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Abstract:

Transportation is one of the main contributors to greenhouse gas emissions. Climate regulations on transportation are often a mix of sector-specific regulations and economy-wide measures (such as emission pricing). In this paper we analyse the effects on economic welfare, abatement costs and emissions of such interacting and partly overlapping climate regulations for private transportation. Our focus is on Norway, a nation where high taxation of conventional fossil-fuelled cars has paved the floor for another pillar of climate policies: promotion of electric vehicles (EVs) in private transport. Our contribution to the literature is two-fold. First, we analyse the costs and impacts of the partly overlapping climate regulations in transportation – the cap on domestic non-ETS emissions and the goal of all new cars for private households being EVs – focussing on the outcome in 2030 in Norway. Second, we respond to an important gap in the literature through a methodological development in economy-wide computable general equilibrium (CGE) approaches for climate policy by introducing EV technologies as an explicit transport equipment choice for private households. We find that, for the case of Norway, combining a specific EV target with policy to cap emissions through a uniform carbon price triples the welfare costs.

Keywords: Climate policy, carbon pricing, green transport policies, overlapping regulations, modelling electric vehicles, CGE-model

JEL classification: C68, H23, Q54, Q58

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Sammendrag

Transport er en av de viktigste kildene til klimagassutslipp: nærmere 25% av energirelaterte klimagassutslipp globalt kommer fra transportaktiviteter. I Norge utgjør utslippene fra transport omtrent en tredjedel av klimagassutslippene. Om lag halvparten av disse kommer fra veitrafikk.

I motsetning til andre store utslippskilder (slik som energiproduksjon og metallindustri) er ikke transportsektoren en del av det europeiske kvotemarkedet EU ETS. Klimapolitiske virkemidler rettet mot transport består ofte av en blanding av generelle virkemidler (som felles utslippspris) og sektorspesifikke reguleringer.

I denne artikkelen analyserer vi samspillet mellom slike delvis overlappende reguleringer i transportsektoren: et utslippstak på innenlandske ikke-kvotepliktige sektorer som medfører en felles utslippspris, og målet om at alle nye privatbiler skal være elbiler. Vi ser på virkningene på rensekostnader, utslipp og velferd i Norge i 2030.

Vårt bidrag til litteraturen er todelt. For det første analyserer vi kostnadene og virkningene av en aktuell politikk: de delvis overlappende klimareguleringene i transportsektoren i Norge. For det andre bidrar vi til metodeutviklingen ved å innlemme elbiler som et eksplisitt teknologivalg for husholdningers transportetterspørsel i en generell likevektsmodell (CGE-modell).

Vi finner at samspillet mellom felles utslippspris og det spesifikke målet for elbiler tredobler velferdskostnadene, sammenliknet med tilfelle der den samme utslippsreduksjonen i ikke-kvotepliktig sektor oppnås med kun felles utslippspris i 2030. For å nå målet om at alle nye privatbiler skal være elbiler i 2030 må dagens gunstige elbilpolitikk beholdes og forsterkes markant. Selv om utslippsprisen i dette tilfellet blir lavere, slik at man unngår å gjennomføre de dyreste tiltakene i resten av ikke-kvotepliktig sektor, blir kostnadene knyttet til at de ekstra utslippsreduksjonene i privat transport svært høye for samfunnet. Velferdskostnadene tredobles, og fallet i BNP er dobbelt så stort i scenariet med overlappende politikk. Samfunnet vil tjene på at en større del av utslippsreduksjonene tas i andre sektorer, og at ikke alle må kjøpe elbil.

1 Introduction

Transportation is one of the main contributors to greenhouse gas emissions accounting for almost one quarter of global energy-related greenhouse gas (GHG) emissions (IEA, 2020a), with a similar proportion applying across the European Union (EU). Hence, policies to reduce emissions from transportation are an important part of climate policies in many countries. While many other large emitters (such as energy and metal industries) are part of the European emission trading system (EU ETS), transportation is not. Climate policies that target transportation are the domain of national authorities alone.[1] The climate regulations on transportation are often a mix of sector-specific regulations and economy-wide measures (such as emission pricing), where the EU and Norway are examples. In this paper we analyse economic effects and emissions impacts of such interacting climate regulations towards transportation.

