap	Consumption of motor vehicle capital equipment adjusted for expected EV share[3].
Electricity for electric vehicle	evfuel	Treated as share of fossil fuel expenditure. Adjusted for expected EV share.
Fossil fuel vehicle capital equipment	fvcap	Consumption of motor vehicle capital equipment adjusted for expected FV share.
Fuel, fossil fuel vehicle	fvfuel	Adjusted for expected FV share.
Public transport (rail and road)	lndtr	Consumption of land transport services.
Public transport (air)	cair	Consumption of air transport services.
Public transport (boat)	cboa	Consumption of water transport services.
Aggregate of other consumption goods	rest	Remaining sectors in private consumption.
Public sector	govt	Aggregate of public expenditure, non-profits, and stock changes.

[2] *In December 2013 there were 17.770 private electric vehicles registered, accounting for 0.71% of the total car fleet of 2.500.265 (Statistics Norway 2014).*

[3] *See section 6.1 on reference scenario.*

5.2.2 Utility tree and key elasticities

The aggregated consumption options listed in table 3 is the basis for our analysis of consumer behaviour in the reference scenario and in the policy shifts. These options are presented in figure 14 as a nested CES utility structure (*see section 3.2.4*).

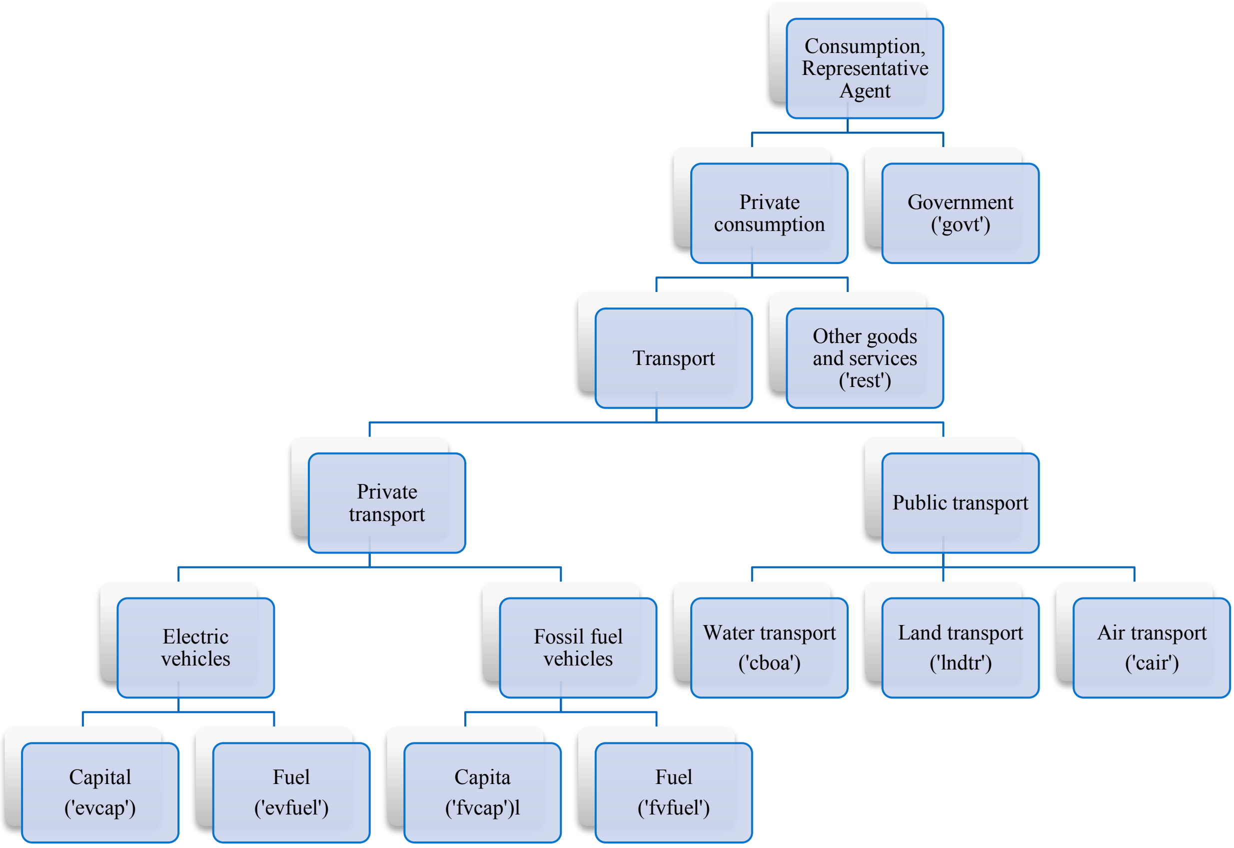


FIGURE 14: UTILITY TREE PREFERENCE STRUCTURE.

Figure 14 is a visual representation of the nested CES function for the representative agent's utility. The top layer is his total consumption, which is further divided into the aggregated consumption options we have specified on the lower levels of the tree. Between different goods in each nest, (e.g. between EV and FV), the elasticity of substitution captures the preference parameter that determines the ease of substitution between the goods.

The elasticities of substitution used in the consumption analysis are listed in table 4. For the nests labelled 'Consumption, Representative Agent', 'Private consumption', 'Transport', and 'Public transport', we have used the same elasticities as those found in Statistics Norway's model SNoW which build on the works of Aasness and Holtsmark (1993) and Wold (1998).

TABLE 4: ELASTICITIES OF SUBSTITUTION.

Nest	**Elasticity of substitution, σ**
Top layer	0
Home	0.5
Transport	0.5
Public transport	0.5
Private transport	2.74
FV	0
EV	0

Table 4 shows that the top level has an elasticity of substitution equal to zero. This means that the representative consumer cannot substitute private consumption for public consumption. Next, there is a certain level of substitution between transport services and other goods in the economy, represented by an elasticity of substitution at 0.5. It seems natural that, for instance, a price increase for air travel might induce more expenditure on video conference equipment, or that a holiday is spent at home with more restaurant visits to replace the now more expensive trip abroad.

The nest of private and public transport, '*Transport*', is also given an elasticity of substitution at 0.5. Here, the level of substitution is arguably affected by factors such as the quality of public transportation and whether the analysis is focused on a city or rural areas etc. In general, the easier it is to substitute a private mode of transportation for public transportation, the larger is the elasticity of substitution.

At the bottom level, between fuel and car capital equipment for each vehicle technology, we have chosen zero (Leontief) substitution. In other words, there is no substitution between the car itself and the fuel it uses in our model. Realistically, a consumer could choose to spend more on the car when fuel prices change (e.g. purchase a more fuel-efficient car). Nonetheless, we have chosen to ignore this substitution option to focus on the effects of the policy changes on the substitution between EVs and FVs.

The elasticity of substitution between electric vehicles and fossil fuel vehicles is hard to determine, especially for 2030. This parameter has been the focus of a parallel research undertaken by Head of Research at Statistics Norway, Taran Fæhn (*see Appendix for details*). To calculate this, bottom-up information on the technological development of electric vehicles (e.g. range, battery cost etc) was used. This was thought more relevant than historical data traditionally used to calculate the CGE parameters (Bye et al. 2016), especially when dealing with an immature technology that is developing rapidly. Based on the report on the policy costs of phasing in electric cars written by the Norwegian Environment Agency (MDIR 2016), the perceived disadvantages of electric cars (e.g. shorter range, fewer models) was quantified and adjusted for to make electric and fossil fuel vehicles qualitatively equal. The difference between the goods should then only capture preferences for either technology. This parallel research suggests an elasticity of substitution at 2.74 in 2030, which is what we will use in our model. Several factors might influence this parameter, and these are discussed further in chapter 7.

These elasticities play a key role in determining the welfare changes induced by a new policy. Larger elasticities mean better options for substitution and hence a more flexible economy. This will help to lower the magnitude of welfare changes induced by a policy change, as consumers can easily adopt to the new circumstances.

If we assume no market imperfections, a change in welfare from an economy in equilibrium is, by definition, negative. However, there are existing taxes in our model that either distort optimal consumption (for instance to generate tax revenue) or that are placed to improve social welfare by internalising an external effect (*a Pigouvian tax*, *see section 3.7*). Counterfactual policy scenarios that introduce new taxes or subsidies can therefore both strengthen or counteract the welfare effect of existing taxes.

5.3 The base year 2013

To perform a general equilibrium analysis, it is of central importance to choose a base year that was not severely affected by shocks to the economy that would move it away from an otherwise 'normal' situation or equilibrium. In the last decade, two such major shocks have impacted the global and the national economy. The financial crisis of 2008 and the economic turmoil in its aftermath is still felt world-wide. More recently, the severe drop in world crude oil starting in 2014 had a large impact on global activity levels (Rogoff 2016), and affected oil-dependent economies like Norway particularly hard. Hence, we chose 2013 as the base year for our analysis, to move as far away as possible from the aftermath of the financial crisis while still not using national records affected by the severe drop in world crude oil prices in 2014.

5.3.1 Social Accounting Matrix for Norway 2013

Our social accounting matrix (SAM) (table 5) is based on an input/output table (IOT) of official figures from Norwegian national accounts (Statistics Norway 2015). This follows the stylized SAM presented in figure 13. On the left, production sectors are listed vertically. They deliver intermediate goods to all production sectors and consumer goods to all final use sectors, which are all listed horizontally. On the production side of the table, the IOT presents each sector's expenditure on intermediate goods used in production along with primary factors of production and taxes. Similarly, the consumption side of the table gives detailed information about the expenditure on goods from specific production sectors. Stock changes and investments are, as discussed, included in the aggregate 'govt' with public spending. Finally, both imports and exports by sector are reported.

TABELL 5: SOCIAL ACCOUNTING MATRIX FOR NORWAY IN BASE YEAR 2013. MILL. NOK.

SAM2013	Production								Final use										
Mill.NOK	**mvh**	**oil**	**ele**	**wtp**	**otp**	**atp**	**ets**	**non**	**evcap**	**evfuel**	**fvcap**	**fvfuel**	**lndtr**	**cair**	**cboa**	**rest**	**govt**	**exp**	**Total**
mvh	182	5	1	2	198	3	142	2858	0	0	6799	1	0	0	0	107	-5514[4]	2718	**7502**
oil	67	7528	293	2462	3744	211	7198	29319	0	0	72	8666	0	0	0	2131	24888	71298	**157876**
ele	84	2753	2258	124	786	170	8734	23634	0	0	6	6	0	0	0	24223	933	4945	**68656**
wtp	23	463	68	12741	2354	82	4825	8342	0	0	16	16	0	0	6306	774	7312	109466	**152788**
otp	228	4849	153	790	8351	283	8709	56889	0	0	6239	434	15358	0	0	34917	14735	30538	**182472**
atp	23	310	44	277	4812	5199	2470	11721	0	0	462	4	0	7362	0	434	2664	9534	**45315**
ets	387	69023	36	1685	7339	221	18145	33816	0	0	20	20	0	0	0	1562	118536	636758	**887548**
non	1633	18791	7851	17217	44047	8749	89317	1110093	0	0	40928	2329	0	0	0	581640	1291683	322151	**3536428**
Import	2405	29762	2177	58889	35288	14974	75369	340085	0	0	20960	4737	44	3487	828	214488	55713	16335	
TX[5]	18	771	5612	-4651	-5471	-465	6032	42450	0	0	31489	18378	1232	868	310	136318	58012	0	
K[6]	578	10801	41159	34914	42281	3717	575963	686256											
L[7]	1876	12819	9004	28339	38744	12171	90646	1190965											
Total output value	**7502**	**157876**	**68656**	**152788**	**182472**	**45315**	**887548**	**3536428**											

[4] *The negative number here does not imply negative public consumption. As specified in table xx, the category 'govt' includes stock changes and investments, which can be negative.*

[5] *TX = taxes less subsidies on products + other net taxes on production*

[6] *K = consumption of fixed capital + operating surplus*

[7] *L = Compensation of employees*

Relating back to our theoretical framework for general equilibria (*see chapter 3*), it is an essential assumption that the output value from each production sector equals the total final use of goods from that same sector for the markets to clear. We can see in table 5 that the column sums for total output value equal the row sums for intermediate use and final use. In other words, the market-clearing condition holds and the social accounting matrix for our base year is micro-balanced.

5.3.2 EMISSIONS BY SECTOR, 2013

Emission data by sector is presented in table xx below. The data is gathered from Statistics Norway (2017), and aggregated in the same way as sectors used in the social accounting matrix. In addition to energy-related emissions, we have also modelled process emissions from manufacturing industries. Process emissions are unrelated to energy use, but stem from industrial processes such aluminium and cement production. These emissions are not typically included in CGE, but contribute to a more complete overview of total emissions (Bye et al. 2015).

TABLE 6: TOTAL EMISSIONS BY SECTOR IN BASE YEAR 2013. MEASURED IN KTON CO2 FOR DETAILS.

	mvh	**oil**	**ele**	**wtp**	**otp**	**atp**	**ets**	**non**
Process CO2	0.3	2472.4	0.1	6.9	11.5	0.1	4798.3	385.6
Energy-related CO2								
-oil	13.4	2192.5	643.2	1598.1	5461.9	1232.7	13564.3	5109.9
-ets	0.0	139.0	0.0	0.0	0.0	0.0	83.0	2.3
-non	0.0	66.5	0.0	0.0	0.0	0.0	489.6	1043.4
Total	13.6	4870.4	643.3	1605.0	5473.4	1232.8	18935.3	6541.1

The majority of emissions stem from the use of energy in production, the so-called energy-related emissions. However, process emissions are important to account for as they make up large shares of total emissions from certain sectors. For instance, in the refined petroleum sector (‘*oil*’), about half of total emissions are process-related. It is also worth noticing in table 6 that emissions from non-transport related sectors outside of the EU ETS (*non*) have significantly lower CO_2 emissions than the aggregate for non-transport ETS (‘*ets*’). This is, as discussed, because most emissions from non-ETS sectors other than transport are not carbon dioxide, but other greenhouse gases (e.g. methane from agriculture). As previously discussed, CO_2 is the most relevant greenhouse gas in transportation and we have therefore chosen to only include this greenhouse gas in our analysis.

6 Analysis

6.1 The reference scenario, R2030

To analyse the effects of introducing new policies in 2030, we need a reference scenario that describes the Norwegian economy in 2030 without new policies. The reference scenario created for this analysis, R2030, is based on the *White Paper on the Long-term Perspectives on the Norwegian Economy 2017* (Meld.St.29 (2016-2017)). The report is prepared for Parliament by the Ministry of Finance and aims to give sound predictions about the future development of macro-economic variables and general trends in the economy. Based on these predictions, we have created R2030 by assuming the following changes from 2013:

Population: Statistics Norway predicts higher-than-usual population growth between 2015-2020 due to an extraordinary refugee situation before growth rates level off (Meld.St.29 (2016-2017)). These predictions suggest a total population in Norway in 2030 of 5.9 million, up 17% from our base year, 2013 (Statistics Norway 2013). The labour force is simply assumed to be the same share of the total population as in the base year.

Access to capital: We assume a balanced growth path between the labor force and access to capital, leading capital access to grow by an equivalent 17%.

6.1.1 Assumptions for electric and fossil fuel vehicles in 2030

The following assumptions were made to forecast the shares of electric vehicles and fossil fuel vehicles in 2030.

Share of electric/fossil fuel vehicles: The Institute for Transport Economics has made predictions for the number of cars in the private car fleet in 2030 and the shares for each technology (Fridstrøm & Østli 2016). The results they find are listed in table xx. From this, we have aggregated all electricity-based zero emission technologies to one aggregate that we refer to as electric vehicles or *EVs (shaded green in table 7)*. This aggregate consists of battery-electric vehicles and plug-in hybrids. Similarly, we have created a fossil fuel vehicle aggregate that combines petrol, diesel, and gas. We will refer to this as fossil fuel vehicles or *FVs* (*shaded red in table 7)*.

TABLE 7: FORECASTED NUMBER OF CARS IN 2030 BY TECHNOLOGY (FRIDSTRØM & ØSTLI 2016).

Petrol	**Diesel**	**Battery-electric**	**Plug-in hybrid**	**Non-chargeable hybrid**	**Hydrogen**	**Natural gas**	**Other**	**Total**
330292	600125	1068245	646887	428398	20	126	5	3074073

The share of EVs in 2030 is then found to be 56% in 2030. The share of FVs is the remaining 44%.

EV/FV capital costs: In the official input/output table underlying our social accounting matrix (Statistics Norway 2015) the consumption group "transport equipment" is interpreted as expenditure on cars themselves (capital equipment, not the costs of fuels). This expenditure is split between *evcap* and *fvcap* by the shares derived from table 7 (EVs 56%, FVs 44%).

EV/FV fuel costs: Total expenditure on fuel in the base year is split between EVs and FVs. This is done by calculating shares based on expected costs of fuels in 2030, energy use by technology, and driven kilometer per car. The estimates for number of cars by technology are found in Fridstrøm & Østli (2016) Remaining data (for 2030) is gathered from the Norwegian Environment Agency (MDIR 2016).

TABLE 8: FUEL COSTS AND DRIVING DISTANCE, 2030.

All numbers for 2030 (MDIR 2016).

Petrol/diesel (no taxes)	NOK 6.12/liter
Petrol use, small cars	0.067 liters/km
Electricity	NOK 0.58/kWh
Energy use, small EV	180 kWh/km
Distance driven	13835 for both EVs and FVs

Based on the numbers in table 8, we find that total expenditure on private car fuel in 2030 is split 24% on electric vehicles and the remaining 76% on fossil fuel vehicles.

Export/Import: To re-balance the input/output table (*see SAM, table 5*), we have assumed that the excess petrol in the economy from reduced domestic demand is exported. Conversely, import of electricity is increased to accommodate the new demand for electricity as fuel for electric vehicles.

Climate policy for private cars: We assume that there are no incentives for electric vehicles in R2030, as these are only extended until 2020 and then meant to be phased out (*see chapter 2*). This implies that EVs are subject to the same taxes as FVs in the reference scenario at 29% (the same tax rate as in the base year 2013). Finally, and as discussed in chapter 2, the requirement for biofuels mixed in conventional petrol is omitted from this analysis due to the uncertainty around its enforcement. It is also thought more relevant for heavy duty transport where electrification is more difficult than in private transportation.

6.1.2 GREENHOUSE GAS EMISSIONS BY SECTOR IN R2030

Table 9 presents current and forecasted greenhouse gas (GHG) emissions by sector (Meld.St.29 (2016-2017)). This shows that GHG emissions measured in CO_2-equivalents (CO_2e), amount 27.5 Mtons from non-ETS sectors in 2005. This is the benchmark year for the non-ETS climate goal. To meet the goal, this needs to be reduced by 40% to 16,5 Mtons by 2030. To translate that into a specific goal for only CO_2, we use the share of CO_2 of total GHG emissions in 2030. This is found to be 40.4 Mtons/48.3 Mtons (Meld.St.29 (2016-2017)). Using this ratio, we find that CO_2 emissions from non-ETS sectors must be reduced from 16.8 Mtons in R2030 14.0 Mtons of CO_2 in the policy scenarios.

TABLE 9: EMISSIONS OF GREENHOUSE GASES (GHGS) IN NORWAY BY SECTOR. MTONS CO2E.

Year	**1990**	**2005**	**2015**	**2020**	**2030**
Total emissions	**51.7**	**55.1**	**53.9**	**51.8**	**48.3**
ETS		**27.5**	**26.6**	**26.3**	**25.2**
-Oil and gas extraction		12.9	14.0	13.9	12.8
-Industry		13.6	10.8	11.1	11.0
-Other sources		1.0	1.8	1.3	1.4
Non-ETS		**27.6**	**27.3**	**25.5**	**23.1**
-Transportation		14.9	15.6	14.9	13.5
-Road traffic*		9.7	10.3	9.7	8.4
-Agriculture		4.6	4.5	4.3	4.4
-Other sources		8.1	7.2	6.2	5.2
Sequestration, forest	-10.5	-24.7	-24.4	-23.4	-21.2
Emissions incl. forest	41.3	30.4	29.5	28.4	27.1
Total mainland Norway	43.5	39.8	38.8	36.7	34.4

*part of transportation. Source: (Meld.St.29 (2016-2017))

As evident from table 9, most sectors are expected to lower emissions in 2030 compared to 2015. An important factor behind this development is improved technology in these sectors. Our model does not account for endogenous technology changes. To take account of this development, emission coefficients for each sector are reduced by similar percentages to their associated sectors development in the relevant period (2015-2030) presented in the white paper. For some sectors, it was necessary to assume somewhat better emissions-related technology in 2030 than suggested by the white paper in order to match the reference scenario for total emissions in 2030.