Our focus is on Norway, a nation that is characterised by many interacting, and partly overlapping, climate regulations in the transportation sector. In Norway, transportation activities account for a third of GHG emissions.[2] Road transport is responsible for just over half of these (17%) and almost 35% of the non-ETS emissions.[3] Norway, in a similar manner to the EU, has newly submitted more ambitious targets for GHG emission reductions under the Paris agreement: 50-55% reduction in 2030 and the long-term reduction goal of 90-95% reductions in 2050, both compared to 1990 (Ministry of Climate and Environment, 2021). About half of Norway's emissions are included in EU ETS. The domestic targets of 45-50% reductions in non-ETS sectors are more challenging to achieve.

Transportation activities face extensive climate regulations in Norway (Ministry of Finance, 2020; Fridstrøm, 2021). High taxation of conventional fossil-fuelled cars has paved the floor for another pillar of the Norwegian climate regulations involving promotion of electric vehicles (EVs) in private transport. In 2020, almost 50% of all new private cars sold were EVs. Although the original target for the favourable EV policy (50 000 EVs on road) was reached in 2015, the current policy documents include another target for the transportation sector: all new private vehicles should be EVs in 2025 (Ministry of Climate and Environment, 2021). More details about the Norwegian EV policies are provided in section 2.

[1] The climate policies in the EU allow for flexible mechanisms also in the non-ETS sectors and there are some examples of common policy in the EU, for instance CO_2 emission performance standards for new cars, https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en. The newly launched EU fit for 55 has high ambitions for emission reductions in private transportation with a specific target of 100% new zero-emission cars in 2035 and suggests establishing a quota market for transport and building sectors from 2026, https://ec.europa.eu/commission/presscorner/detail/en/ip_21_3541

[2] https://www.ssb.no/natur-og-miljo/forurensning-og-klima/statistikk/utslipp-til-luft

[3] miljostatus.miljodirektoratet.no

Our contribution to the literature is two-fold. First, we analyse the impact of interacting and partly overlapping climate regulations in transportation, specifically the consequences of two policies: the cap on domestic non-ETS emissions and the goal of all new cars for by private households being EVs. With one primary objective, the use of multiple policy instruments can create expensive overlaps (Tinbergen, 1952). The use of multiple instruments is justified in the presence of multiple externalities or imperfections (Bennear and Stavins, 2007; Goulder and Parry, 2008). For example, if the consumers are characterised by short-sightedness or there are considerable uncertainties regarding future climate externalities and regulations, current market signals alone may lead to limited development and adoption of more climate-friendly technologies (Lehman and Gawel, 2013). There may also be positive externalities, such as technology spillovers in battery and car technologies, or network and learning effects in the markets for new technologies as EVs, that support the argument for subsidies for new technologies (Greaker and Midttømme, 2016; Acemoglu et al.,2012). However, simply piling multiple instruments does not guarantee that they will achieve the intended goal and the costs can be excessive (Böhringer et al., 2009; Fankhauser et al., 2010; Böhringer et al., 2016). Moreover, the use of multiple instruments is usually driven by politics more than by economic considerations (Fankhauser et al., 2010). Here we demonstrate that layering different policy actions can potentially increase the welfare costs of each individual action.

Second, we respond to an important gap in the literature through a methodological development that involves including the EV technologies as an explicit transport equipment choice for private households in a top-down disaggregated computable general equilibrium (CGE) model designed particularly for climate policy analyses. The CGE model developed here ensures that we bring focus on how the economy-wide impacts of the electrification of private transport are transmitted through prices and will influence electricity demand in other industries and stimulate investments in new electricity production and grid capacity. Such generic development in CGE specification is crucial given that, to date, EVs constitute a relatively new and not yet a wide-spread technological option, with the implication that their deployment has not been thoroughly studied in economy-wide models. Some top-down models have attempted to include more detail about specific transport technologies. For example, Li et al. (2017) and Zhang et al. (2018) use CGE models augmented with transport choice mode and other transport technological details to investigate the role and contribution of the transport sector to emission reduction. Others, for example, Alabi et al. (2020), study the wider economy impacts of electrification of the transport sector in a CGE model, focussing on implementing and recovering the costs of investment needs in the electricity industry that are necessary to deliver enough electricity for the EV rollout in the UK. The EV rollout in the CGE model is modelled by applying a soft-linking approach to an energy system model (UK TIMES). A recent paper by Ghandi and Paltsev (2020) studies the global emission impacts of

EVs in private transportation in a global CGE model (EPPA). Our contribution is to combine the modeling and features of ambitious EV and climate policies (exemplified by the Norwegian policy), detailed modeling of EV technologies in private transportation and overall electrification of the economy, in an economy-wide consistent framework.