6.2 Policy scenarios

We have chosen to analyse two possible policy approaches to comply with the climate goal for non-ETS sectors. Both succeed in limiting total CO_2 emissions from non-ETS sectors to 14.0 Mtons in 2030. This entails a cut of 2.9 Mtons CO_2 from the reference scenario. However, the associated welfare costs from altered production and consumption patterns are very different in each scenario.

In practical policy, a balance between the two policy options is perhaps the most relevant, a point I will discuss further chapter 7. However, investigating social costs of the two alternatives presented here will help guide policy and be a useful tool to strike the right balance in the policy mix.

6.2.1 A uniform non-ETS carbon tax (S1)

The first counterfactual to the reference scenario (R2030) is labelled 'S1'. In S1, we introduce a uniform, non-ETS carbon tax. More specifically, we implement an input tax on the use of fossil energy *('oil')* in all non-ETS production and final use sectors[8]. This tax is additional to existing taxes in the economy. The tax rate was adjusted incrementally through an iterative process in GAMS/MPSGE until just high enough to induce the necessary cuts in CO_2 emissions from the reference scenario to reach the 2030 climate goal for the non-ETS sector.

In our model, all taxes are aggregated in the row labelled '*tx*' (*see table 5)*, meaning that the rest of the input/output-table uses prices exclusive of taxes. Taxes in our model are implemented as output taxes. This is important because the tax introduced in S1 increases the price paid for fossil energy (*'oil'*) by 55%. The price paid for this fossil energy is uniform across sectors. Hence, the new carbon tax introduced in S1 is also uniform and thus a cost-effective policy tool to reduce non-ETS emissions. In reality, prices paid for fossil energy are differentiated across sectors as they are subject to politically determined, sector-specific taxes. This differentiation causes distortions in the economy, and an uneven playing field for production sectors. An added tax would then maintain, or even amplify existing distortions, depending on how it was implemented.

6.2.2 A subsidy on electric vehicles (S2)

We have labelled the second counterfactual to R2030, 'S2'. In this scenario, government wants to meet the same CO_2 emission goal of 14.0 Mtons by subsidising the purchase of electric vehicles (the tax introduced in S1 is not present in S2). Specifically, the subsidy is implemented as a negative output tax on electric vehicle capital equipment. Because we assume no relative benefits to electric

[8] Mvh, wtp, otp, non, and all final use sectors, see table 5.

cars over fossil fuel cars in 2030 in our reference scenario, electric cars are subject to the same taxes as fossil fuel cars in R2030. These taxes on electric cars are removed and replaced with a subsidy in S2. A similar iterative process to the one carried out in S1 was also completed for S2 until we had arrived at the necessary cut in emissions.

The S2 scenario is chosen to illustrate an amplification of the current support to electric vehicles. S2 thus serves as an alternative to implementing a uniform tax rate across all non-ETS sources, a policy that is expected to meet the goal at a lower cost.

6.3 Results

6.3.1 Effects of a uniform carbon tax in the non-ETS sectors (S1)

Figure 15 shows the total CO_2 emissions from non-ETS sectors for increasing levels of a uniform carbon tax in these sectors.

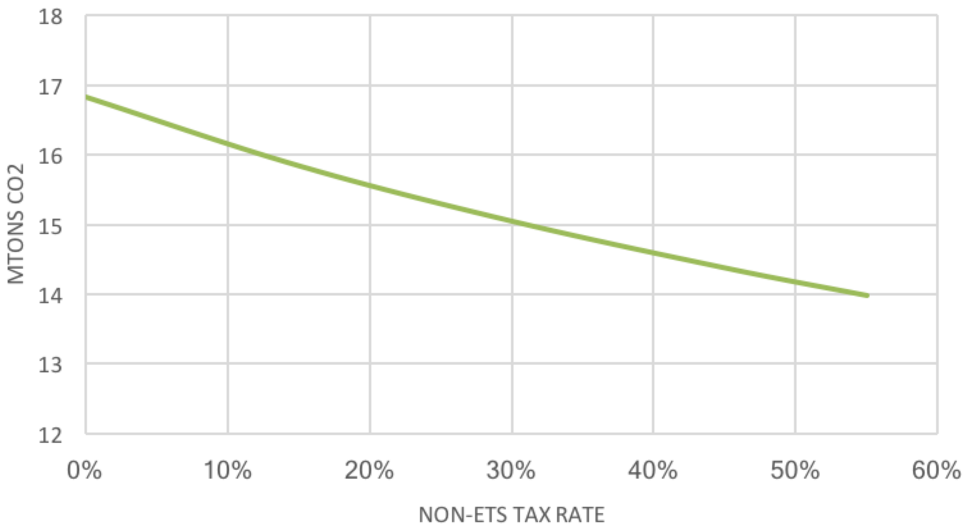
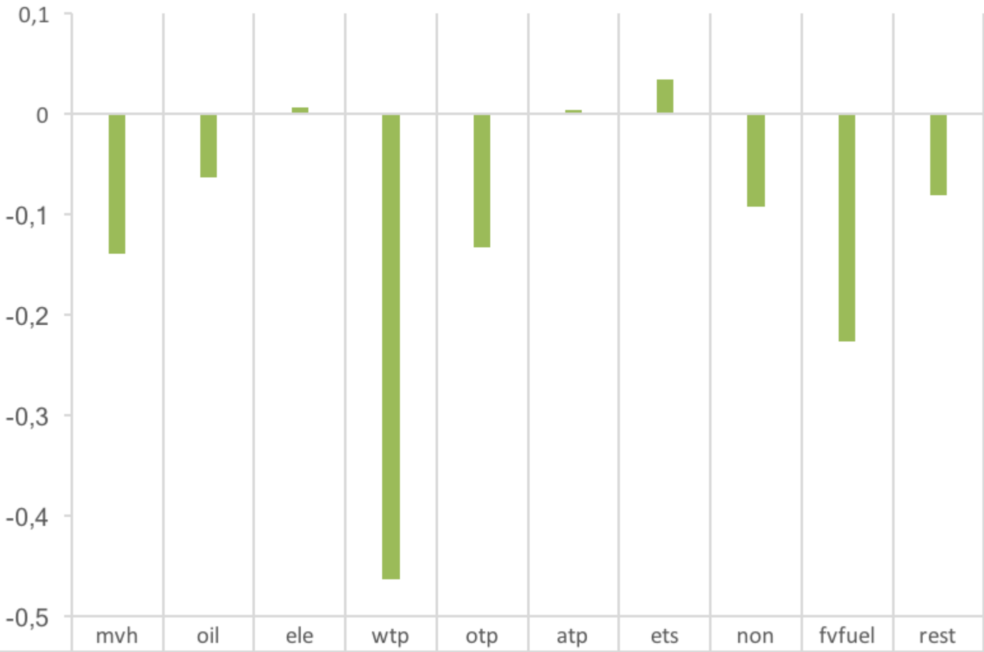


FIGURE 15: TOTAL CO2 EMISSIONS FROM NON-ETS SECTORS FOR DIFFERENT RATES OF UNIFORM CARBON TAX.

In the reference scenario, R2030, non-ETS sectors emit a total of 16.9 Mtons CO_2. Figure 15 shows the decrease in total CO_2 emissions from these sectors for increasing levels of the new tax rate on the use of fossil energy. To reach the goal of 14.0 Mtons in 2030, we need to implement a tax rate at 55%. This means that the price on fossil energy, exclusive of existing taxes, is increased by 55% for non-ETS sectors. Total CO_2 emissions are reduced by 2.9 Mtons with this policy approach.



	mvh	oil	ele	wtp	otp	atp	ets	non	fvfuel	rest
Change from R2030	-13,9 %	-6,3 %	0,6 %	-46,3 %	-13,2 %	0,4 %	3,5 %	-9,2 %	-22,6 %	-8,1 %

FIGURE 16: EMISSION CHANGES FROM R2030 IN S1.[9]

Figure 16 shows the changes in emissions in all sectors as a result of the 55% additional tax rate in S1. The largest relative reductions in CO_2 emissions in this scenario are found in water transport services (46.3%), private consumption of fossil fuel (22.6%), the production of motor vehicles and parts (13.9%), and in public transport services on road and rail (13.2%). It is worth noting that while relative changes in emissions from the production of motor vehicles and parts is large, absolute changes are small. This sector is small in Norway which is reflected in total output value (*see table 5*) and absolute emissions (*see table 6*).

The changes in emissions from the tax introduced in S1 are driven by altered consumption patterns responding to the increase in the domestic price of fossil energy. Reduced demand leads to lower activity levels for the affected production sectors. In the new equilibrium, the consumption of petrol is 21.4% lower than in the reference scenario. Conversely, the consumption electricity for fuel in electric vehicles is 18.4% higher in S1 compared to R2030. In other words, even with no direct support policy for electric vehicles, there is still a large shift towards electric vehicles in S1 as a result of the carbon tax. The demand for electric vehicles does, inter alia, respond to relative prices, which fall for goods without emissions.

[9] *See table 3 and 4 for sector names and corresponding short-hand names*.

The carbon tax successfully reduces emissions from the sectors it applies to, but it is important to notice the rebound effects elsewhere in the economy. Most notably, emissions from the aggregated ETS-sectors ('*ets*') increases by 0.65 Mtons CO_2 in S1, up 3.5% from the 18.5Mton CO_2 these sectors emitted in R2030.

6.3.2 Welfare costs of the uniform carbon tax (S1)

TABLE 10: KEY OUTPUT PARAMETERS IN S1.

Key output parameters	
GDP	-0.14%
Welfare change %	-0.25%
Welfare change, monetary value	NOK - 8.3 bn.
Average social abatement cost	NOK 2900/tCO_2

Table 10 lists some key results to evaluate the policy costs of scenario S1. The assumption of one representative agent entails that all economic costs and gains eventually make their way to this representative agent and affects its welfare. Therefore, we can measure welfare as the representative agent's total consumption and the policy cost as a change in total consumption. To measure the welfare change, we use equivalent variation. Equivalent variation is defined as the income change needed to compensate the consumer for the change in current prices (*see chapter 3.10*). This is exactly what is measured by means of the CES consumption function.

We measure the welfare change this as the percentage change in total consumption from the benchmark value in R2030. In S1, the total welfare loss from R2030 is estimated to be 0.25%. Measured in monetary terms, the welfare loss is NOK 8.3 bn. As previously stated, 2.9 Mtons of CO_2 must be cut from non-ETS sectors to meet the climate target in 2030. This implies that the average, social abatement cost is NOK 2900/tCO_2. If the marginal abatement curve is linear, the marginal cost of abatement will be NOK 5800/ton $CO_{2,}$ twice that of the average abatement cost.

In a first-best world with no market failures or initial policy interventions, the optimal policy would be to set a uniform carbon tax on all emissions in the non-ETS to meet the target. In this way, the tax would minimise the distortions of consumption and production from the reference scenario, which we assume represents an economy in equilibrium. However, the Norwegian economy is an imperfect economy with both market failures and existing taxes. The model accounts for several of the existing price wedges in the economy, first of all those arising from policy interventions. These affect the computed welfare costs, potentially in both directions. Negative contributions to welfare can be counteracted by spending the carbon tax revenue in ways that alleviate distorting taxes (*inducing so-called 'double dividends'; see chapter 3.9*). Note that our model does not incorporate welfare gains from internalising negative externalities of emissions. In a small economy like the Norwegian, the externalities from (own) carbon emissions are very small. Other externalities, like local pollution, noise etc. would be of larger importance (*see also section 3.6 on the social cost of carbon*).

6.3.3 Effects of a subsidy on EVs (S2)

Figure 17 shows the emissions reduction for a set of subsidy rates placed on the purchase of electric vehicles.

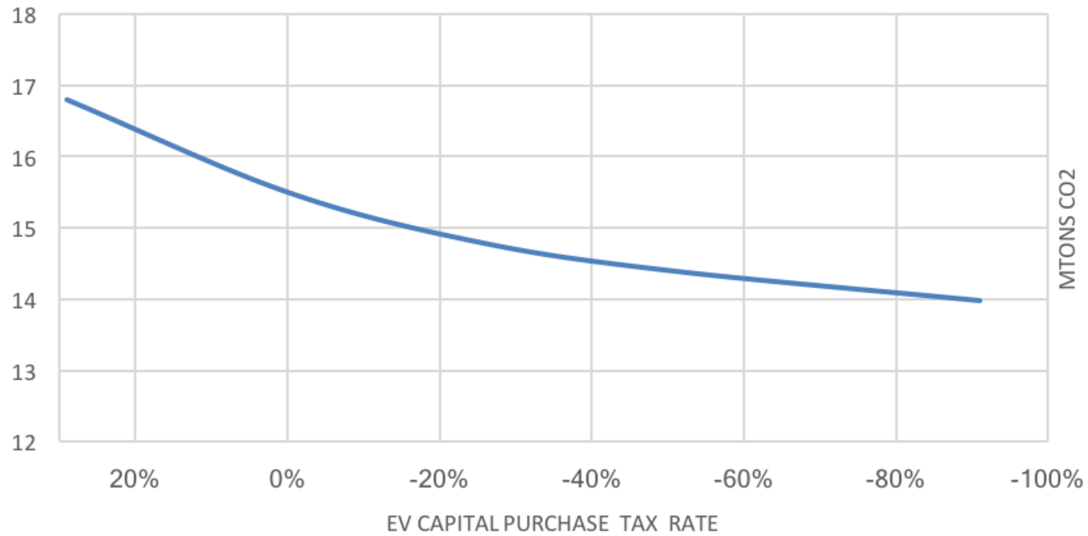


FIGURE 17: TOTAL NON-ETS EMISSIONS WITH VARIOUS EV SUBSIDY RATES.

As evident from figure 17, policy scenario S2, by assumption, reaches the necessary emission reductions to meet the goal at 14.0Mtons CO_2 in 2030. In the reference scenario R2030, electric vehicles (EVs) are subject to the same tax rate as fossil fuel vehicles (FVs) of 29%. In other words, there is no relative tax wedge between electric and fossil fuel vehicles in R2030. To cut emissions by 2.9 Mtons CO_2 using only a subsidy for EVs, the original tax rate on the purchase of EVs must be replaced by a subsidy of 91%.

The effects on emissions from each sector as a result of policy scenario S2 are presented in figure 18.

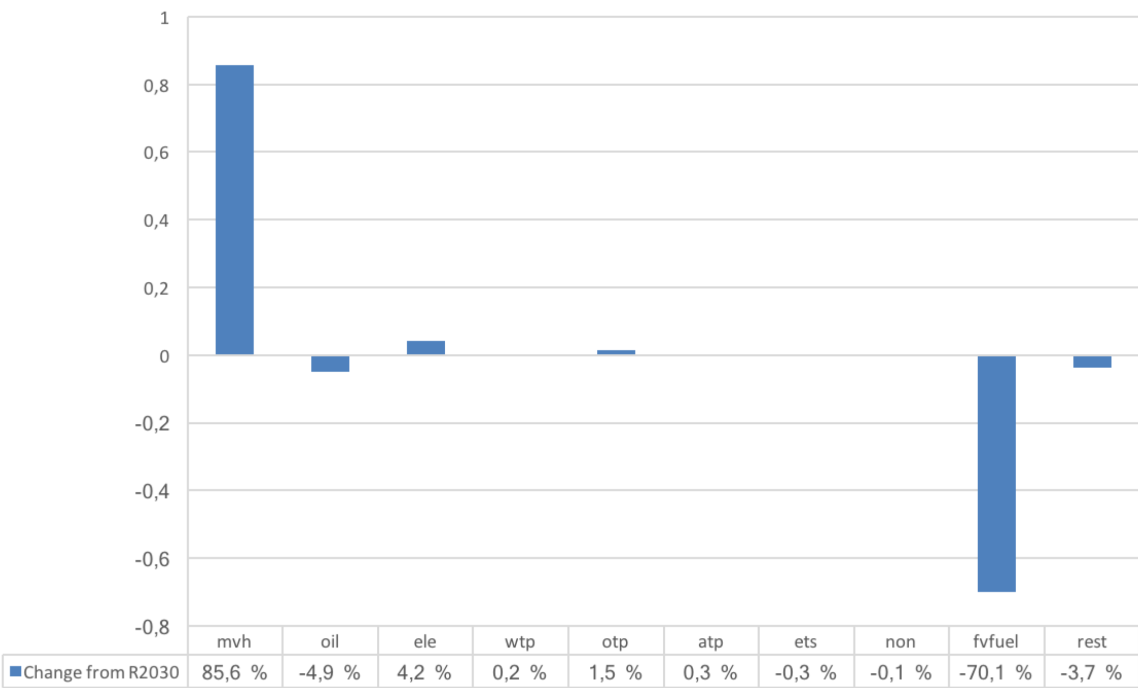


FIGURE 18: EMISSION CHANGES FROM R23030 IN S2.

The substantial subsidy on EVs changes consumption significantly in response to new prices. The market-clearing domestic price exclusive of taxes and subsidies is 62.2% lower in S2 than in the reference scenario. The subsidy to EVs leads to a substantial shift away from FVs, and hence, emissions from this sector are reduced by 70.1% (see figure 18). Further, the figure shows that emissions from the production of fossil energy is reduced by 4.9% as activity levels in this sector fall in response to reduced demand for petrol. Again, there is a large relative change in the production of motor vehicles and parts, but absolute emissions are small due to the size of this sector in Norway.

6.3.4 Welfare costs of the EV subsidy (S2)

TABLE 11: KEY OUTPUT PARAMETERS IN S2.

Key output parameters	
GDP	0.43%
Welfare change %	-1.00%
Welfare change, monetary value	NOK -32.8 bn.
Average social abatement cost	NOK 11400/tCO_2

Table 11 lists the key results from the EV subsidy. This policy stimulates economic activity, leading GDP to increase by 0.43%. However, when looking at the changes in welfare for the representative agent, it becomes obvious that this is a very expensive way to meet the reduction goal for the non-ETS sector. Total welfare is reduced by 1% with this policy compared to the reference scenario in 2030. This translates to a welfare loss of NOK 32.8 bn., four times larger than the welfare loss induced by the carbon tax (S1). As this policy also needs to induce emission cuts of 2.9 Mtons to meet the climate target, the average social abatement cost amounts to NOK 11400/tCO_2. Again, if the marginal abatement curve is linear, this implies a marginal abatement cost of NOK 22800/tCO_2, twice that of the average abatement cost. This implies that in our model, meeting the non-ETS climate goal with an electric vehicle subsidy is four times as expensive as meeting it with a uniform carbon tax.

6.3.5 Comparison and discussion of the policy alternatives

Both policy options successfully reduce the necessary 2.9 Mtons of CO_2 from non-ETS sectors. However, the distribution of emissions from each sector varies between the two scenarios. Table xx shows the emissions from each sector in R2030, S1, and S2.

TABLE 12: EMISSIONS BY SECTOR. MTONS CO2.

Emission source	**R2030**	**S1**	**S2**
Total Emissions	**41.0**	**38.5**	**37.9**
ETS sectors	**24.2**	**24.6**	**23.9**
Refined petroleum products	4.0	3.8	3.8
Production and distribution of electricity	0.6	0.6	0.6
Air transport services	1.1	1.1	1.1
Rest-ETS	18.5	19.2	18.5
Non-ETS sectors	**16.8**	**14.0**	**14.0**
Motor vehicles and parts	0.02	0.01	0.03
Water transport services	1.5	0.8	1.5
Land transport services	5.3	4.6	5.4
Rest non-ETS	5.4	4.9	5.4
Consumption of petrol	4.2	3.2	1.3
Rest private consumption	0.5	0.5	0.5

In table 12 there are several implications of the policies that are worth noticing. First, emissions from the production and distribution of electricity remain unchanged. Activity levels in this production sector increase in both scenarios but this sector is associated with very low emissions in Norway as electricity is almost exclusively produced by hydropower. Emissions from air transport services do not change in S1 as it is part of the ETS and hence not subject to the tax. The fact that it does not change with an EV subsidy implies that there limited substitution between transport services provided by electric vehicles and air travel.