Our contributions emerge through our study of the outcomes of two climate policy scenarios in 2030, relative to a baseline scenario, using the CGE model SNOW (Fæhn et al, 2020). First, a *cap-only scenario,* where a cap on emissions induces a uniform emission price in non-ETS sectors. Second, a *cap and EV target scenario* where the emission cap in the non-ETS sectors is *supplemented* with the specific EV target, requiring that all new cars sold to private households are EVs by 2030. In both cases, we bring focus on consequences in terms of how abatement costs interact with economy-wide welfare costs (measured by changes in household utility).

Our main findings are as follows. We show that in the case of Norway, the interacting and partly overlapping policies triple the welfare costs, compared to only capping emissions by a uniform carbon price. As the total cap for emissions from the non-ETS sectors is the same in both cases, less abatement is needed from other non-ETS sectors when households contribute more to emission reduction through increased use of EVs. Hence, the most expensive abatements in other sectors can be avoided in the cap and EV target scenario, and this transforms into a lower emission price for the whole non-ETS segment: the carbon price is about half of that in the cap-only scenario. In short, the lower emission price benefits all other non-ETS sectors at the expense of households. Yet, the total costs to the society are higher due to high costs in private transport, even though the most expensive emission abatements in the non-ETS production sectors are avoided. The household welfare cost triples and the GDP loss is twice as large as that observed in the cap-only scenario. This implies that the economy becomes less efficient in reducing the emissions with overlapping policies.

We note that the increased roll-out of EVs (due to the goal of all new cars being EVs) is achieved by an implicit subsidy (shadow price) to EVs, doubling the shadow price in the baseline and in the cap-only scenario. This reflects the very high costs for the consumer of being effectively forced to purchase only EVs. This also implies that stronger EV policies (in the form of more benefits to EVs and higher taxes or restrictions on conventional vehicles) are needed to reach the EV sales target of 100%. This is confirmed by our cap-only scenario, which demonstrates that an EV target of 100% is not reached, despite the high CO_2 price (which is seven times higher than in the baseline).

The paper is organised as follows: Section 2 gives an overview of the Norwegian case regarding EV outreach and electrification of the economy and compares it to other countries. Section 3 describes the numerical CGE model SNOW, including the modelling of EVs. Section 4 presents the scenarios and policy analyses, section 5 studies the robustness of the results by some sensitivity analyses, while section 6 concludes.

2 Electrification and EV policies: The case of Norway

Conventional fossil-fuelled cars with internal combustion engines (ICEs) are heavily taxed in Norway: there is a carbon tax of 55 EUR/ton CO_2 on fossil fuels, in addition to an extensive CO_2 component in the registry tax (Ministry of Finance, 2020). Moreover, the annual traffic insurance fees and excise taxation on fossil fuels include local externality costs (Fridstrøm, 2021). Complementing this, policies promoting EV uptake and use have been in place for more than 20 years in Norway, see Table 2.1. Support schemes to EVs involve both fiscal instruments (e.g., exemption from VAT on purchase, registration tax and annual vehicle tax) and non-fiscal support instruments (such as exemptions from road tolls, no user fees on roads, use of bus lanes, free or reduced parking fees, free domestic car ferries and access to free or low-cost charging). In short, there are clear disincentives for continued reliance on fossil-fuelled vehicles.