Further, and as mentioned, the carbon tax induces 0.65 Mtons of CO_2 to leak to the aggregate of other ETS sectors. With a subsidy to electric vehicles, there is instead some leakage to another non-ETS sector, namely the production and motor vehicles and parts. Another problem, which is perhaps even more important, is that the emission cuts induced by the carbon tax in water transport services, land transport services, and the aggregate for remaining non-ETS sectors are not realised with the EV subsidy. These effects contribute to the substantial subsidy necessary to cut non-ETS emissions by 2.9 Mtons CO_2. In S1, the main leakage was to other ETS sectors where emissions are capped. This should only lead to an upward pressure on ETS quota prices. The fact that emissions leak to another non-ETS sector in S2 means that we need an extreme subsidy to meet the goal. The welfare loss within this model then turns out to be four times as large as in the situation where the goal is met by taxing non-ETS carbon emissions directly.

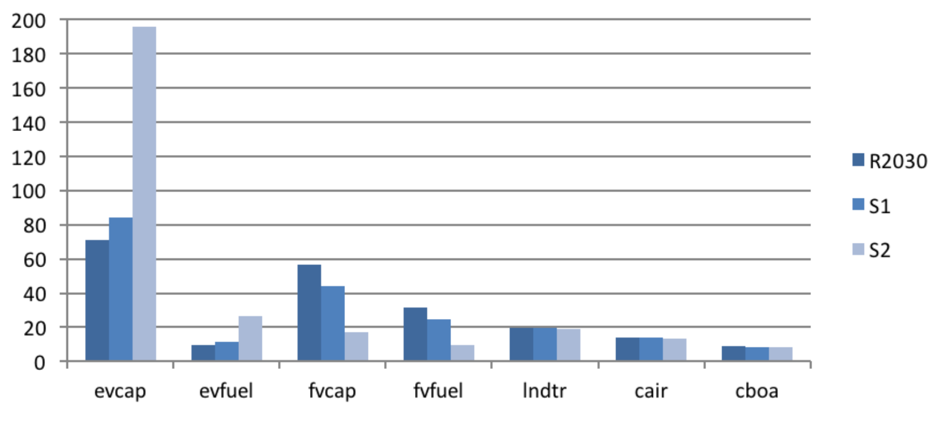


FIGURE 19: CONSUMPTION BY TRANSPORT SECTOR. BN NOK.

Consumption of various transportation modes is presented in figure 19. The largest effects of the policy scenarios are, as expected, between electric vehicles and fossil fuel vehicles, with a proportional change in their associated fuels (this follows from our assumption that the elasticity of substitution between capital and fuel is zero, see section 5.2.2). Consumption of land transport services (‘lndtr’), air transport services (´cair´), and water transport services (‘cboa’) is reduced in both S1 and S2, but only marginally. This is likely influenced by the limited possibility to substitute public for private transportation given by the elasticity of substitution, $\sigma = 0.5$. As the area of interest here is Norway, this elasticity must be interpreted as an average of cities and other areas in Norway. If one wanted to the effects of these policies in areas where public transportation is easily accessible, this elasticity should be increased correspondingly. Due to the time constraint for this thesis, a sensitivity analysis of various elasticities is not included here, but is recommend for further research on this topic.

7 DISCUSSION OF EFFECTS OUTSIDE THE MODEL

This research set out to investigate how the emissions reduction goal in 2030 for the Norwegian non-ETS sector could be met. We investigated two concrete policy options: a subsidy on the purchase of EVs and a uniform non-ETS carbon tax. Our main objective was to answer whether electric vehicle incentives should be the main policy to meet Norway's non-ETS climate goal. From an economic point of view, this policy option should only be supported if it achieves its goal cost-effectively. Our results suggest that this is not a cost-effective policy option. Rather, we find that using an electric vehicle subsidy to reach the objective is four times more expensive than using a uniform non-ETS tax, measured in total welfare loss. Might there be other reasons to justify subsidies to zero emission vehicles?

Advocates of EV subsidies often point to the fact that they produce less negative externalities than their fossil fuel counterparts, e.g. a cleaner local environment and less noise pollution (see section 2.6). However, an electric vehicle (EV) subsidy can be problematic as EVs still contribute to both pollution and noise, and additionally exhibit many other of the same negative externalities as those produced by fossil fuel vehicles, such as congestion, road wear, and accidents. Arguably, these should not be subsidised. If the goal of the policy is a cleaner local environment or less congestion, one can just as easily argue that we should instead increase investments in public transportation. In general, and as discussed, economic theory suggests one instrument per goal to meet the objectives effectively. The stated goal for the current EV policy scheme is to reduce greenhouse gas emissions from road traffic. Hence, we conclude that subsidising the purchase of electric vehicles is not a targeted policy to achieve that objective. Instead, we should tax carbon emissions directly and uniformly.

The 'polluter pays' –principle is fundamental in Norwegian climate policy. However, the government's strategy also emphasizes that research and development (R&D) of new, clean technologies should be a priority (St.meld. nr 21 (2011-2012)). Further, it is a stated goal that Norway should contribute to technology development, not just for the sake of Norway but for the benefit of general technology advances (NOU 2009:16). Whenever there is knowledge spill-over from R&D and/or lowered costs from learning by doing, there are positive externalities in technology development. This can justify government support for immature technologies such as electric vehicles. New technologies often face significant market-entry barriers because existing technologies enjoy economies of scale and low cost of production from extensive learning. These factors can lead to carbon lock-in, meaning that we lock ourselves into an infrastructure based on carbon-intensive or 'dirty' technologies even when clean alternatives are desirable from a societal point of view. Avoiding this path-dependency is a strong argument for government intervention that lowers market barriers for new, clean technologies (Martinsen 2011).

Clean technologies are also frequently subject to positive network effects. These arise if one agent's adoption of the good increases the benefit of other adopters and/or strengthens incentives to adopt the good (Farrell & Klemperer 2007). For instance, it is risky to try new technologies such as the electric car when well- established alternatives are much more accessible. For instance, the availability of charging stations is very limited compared to conventional gas stations. However, if you are frequently exposed to the new technology, the barriers for adopting it yourself are likely to be reduced.

Many economists agree that rather than 'picking winners', government might want to avoid subsidising one particular technology, and instead impose a direct, Pigouvian tax and subsidies to general R&D. This may, however, not lead to an optimal level of technology diffusion in light of positive network effects. Greaker and Midttømme (2016) explored whether a Pigouvian tax would induce the optimal level of clean technology diffusion. Specifically, they looked at whether a failure to account for network effects in emission taxes led to *excess inertia*, meaning that a greater market share for one technology would increase welfare, but was still not successfully diffused into the market. This can be analysed as a coordination game with two Nash equilibria. Even when one equilibrium is clearly better than the other, there is a need for substantial policy help to increase the market share of the new technology and move to the superior Nash equilibrium. The specific case of EV introduction in Norway was used as an example to illustrate how an emission tax might fail to harness these positive network externalities. The conclusion in this research was that a standard Pigouvian tax was about half that of the current tax, and even further below the optimal tax (Greaker & Midttømme 2016). This is in line with previous research that estimates the benefits of stimulating R&D and technology diffusion directly. For instance, Grubb et al. (1995) find this effect to be seven times larger than the direct Pigouvian benefits of reduced emissions.

Finally, a uniform non-ETS carbon tax might prove politically infeasible and create resistance towards climate policy. Electric vehicle subsidies are likely much easier to implement and therefore politically attractive. However, our two policy options represent extremes, and a policy mix that strikes the right balance between the two would likely be a more realistic outcome, perhaps in combination a road use tax that directly targets some of the discussed negative externalities of motor vehicles.

As discussed in chapter 2, there will probably be an opportunity for Norway and other European countries to meet part of their non-ETS obligation through a one-time purchase of ETS quotas. This will not be sufficient to meet the non-ETS requirement, but will contribute to improve the cost-effectiveness of emission abatement by lowering the marginal abatement cost in non-ETS and have an upward price-effect on ETS quotas, thus contributing to equalizing marginal costs of abatement. This relates to our discussion about flexibility in meeting the required reduction goal. The opportunity to outsource emission abatement must be expected to improve cost-effectiveness short term. It would also mean that a lower non-ETS carbon tax rate is needed to meet the 2030 climate goal for this sector.

However, it must also be expected to reduce incentives to invest in clean technology and emission abatement at home and in comparable high-cost EU countries. The long-term effects might be net negative if other countries gain competitive technological edge over Norway because flexibility was used to avoid a necessary transition to a low-carbon society at home. This is an argument in favour of supporting associated industries to electric vehicles, even if the production of the actual vehicles is a small industry in Norway. The EU has signalled even stronger requirements for climate policies after 2030, which would prove detrimental to Norway had it not prepared itself for a low-carbon future. Supporting electric vehicles help create viable ‘green’ associated industries, e.g. a market for used EVs, proper recycling of batteries, electric car service, and charging stations (Greaker & Midttømme 2016), which can be an argument for supporting one, promising technology.

A final point relates to the generation and use of motor vehicle fuel. Generation of electricity is included in the EU ETS and as such required to either abate excess emissions or purchase quotas so they are reduced elsewhere. There are no carbon emissions associated with the use of electricity as fuel in zero emission vehicles. Conversely, while the production of petrol products is covered by the ETS, the emissions from the use of petrol in fossil fuel vehicles is one of the largest sources of emissions outside of the ETS. A study by Gavenas et al. (2015) finds that more than 90% of oil-related emissions are associated with consumption, not production. A policy that electrifies the private transport fleet will in effect move the largest source of non-ETS emissions into the European quota market. The emissions from the ETS are capped, and embedding the transport sector into the ETS will therefore not increase ETS emissions, but instead have an upwards price effect on EU ETS quota prices. While these effects must be expected to be marginal when only the Norwegian private car fleet is electrified, this might prove a significant point if the rest of Europe switch to electric vehicles.