Table 2.1 Norwegian EV policy measures

Incentive	Trial period	Permanent
Temporary exemption from on-off registration tax	1990-1995	1996
Exemption from annual vehicle tax**		1996
Exemption from road tolls*		1997
Exemption from parking fees on municipal owned parking facilities*		1999
Reduced company car tax		2000
Exemption from VAT		2001
Use of transit lanes*	2003-2005	2005
Further reduction in company car tax		2009
Exemption from car ferry fees*		2009

Source: Aasness and Odeck (2015), Ministry of Finance (2017; 2020)

**In recent years these exemptions have been modified, e.g., in large cities as Oslo and Bergen EVs pay reduced fees at toll roads, the availability of free parking and charging is reduced all over the country, reduced car ferry fees, restrictions on the use of bus lanes during rush hour etc.*

***From 2021 all EVs pay an annual insurance fee, as the ICEs (Ministry of Finance, 2020).*

There are almost 347 000 EVs and 142 000 PHEVs (plug-in hybrid EVs) on road in Norway now, more than 20% of the total private car stock.[4] In 2020, the sales of EVs and PHEVs in Norway amounted to 106 000 cars, more than 3% of the global sales.[5] From the start in 1996, with very limited choice of EVs at the market, to 2020, with EVs constituting over 50% of the new private car sale, makes a tremendous

[4] https://www.ssb.no/transport-og-reiseliv/landtransport/statistikk/bilparken

[5] https://elbil.no/elbilstatistikk/; https://www.theguardian.com/environment/2021/jan/19/global-sales-of-electric-cars-accelerate-fast-in-2020-despite-covid-pandemic; https://www.ev-volumes.com/

difference. The initial high taxation of ICEs has made it easy to promote EV sales by exempting EVs from most or all of the ICE taxation, instead of offering direct subsidies to EVs, and contributed to this development. The fiscal effects of these exemptions were insignificant for the first 15-18 years, but with a market share approaching 50%, the revenue loss amounts to 19.2 billion NOK in 2019 (Ministry of Finance, 2020), more than 20% of the revenue from all taxation of ICEs in 2019.

Indeed, to date Norway has been at forefront with its generous support schemes and relatively high share of EVs. Yet, as EV technologies become mature, other countries are likely to consider policies related to EVs (Ghandi and Paltsev, 2020). The CO_2 emission performance standards for new passenger cars and new vans from 2020 onwards in EU (EU, 2019) is an example.[6] Denmark has newly established a strategy for electrification of private transport that builds on temporary subsidies to EV purchases and a goal of 100% new EVs in 2030 (Kommisionen for grøn transport, 2020).[7] In several EU countries (France, Netherlands, Sweden, Germany), Canada and parts of US, a buyer's premium (a direct subsidy) of around 6000-9000 EUR has been offered lately to purchasers of new EVs, and in most EU countries EVs pay no registration fee.[8] Even with such promotion policies, the market penetration is still quite limited with EV market shares of 1-5% of new cars in most of these countries. The Netherlands has been an exception for several years, though, with more benefits for EV buyers compared to other EU countries and reaching a market share of more than 20% for new EVs in 2020. The introduction of new low- and middle cost EV models with wider driving range in 2020 may also contribute to the increased market share.

When considering the effects of the policies and the interaction of the policies with Norway's climate policy regulations in general, it is important to keep in mind that these depend on a range of factors and conditions prevailing in the Norwegian context that may not be present (at this point in time) in other nations but may emerge over time. There could be some general lessons learned from the Norwegian case.

First, the Norwegian electricity market is characterised by the majority of households using electricity for heating and other domestic energy purposes: about 90% of residential energy demand (incl. heating)

[6] https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en

[7] https://www.ft.dk/samling/20201/lovforslag/l129/index.htm, https://easyelectriclife.groupe.renault.com/en/outlook/cities-planning/subsidies-in-germany-how-do-they-work/

[8] https://www.reuters.com/article/uk-germany-autos-subsidy-idUKKBN27W2FT,
https://electrek.co/2021/01/08/the-netherlands-69-all-electric-market-share/,
https://www.rvo.nl/sites/default/files/2021/03/Statistics%20Electric%20Vehicles%20and%20Charging%20in%20The%20Netherlands%20up%20to%20and%20including%20January%202021.pdf
https://iea.blob.core.windows.net/assets/af46e012-18c2-44d6-becd-bad21fa844fd/Global_EV_Outlook_2020.pdf

is met by electricity. The *additional* electricity demand that stems from EV charging is therefore relatively small.[9] Hence, the need for additional electricity production capacity development to support further EV rollout is limited. The electricity market with flexible prices, production and trade, accommodates this increase in demand. Also, the need for additional investments in electricity grids are smaller in Norway than in most other countries (NVE, 2020). In other nations, such as the UK, extensive network investment and cost recovery through user bills constrains household consumption for an extended timeframe, as shown by Alabi et al. (2020). Kühnbach et al. (2020), on the other hand, find that increased EV rollout may reduce electricity prices for households in Germany since the additional electricity demand increases the overall utilization of the grid. This result is based on an analysis combining four energy system models.

Second, the housing and settlement pattern in Norway is different from many other countries, with implications for charging infrastructure: more than 75% of households live in detached or semi-detached houses and can charge EVs at home, so that a decentralised load requirement prevails. On the other hand, sparsely populated areas and large distances imply that driving range is an issue that may limit how easily the households adopt EVs. Hence, investments in infrastructure for charging EVs are needed to promote the uptake of EVs, especially outside large cities. In more densely populated countries, investing in charging infrastructure may be easier and cheaper.

Third, the Norwegian electricity production is almost exclusively renewable (about 98% from hydropower and wind power). Hence, electrification of transportation will not increase emissions related to domestic electricity production, as would be the case in countries that are more reliant on fossil-fuelled electricity production and/or at a less advanced stage of deploying renewables, again such as the UK. However, Norway is connected to the European electricity market, with the implication that the electricity mix may involve higher indirect emissions. In short, increasing electricity import or reducing exports may change the total emissions from European electricity production. Nevertheless, electricity production is part of EU ETS, so any change in emissions is within the ETS quota (but would influence the EU ETS price).

Fourth, Norway has no domestic car industry. Consequently, the EVs must be imported, and these costs depend to a large extent on the technological developments in the rest of the world. Positive productivity impacts on car and technology industries would accrue both to importing and exporting countries. However, there could also be short- and medium-term transitional benefits and costs for the car industry and the wider economy. Countries with domestic car or battery production are likely to experience

[9] The total electricity consumption for charging EVs with the 100% EV target has been estimated to be less than 4 TWh in 2030, which is less than 3% of Norway's total electricity consumption (NVE, 2017).

higher benefits (which might be counterbalanced by losses in conventional vehicle production). For example, Alabi et al. (2020) and Turner et al. (2018) find potentially offsetting losses in the UK manufacture of petrol and/or diesel-powered vehicles, with a risk of net contraction in wider industry if sufficient EV production does not locate within that nation. On the other hand, both studies show that more substantial wider economy gains may emerge from expansion in the electricity industry, where domestic supply chain content is significantly higher than in the production and distribution of petrol and diesel. The German car industry, which is the major supplier to the EU market, launched an ambitious EV strategy in 2019, presenting new EV models in 2019 and an ambitious plan for EV development towards 2025.

Fifth, high initial taxation of ICEs has made it easier to use tax exemptions for EVs in Norway, instead of direct subsidies/payments. Since the political cost of direct subsidies is likely to be higher than the cost of using tax exemptions, countries opting for subsidizing EVs rather than taxation of substitutes may find it more difficult to implement costly EV policies. On the other hand, Norway has made significant progress in the uptake of EVs already, with the implication that our baseline includes a high share of new EVs. Our results suggest that the costs of reaching 100% EV share are high at the margin, though. This implies that the costs of electrification of transport through EVs could be lower in other countries that are starting from a lower base (as long as they do not push to 100% target). For example, the Danish governments earlier policies towards promoting EVs have been characterised by an on-and-off-strategy, as direct subsidies and registration fee exemptions have changed from one year to another, resulting in a low market share for new EVs. The recently launched strategy has a clear plan of phasing out the subsidies towards 2030 (Kommisionen for grøn transport, 2020).

These specific Norwegian features are all incorporated in our CGE model and play decisive roles for the analysis. Modelling EVs as a technology choice in private transportation and including all the favourable policies are pivotal for the policy analysis, in combination with the detailed modelling of Norway's ambitious climate policies and diverse policy instruments. Electrification of private transport cannot be separated from the characteristics of supply and demand for electricity in the rest of the economy, and all features of such interactions are modelled, in addition to the specific characteristics of Norway as a small, open economy with a trade intensive, specialised industrial structure. There are some recent examples in the literature of including more details about specific transport technologies in CGE models, see e.g., Li et al. (2017), Zhang et al. (2018), Alabi et al. (2020) for country studies, and Ghandi and Paltsev (2020) for global impacts of EVs in private transportation. There are also a few studies of the Norwegian experience in partial models, see Aasness and Odeck (2015); Holtsmark and Skonhoft (2014); Aurland-Bredesen (2017). But none combines the features of ambitious EV and climate policies, a highly electrified economy, EV technologies in private transportation, in an economy-wide consistent framework.