8 CONCLUDING REMARKS AND SUGGESTED FURTHER RESEARCH

Throughout this thesis we have tried to answer the question of whether subsidising electric vehicles is the right policy to meet Norway's climate goal for its non-ETS sectors. Our results suggest that, within the limitations of our model, this is not a cost-effective climate policy. If we instead opted to impose a carbon tax on the use of fossil energy in non-ETS sectors, we could meet the same goal at one fourth of the costs induced by the electric vehicle subsidy.

However, as discussed in chapter 7, there are several dynamic and political effects not captured in our model that to some extent might justify electric vehicle subsidies after all. Importantly, electrifying the car fleet moves emissions from transportation, the most polluting non-ETS sector, and embeds them in the EU ETS where emissions are capped. The result is an upward price effect on emissions quotas and stronger incentives to abate carbon emissions.

Our analysis is based on a CGE model of the Norwegian economy built for this thesis. It provides a strong foundation for ex ante policy analysis. However, the problem of insufficient data is a persistent one in CGE modelling, often forcing modellers to use rather arbitrary values, or 'coffee table elasticities' as coined by Dawkins et al. (2001). Empirical work can provide some insight into appropriate functional forms, but some educated guesswork is needed. Further research should therefore increase the robustness of our results by conducting a sensitivity of key elasticities, in particular between electric and fossil fuel vehicles. This was calculated using the latest-available bottom-up information and forecasts regarding the development of EV range, battery costs etc. Forecasting of a rapidly evolving technology is difficult, and the model should be updated when new data is available.

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APPENDICES

THE COMPUTATION OF THE ELASTICITY OF SUBSTITUTION BETWEEN EVS AND FVS

Authored by Head of Research at Statistics Norway, Taran Fæhn.

The basis for this part of the research is the study on policy cost of phasing in electric vehicles carried out by the Norwegian Environment Agency (2016) and the resulting emission levels of CO_2. The costs of a larger EV share in 2030 are in this report related to compensating the consumer for the increased user-cost of the 2030 fleet. The costs of increasing the EV share of the fleet indicates how much the consumer must be compensated for being willing to take on these larger costs. This is exactly what we need to calculate the CES parameter. It can be interpreted as the inclination to increase the 2030 relative use of EVs to FVs for each percent increase in the relative user-cost of FVs to that of EVs.

MDIR (2016) has compared four different scenarios. However, only two are based on comparable time profiles and describe the status of the 2030 fleet (the others look at the 2025 fleet). These two are coined Measure 1 and Measure 2 in MDIR (2016). We compare these two 2030 states to calculate the CES parameter. The 2030 fleets in the two states are assumed to provide equal services in terms of passenger transportation, .i.e., we can interpret the two fleets to provide the same consumer utility. The data we need is then: The share of EVs to FVs in the two states and the user-cost of the FV fleet to the EV fleet in 2030, respectively.

The EVs and FVs in the fleet, and also the compositions of vintages, are available from MDIR (2016). When comes to the user-costs of the EVs and FVs in 2030, these will depend on the composition of vintages in the fleets and their respective user costs. The higher the EV share, the faster will be the phasing-in of EVs and the share of relatively costly, early-vintage EVs in the 2030 fleet. The user-costs of a vintage consist of the annuities of the investment costs in the vehicles and infrastructure (chargers) and the vintage's yearly energy and maintenance costs. Since EVs are to produce the same level of utility as FVs according to the CES preference structure, the user-costs of the former should also include the value of the consumer's disadvantage when buying and using an EV instead of a FV. MDIR (2016) provides vintage estimates for all these cost elements, also for the disadvantages.

Finally, the user-cost of a FV to an EV in a given vintage will include the value of the policy intervention necessary, i.e. the price wedge needed to incentivise the consumer to increase the share of EVs in the vintage. In MDIR (2016) this compensation is set so as to fill the cost gap between the two vehicles (including the disadvantage cost). Together with the disadvantage value, the policy intervention is calibrated to the actual price wedge in 2016 and assumed to fall over time as the EV and battery technology advances and gradually approaches the costs of FVs. It can, therefore, be regarded as the overall effect of all tax and subsidy instruments imposed on EVs and FVs, and should, in principle, also include all other, non-fiscal, policy interventions. This price wedge is the only policy intervention included in the cost estimates: Since only relative costs matter for the CES parameter, policies that affect the user costs of EVs and FVs similarly can be abstracted from.

MDIR (2016) have data for both small and large cars. In our calculation we have used only the data for the small cars, since these are regarded more comparable and more certain by MDIR (2016). Implicitly we then assume that relative shares react similarly to relative user-costs also in case of other types of cars. Moreover, we do not treat hybrid cars as a separate type of car, which imply that we assume they can be regarded as partly EV and partly FV.

There are several caveats to be aware of with our calculation. First, comparing only two states, both being future scenarios based on single experts' anticipations, is a weak empirical foundation. MDIR (2016) carefully describes the assumptions and stresses uncertainties and simplifications made. However, since EVs have been around for a very short period, and the technological development is extremely rapid, the alternative of using historical data is not more appealing. To our knowledge, no empirical study on historical data is yet made.

Second, there is a serious shortcoming with the necessary compensation estimates as set by MDIR (2016). Since the phasing-in of EVs is faster in Measure 2 than in Measure 1, it is unreasonable to assume that the same compensation per car (in a given vintage) is necessary. In accordance with consumer theory, compensation on the margin should be expected to increase, so that average compensation should be higher in Measure 2 than in Measure 1. In our calculations, compensation is higher. However, this is not because of higher average compensation within the same vintage, only because the weights of early vintages, which are more costly/less technologically advanced, increase. The excess user-cost of Measure 2 over Measure 1 is therefore underestimated; more is actually needed to incentivise the more ambitious measure. Subsequently, the elasticity is lower than assumed in MDIR (2016), but we don't have data to estimate how much lower. We address this uncertainty by halving the CES parameter in a sensitivity analysis.[10] The problem reflects the more general objection that bottom-up cost estimates are usually based not on preference theory and economic reasoning, but on technological information.