Generally, our findings suggest that the cost of interacting and partly overlapping regulations in electrification of Norwegian private transportation is high, but elucidation of the drivers of these findings is intended to inform investigation as to the extent to which costs may be even higher or potentially lower in another national context. In short, the implications of EV policies and lessons emerging from the analyses presented below are likely to be characterised by a combination of country-specific and more generic effects.

3 Method: The CGE-model SNOW

We use the CGE-model SNOW to analyse the impact of the interacting climate policies. SNOW is a multi-sector CGE model for the Norwegian economy (Rosnes et al., 2019; Bye et al., 2018). The model assumes optimising agents: profit-maximizing producers and a representative household maximizing utility. The model finds equilibrium prices and quantities by simultaneously solving the set of equations that satisfy the profit-maximisation and utility-maximisation conditions. The solution determines production, consumption, export and import levels for all goods, input use in each industry, relative prices of all goods and input factors (labour, capital and energy resources), and emissions to air. The consumer price index is numeraire.

Labour and capital are perfectly mobile between industries, implying that firms' investments can take place incrementally and instantaneously and the labour market is always in equilibrium. Total capital inflow is given in the base year and then endogenized in line with domestic investment, which in turn is determined by household saving in each period, since the representative household receives all income in the model. Total capital is distributed to domestic sectors equalising the real rate of return between sectors.

The model is of a small, open economy; thus, the world market prices are considered as exogenous. Domestic and imported goods are considered imperfect substitutes and goods used in the domestic market correspond to a constant elasticity of substitution (CES) composite of domestically and imported goods in line with Armington (1969) modelling. Similarly, production in each sector consists of goods sold to the domestic and international market with a constant elasticity of transformation (CET) function. A stylized version of the model is presented in Appendix C.

Emissions of seven GHGs (CO_2, CH_4, N_2O, HFK, PFK, SF_6, NF_3) are included, in addition to other pollutant compounds (NO_x, SO_2, NH_3, NMVOC; PM_{10}, $PM_{2,5}$), see section 3.3 for more details. The model includes a detailed module of consumers' choice between EVs and conventional ICEs cars (incl. vintages), see section 3.1.1 and appendix B.

The model is calibrated to the Norwegian national accounts and environmental accounts from Statistics Norway.[10] The input-output tables are prepared by Statistics Norway.[11] As the analysis focuses on policies targeted in 2030, including detailed modelling of EV technologies, we use a dynamic recursive version of the model to make a projection of the Norwegian economy in 2030. In the dynamic recursive model, investments depend on previous year's prices, implying "backward-looking" expectations. Recursive models provide greater flexibility in details of the modelling and policies that can be analysed, compared to forward-looking models, see Babiker et al. (2009). Details of the modelling of households' savings and firms' investments are given below, see also the stylized model in Appendix C. Our baseline projection is described in section 4.1.

3.1 Households

SNOW features a representative household that owns and receives net-of-tax income from labour, capital and natural resources as well as transfers from the government. Tax revenue (net of subsidies) is collected by the government, but reallocated to the household sector, so that all tax revenue eventually goes to the household. The representative household maximizes utility subject to the income constraint, while labour supply is exogenous in this model version.[12] Household savings are determined endogenously by a Cobb-Douglas function of consumption and savings, see Appendix C for more details.

Household consumption demand is determined by a nested Constant Elasticity of Substitution (CES) function as depicted in Figure 3.1.[13] At the top level, aggregates of housing services, transport services and other goods and services are combined (and can substitute each other) to give total material consumption. At the second level, the CES function describes the three main aggregates as combinations of dwellings and energy use (in housing services), public and private transport (in transport services), and all other goods and services (see Table A 2 in Appendix A for the complete list of all goods for final consumption). The third level in the energy-in-housing aggregate specifies substitutable energy sources. The consumer can choose between the following sources for residential heating: electricity, district heating, gas, paraffin and heating oil, coal, fuel wood and pellets. The expenditure share for electricity

[10] The base year of the model is 2013.