---

[10] We have considered including large cars into our calculations. If, on the margin, consumers will demand larger cars, and these are associated with higher compensation, marginal compensation will increase. However, the underlying problem that *within the same type* of cars, compensation increases on the margin, will not be solved: still, Measure 2 will involve more cars of the same type than Measure 1 (both of small and large cars).

```
$Title Model EV_REF: Simple model of Norwegian economy (2013) for EV analysis

*       Tolerance for replication check (reflecting the monetary units):
scalar objtol   Tolerance for replication check of benchmark data /1e-3/;


* Section (i)    Data specification and benchmarking

Sets       g      All sectors
/mvh,oil,ele,wtp,otp,atp,ets,non,evcap,evfuel,fvcap,fvfuel,lndtr,cair,cboa,rest,govt/,
           i(g)   Produced goods          /mvh,oil,ele,wtp,otp,atp,ets,non/,
           c(g)   Household consumption   /evcap,evfuel,fvcap,fvfuel,lndtr,cair,cboa,rest,govt/,
           o(g)   Transport-related consumption /evcap,evfuel,fvcap,fvfuel,lndtr,cair,cboa/,
           f      Factors of production   /K,L/,
           h      Emission sectors        /coa,oil,crp,i_s,avk/,
           n(g)   Non-ETS and final tax   /mvh,wtp,otp,non,fvcap,fvfuel,lndtr,cboa,rest,govt/ ;
Alias (i,j),(f,ff);


* The two following tables are for 2013.

Table SAMimp(*,*) Social Accounting Matrix Imports (1000NOK)
         mvh      oil      ele      wtp      otp      atp      ets       non        evcap    evfuel   fvcap    fvfuel
lndtr    cair     cboa     rest     govt      exp
mvh      525767    0        0        0       570542   0        317303    8232259    0        0        16277452 0
0        0        0        133044   27357633  776000
oil      68699    12611951 204978   11302955 4750649  5865252  12138000  38828739   0        0        1052412  4737352
0        0        0        9632990  840039    802000
ele      4445     256814   6163     4748     31419    7274     782966    1060289    0        0        0        0
0        0        0        1067968  -97088    0
wtp      745      12186    1017     10043    10896    3577     30890     258192     0        0        0        0
0        0        827638   0        -135186    0
otp      9677     316323   45       41283886 1895255  5333979  504215    2669419    0        0        12068    0
```

```
43858    0        0        0         2385277    0
atp      6805     111368   9294      91784     2184603  1349696  282321    2438379   0        0        0        0
0        3487034  0        0         -28288     190000
ets      1079201  12252897 19034     28783     4620639  57773    24793115  18442596  0        0        0        0
0        0        0        1397372   -1992410   637998
non      709292   4200599  1936709   6166993   21224258 2356556  36520303  268154658 0        0        3617834  0
0        0        0        202257114 27382529   13928997;

Table SAMdom(*,*) Social Accounting Matrix Domestic Production (1000NOK)
        mvh      oil      ele       wtp      otp      atp      ets       non        evcap    evfuel   fvcap    fvfuel
lndtr    cair     cboa     rest      govt       exp
mvh     182438   5117     755       1908     197833   2977     141787    2858293    0        0        6799280  651
0        0        0        106718    -5513530   2717768
oil     66954    7528035  293032    2461859  3743530  210943   7197783   29319173   0        0        71577    8666028
0        0        0        2130817   24888038   71298189
ele     83529    2753259  2258438   123964   785809   170091   8734135   23634466   0        0        5683     5743
0        0        0        24222911  932622     4945365
wtp     22522    463111   67697     12740744 2354245  81683    4824774   8342152    0        0        16165    16334
0        0        6306362  773998    7312464    109465712
otp     227757   4849229  152876    790147   8351026  282604   8708561   56888807   0        0        6239012  433782
15358142 0        0        34917147  14735186   30537718
atp     22846    309889   43841     277147   4811790  5198915  2469709   11720928   0        0        461733   4480
0        7361966  0        434064    2663675    9534192
ets     386628   69023379 36443     1684816  7338937  221154   18144832  33816489   0        0        19998    20190
0        0        0        1561837   118535723  636757549
non     1632891  18791182 7851129   17216602 44046763 8749115  89316681  1110092638 0        0        40927786 2329440
0        0        0        581640020 1291683316 322150512
tx      17804    770661   5611549   -4651379 -5471194 -464589  6031625   42449523   0        0        31489000 18378000
1232000  868000   310000   136318000 58012000   0
K       578000   10801000 41159000  34914000 42281000 3717000  575963000 686256000
L       1876000  12819000 9004000   28339000 38744000 12171000 90646000  1190965000
imp     2404631  29762138 2177240   58889192 35288261 14974107 75369113  340084531  0        0        20959766 4737352
43858    3487034  827638   214488488 55712506   16334995;


* The two following tables are for 2030.

Table SAMimp30(*,*) Social Accounting Matrix Imports (1000NOK)
         mvh      oil      ele      wtp      otp      atp      ets       non        evcap     evfuel    fvcap
fvfuel     lndtr    cair     cboa     rest      govt       exp
```

```
mvh      525767   0        0        0        570542   0        317303    8232259    9081787.36 0         7195664.64
0         0        0        0        133044    27357633   776000
oil      68699    12611951 204978   11302955 4750649  5865252  12138000  38828739   587179.246 0         465232.754
3615856   0        0        0        9632990   840039     802000
ele      4445     256814   6163     4748     31419    7274     782966    1060289    0          1121496   0
0         0        0        0        1067968   -97088     0
wtp      745      12186    1017     10043    10896    3577     30890     258192     0          0         0
0         0        0        827638  0         -135186    0
otp      9677     316323   45       41283886 1895255  5333979  504215    2669419    6733.18    0         5334.82
0         43858    0        0        0         2385277    0
atp      6805     111368   9294     91784    2184603  1349696  282321    2438379    0          0         0
0         0        3487034 0        0         -28288     190000
ets      1079201  12252897 19034    28783    4620639  57773    24793115  18442596   0          0         0
0         0        0        0        1397372   -1992410   637998
non      709292   4200599  1936709  6166993  21224258 2356556  36520303  268154658  2018522.25 0         1599311.75
0         0        0        0        202257114 27382529   13928997;

Table SAMdom30(*,*) Social Accounting Matrix Domestic Production (1000NOK)
        mvh      oil      ele      wtp      otp      atp      ets       non        evcap      evfuel   fvcap
fvfuel   lndtr    cair     cboa     rest     govt      exp
mvh     182438   5117     755      1908     197833   2977     141787    2858293    3793567.64 154      3005712.36
497      0        0        0        106718   -5513530   2717768
oil     66954    7528035  293032   2461859  3743530  210943   7197783   29319173   39935.433  0        31641.567
6614479  0        0        0        2130817  24888038   73349738
ele     83529    2753259  2258438  123964   785809   170091   8734135   23634466   3170.754   2052909  2512.246
4383     0        0        0        24222911 932622     2893816
wtp     22522    463111   67697    12740744 2354245  81683    4824774   8342152    9019.046   3867     7145.954
12467    0        0        6306362 773998   7312464    109465712
otp     227757   4849229  152876   790147   8351026  282604   8708561   56888807   3480973.58 102691   2758038.42
331091   15358142 0        0        34917147 14735186   30537718
atp     22846    309889   43841    277147   4811790  5198915  2469709   11720928   257617.772 1061     204115.228
3419     0        7361966 0        434064   2663675    9534192
ets     386628   69023379 36443    1684816  7338937  221154   18144832  33816489   11157.618  4780     8840.382
15410    0        0        0        1561837  118535723  636757549
non     1632891  18791182 7851129  17216602 44046763 8749115  89316681  1110092638 22835112.6 551459   18092673.4
1777981  0        0        0        581640020 1291683316 322150512
tx      17804    770661   5611549  -4651379 -5471194 -464589  6031625   42449523   17568867.8 4350710  13920132.2
14027290 1232000  868000   310000   136318000 58012000   0
K       578000   10801000 41159000 34914000 42281000 3717000  575963000 686256000
L       1876000  12819000 9004000  28339000 38744000 12171000 90646000  1190965000
```

```
imp      2404631  29762138 2177240  58889192 35288261 14974107 75369113  340084531  11694222   1121496  9265543.96
3615856  43858    3487034 827638  214488488 55712506   16334995;

Table CO2energy(i,g) Energy-related CO2 emissions (Kton)
         mvh      oil      ele      wtp      otp       atp      ets       non        evcap    evfuel   fvcap    fvfuel
lndtr    cair    cboa    rest      govt
oil      13.351   2192.452 643.180  1598.055 5461.937  1232.732 13564.31  5109.877   0        0        0
4605.633 0        0       0       339.444   0
ets      0        138.961  0        0        0         0        83.047    2.277      0        0        0        0
0        0       0       0         0
non      0        66.528   0        0        0         0        489.6     1043.362   0        0        0        0
0        0       0       0         0          ;

Parameter CO2process(g) Process CO2 emissions (Kton)
/mvh         0.25
 oil         2472.412
 ele         0.150
 wtp         6.934
 otp         11.505
 atp         0.070
 ets         4798.347
 non         385.583
 evcap       0
 evfuel      0
 fvcap       0
 fvfuel      0
 lndtr       0
 cair        0
 cboa        0
 rest        71.025
 govt        0    /;

Table AdjustedEn(i,g) Adjusted emissions table energy-related (Pmeld)
           mvh      oil      ele      wtp      otp       atp      ets       non        evcap    evfuel   fvcap
fvfuel  lndtr   cair    cboa    rest    govt
oil        11.35    1578.57  463.09   1310.41  4478.79   924.55   11529.66  3576.91
3515.31                       339.4
ets        0.00     100.05   0.00     0.00     0.00      0.00     70.59     1.59
non        0.00     47.90    0.00     0.00     0.00      0.00     416.16    730.35
;
```

```
Parameter AdjustedPro(g) Adjusted emissions table process (Pmeld)
/
mvh         0.21
oil         1780.14
ele         0.11
wtp         5.69
otp         9.43
atp         0.05
ets         4078.60
non         269.91
evcap       0
evfuel      0
fvcap       0
fvfuel      0
lndtr       0
cair        0
cboa        0
rest        71.03
govt        0        /;


Parameters
scale     scaling factor (convert data from 1000 NOK to ... NOK)  ;

* Convert all numbers
scale              = 1000;
scale              = 1000000;

SAMdom(i,g)        = SAMdom(i,g)/scale;
SAMimp(i,g)        = SAMimp(i,g)/scale;
SAMdom(f,g)        = SAMdom(f,g)/scale;
SAMdom('tx',g)     = SAMdom('tx',g)/scale;
SAMdom('imp',g)    = SAMdom('imp',g)/scale;
SAMdom(i,'exp')    = SAMdom(i,'exp')/scale;

SAMdom30(i,g)      = SAMdom30(i,g)/scale;
SAMimp30(i,g)      = SAMimp30(i,g)/scale;
SAMdom30(f,g)      = SAMdom30(f,g)/scale;
SAMdom30('tx',g)   = SAMdom30('tx',g)/scale;
```

```
SAMdom30('imp',g) = SAMdom30('imp',g)/scale;
SAMdom30(i,'exp') = SAMdom30(i,'exp')/scale;
*display SAMdom;


Parameters
fd0(f,g)     Benchmark factor demands,
e(f)         Factor endowments,
z0(g)        Benchmark sectoral output
po0(g)       Reference price output tax
pi0(i,g)     Reference price input tax
t(g)         Sectoral tax level,
txrate(g)    Existing ad valorem tax rate
ti(i,g)      Input tax
tirate(i,g)  Input tax rate
vdfm(i,g)    Value of domestic intermediates
vifm(i,g)    Value of imported intermediates
vafm(i,g)    Value of Armington intermediates (domestic & imported)
mrow(i)      Imports from rest of the world
vxm(g)       Exports
vb           Net exports
income       Total income
CO2en(i,g)   Energy-related CO2 emissions,
CO2pro(g)    Process-related CO2 emissions,
CO2total(g)  Total emissions by sector
CO2all       Total emissions ;

* Extract data from original format into model-specific arrays
* all below changed from sam to sam30
fd0(f,g)   = SAMdom30(f,g);
t(g)       = SAMdom30("tx",g);
e(f)       = sum(i,SAMdom30(f,i));

vdfm(i,g) = SAMdom30(i,g);
vifm(i,g) = SAMimp30(i,g);
vafm(i,g) = vdfm(i,g) + vifm(i,g);
mrow(i)   = sum(g, vifm(i,g));
vxm(i)    = SAMdom30(i,"exp");
vb        = sum(g, vxm(g)) - sum(i, mrow(i) );
income    = sum(f, e(f)) + sum(g, t(g)) + sum(i, mrow(i)) - sum(i, vxm(i));
```

```
z0(g)      = sum(i, (vdfm(i,g)+vifm(i,g))) + sum(f, fd0(f,g)) + t(g);
txrate(g)$z0(g)= t(g)/z0(g);
tirate(i,g) = 0;
*p0(g)   = (1/(1-txrate(g)));
po0(g)     = (1-txrate(g));
pi0(i,g)   = (1+tirate(i,g));


CO2en(i,g)   = co2energy(i,g);
CO2pro(g)    = co2process(g);
CO2total(g) = sum(i,co2en(i,g))+co2pro(g);
CO2all       = sum(g, CO2total(g));
display "1", CO2en, CO2pro, CO2total, CO2all;

CO2en(i,g)   = adjusteden(i,g);
CO2pro(g)    = adjustedpro(g);
CO2total(g) = sum(i,co2en(i,g))+co2pro(g);
CO2all       = sum(g, CO2total(g));
display "2", CO2en, CO2pro, CO2total, CO2all;


* Parameters for counterfactuals
Parameters
lendow       Labour endowment multiplier,
kendow       Capital access multiplier ;

lendow    = 1;
kendow    = 1;


* Parameters for checking
* market balance: armington value(total supply) = domestic demand + exports
* zero-profit: output value = input costs
* income balance: total income =total expenditure
parameter
*tradebal
transfer
zeroprof(g)
mrktbal(i)
incbalP
```

```
incbalC
taxinc                    ;

*tradebal     = sum(i, mrow(i)) - sum(i, vxm(i));
*transfer     = sum(g,t(g))-z0("govt");
zeroprof(g)= z0(g)*(1- txrate(g)) - (sum(i, (vdfm(i,g)+vifm(i,g))) + sum(f, fd0(f,g))) ;
mrktbal(i) = z0(i) - sum(g,vdfm(i,g)) - vxm(i);
*incbalP      = sum(g, t(g)) - z0("govt")-transfer;
*incbalC      = sum(f, e(f)) - sum(c,z0(c))+transfer+tradebal;
taxinc = sum(g,t(g)) ;
incbalC     = sum(f, e(f)) - sum(c,z0(c))-vb+taxinc;

display zeroprof, mrktbal,incbalC, taxinc ;
*$exit
* abort$(smax(g, abs(chk(g)) gt objtol))"Zero-profit condition (final) does not hold", chk;
abort$(smax(g, abs(zeroprof(g)) gt objtol))"Zero-profit condition does not hold", zeroprof;
abort$(smax(i, abs(mrktbal(i)) gt objtol))"Market balance condition does not hold", mrktbal;

*-------------------------------------------------
*       Adjust government's negative inputs
parameter
        ig_vdfm(i)       Negative input demand for domestic goods,
        ig_vifm(i)       Negative input demand for imported goods,
        ig_tax           Tax on z0('govt');

ig_tax          = z0("govt")*txrate("govt");
ig_vdfm(i)      = min(0, vdfm(i,"govt"));
ig_vifm(i)      = min(0, vifm(i,"govt"));
vdfm(i,"govt") = max(0, vdfm(i,"govt"));
vifm(i,"govt") = max(0, vifm(i,"govt"));

display ig_tax, ig_vdfm, ig_vifm;

vafm(i,"govt") = vdfm(i,"govt") + vifm(i,"govt");
z0("govt")      = sum(i,vafm(i,"govt")) + ig_tax;
txrate("govt") = ig_tax/z0("govt");

display vdfm, vifm, vafm,z0;

*================================================================================
```

```
$Ontext
$Model:EV_REF

$Sectors:
        Z(g)$z0(g)              !Commodity production index
        W                       !Consumer utility production index
        M(i)$mrow(i)            !Imports
        A(i,g)$vafm(i,g)        !Armington good
        ZX(g)$z0(g)             !CET function for export

$Commodities:
        PC(g)$z0(g)             !Commodity price index
        PF(f)                   !Factor price index
        PW                      !Household utility price index
        PA(i,g)$vafm(i,g)       !Armington price
        PM(i)$mrow(i)           !Import price
        PD(g)$z0(g)             !Domestic price
        PFX                     !Price of foreign currency

$Consumers:
        CONS                    !Representative consumer

$Prod:Z(g)$z0(g)  s:0.5   ag(s):0.75  m(s):0.25
       O:PC(g)        Q:z0(g)                          a:CONS    t:txrate(g)
       I:PA(i,g)      Q:vafm(i,g)      p:pi0(i,g)      a:CONS    t:tirate(i,g)  m:
       I:PF(f)        Q:fd0(f,g)                                                ag:

$Prod:W  s:0  home(s):0.5 trp(home):0.5
+ pub(trp):0.5      priv(trp):2.74
+ fv(priv):0        ev(priv):0
       O:PW             Q:(sum(c,z0(c)))
       I:PD("govt")     Q:z0("govt")
       I:PD("rest")     Q:z0("rest")          home:
       I:PD("fvcap")    Q:z0("fvcap")         fv:
       I:PD("fvfuel")   Q:z0("fvfuel")        fv:
       I:PD("evcap")    Q:z0("evcap")         ev:
       I:PD("evfuel")   Q:z0("evfuel")        ev:
       I:PD("lndtr")    Q:z0("lndtr")         pub:
       I:PD("cboa")     Q:z0("cboa")          pub:
```

```
        I:PD("cair")     Q:z0("cair")         pub:

$Demand:CONS
         D:PW              Q:(sum(c,z0(c)))
         E:PF("K")         Q:(e("K")*kendow)
         E:PF("L")         Q:(e("L")*lendow)
         E:PFX             Q:(-vb)
         e:PD(i)$ig_vdfm(i)       q:(-ig_vdfm(i))
         e:PM(i)$ig_vifm(i)       q:(-ig_vifm(i))


* CET-function for exports
$Prod:ZX(g)$z0(g)       t:4
        O:PD(g)         Q:(z0(g)-vxm(g))
        O:PFX           Q:(vxm(g))
        I:PC(g)         Q:z0(g)

* Imports
$Prod:M(i)$mrow(i)
        O:PM(i)           Q:mrow(i)
        I:PFX             Q:mrow(i)

* Armington function combines domestic and imported goods into intermediate inputs
$Prod:A(i,g)$vafm(i,g)  s:0      dm(s):4
        O:PA(i,g)       Q:vafm(i,g)
        I:PD(i)         Q:vdfm(i,g)            dm:
        I:PM(i)$mrow(i) Q:vifm(i,g)            dm:

$Offtext
$Sysinclude mpsgeset EV_REF

PW.FX =1;

EV_REF.iterlim = 0;
$Include EV_REF.GEN
Solve EV_REF USING MCP;

abort$(EV_REF.objval > objtol) "Base year calibration with emission accounting fails",EV_REF.objval;
* $EXIT
*================================================================================
```

```
parameters
co2enout(i,g)        Energy-related CO2 adjusted for activity level,
co2proout(g)         Process-related CO2 adjusted for activity level,
co2totsector(g)      Total CO2 emissions by sector adjusted for activity level,
CO2allout            Total emissions,
Intermed(i,g)        Value of Armington intermediates (domestic & imported) adjusted for activity level,
Output(i)            Sectoral output adjusted for activity level,
Consump(c)           Level of consumption by final use sector adjusted for acitivity level,
totalconsump         total,
GDP                  GDP,
nets                 non-ETS emissions,
oilnets                   ,
transcons                  ,
tottranscons ;

CO2enout(i,g)       = CO2en(i,g) * A.L(i,g);
CO2proout(g)        = CO2pro(g)*Z.L(g);
co2totsector(g)     = sum(i, CO2enout(i,g)) + CO2proout(g);
CO2allout           = sum(g,co2totsector(g));
Intermed(i,g)       = vafm(i,g)*A.L(i,g);
Output(i)           = z0(i)*Z.L(i);
Consump(c)          = z0(c)*Z.L(c);
Totalconsump        = sum(c,consump(c));
nets                = sum(n,co2totsector(n));
GDP                 = totalconsump + vb + sum(i,ig_vdfm(i))+sum(i,ig_vifm(i));
transcons(o)        =z0(o)*Z.L(o);
tottranscons           =sum(o,transcons(o));
oilnets            = sum(n,intermed("oil",n));
display co2enout,co2proout,co2totsector,
CO2allout,intermed,output,consump,nets,totalconsump,GDP,oilnets,transcons,tottranscons;


*================================================================================
*Reference scenario 2030
*tirate("oil",n) = 0.8;
kendow = 1.17;
lendow = 1.17;

EV_REF.iterlim = 1000;
```

```
$Include EV_REF.GEN
Solve EV_REF USING MCP;

CO2enout(i,g)       = CO2en(i,g) * A.L(i,g);
CO2proout(g)        = CO2pro(g)*Z.L(g);
*co2totsector(g)     = CO2total(g)*Z.L(g);
co2totsector(g)     = sum(i, CO2enout(i,g)) + CO2proout(g);
CO2allout           = sum(g,co2totsector(g));
nets                = sum(n,co2totsector(n));
Consump(c)          = z0(c)*Z.L(c);
Totalconsump        = sum(c,consump(c));
transcons(o)        =z0(o)*Z.L(o);
tottranscons           =sum(o,transcons(o));
GDP                 = totalconsump + vb + sum(i,ig_vdfm(i))+sum(i,ig_vifm(i));
oilnets            = sum(n,intermed("oil",n));
display co2enout,co2proout,co2totsector, CO2allout,nets,consump,totalconsump,gdp,oilnets,transcons,tottranscons;



*==============================================================================
*Shift 1: Uniform non-ETS carbon tax
tirate("oil",n) = 0.55;
*tirate("mvh","evcap")= (-0.3);

*tirate("mvh",g) = 0.8;
*tirate("otp",g) = 0.8;
*tirate("wtp",g) = 0.8;
*tirate("non",g) = 0.8;

EV_REF.iterlim = 1000;
$Include EV_REF.GEN
Solve EV_REF USING MCP;

CO2enout(i,g)       = CO2en(i,g) * A.L(i,g);
CO2proout(g)        = CO2pro(g)*Z.L(g);
*co2totsector(g)     = CO2total(g)*Z.L(g);
co2totsector(g)     = sum(i, CO2enout(i,g)) + CO2proout(g);
CO2allout           = sum(g, co2totsector(g));
nets                = sum(n,co2totsector(n));
Consump(c)          = z0(c)*Z.L(c);
```

```
Totalconsump          = sum(c,consump(c));
GDP                   = totalconsump + vb + sum(i,ig_vdfm(i))+sum(i,ig_vifm(i));
oilnets              = sum(n,intermed("oil",n));
transcons(o)          =z0(o)*Z.L(o);
tottranscons             =sum(o,transcons(o));

display co2enout,co2proout,co2totsector, CO2allout,nets,consump,totalconsump,gdp,oilnets,transcons,tottranscons;
*================================================================================
*Shift 2: Electric vehicle subsidy

txrate("evcap") = -0.91;

EV_REF.iterlim = 1000;
$Include EV_REF.GEN
Solve EV_REF USING MCP;

CO2enout(i,g)         = CO2en(i,g) * A.L(i,g);
CO2proout(g)          = CO2pro(g)*Z.L(g);
co2totsector(g)       = sum(i, CO2enout(i,g)) + CO2proout(g);
CO2allout             = sum(g, co2totsector(g));
nets                  = sum(n,co2totsector(n));
Intermed(i,g)         = vafm(i,g)*A.L(i,g);
Output(i)             = z0(i)*Z.L(i);
Consump(c)            = z0(c)*Z.L(c);
Totalconsump          = sum(c,consump(c));
GDP                   = totalconsump + vb + sum(i,ig_vdfm(i))+sum(i,ig_vifm(i));

display co2enout,co2proout,co2totsector, CO2allout,nets,consump,totalconsump,gdp,txrate;
*================================================================================
```

Norges miljø- og biovitenskapelig universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway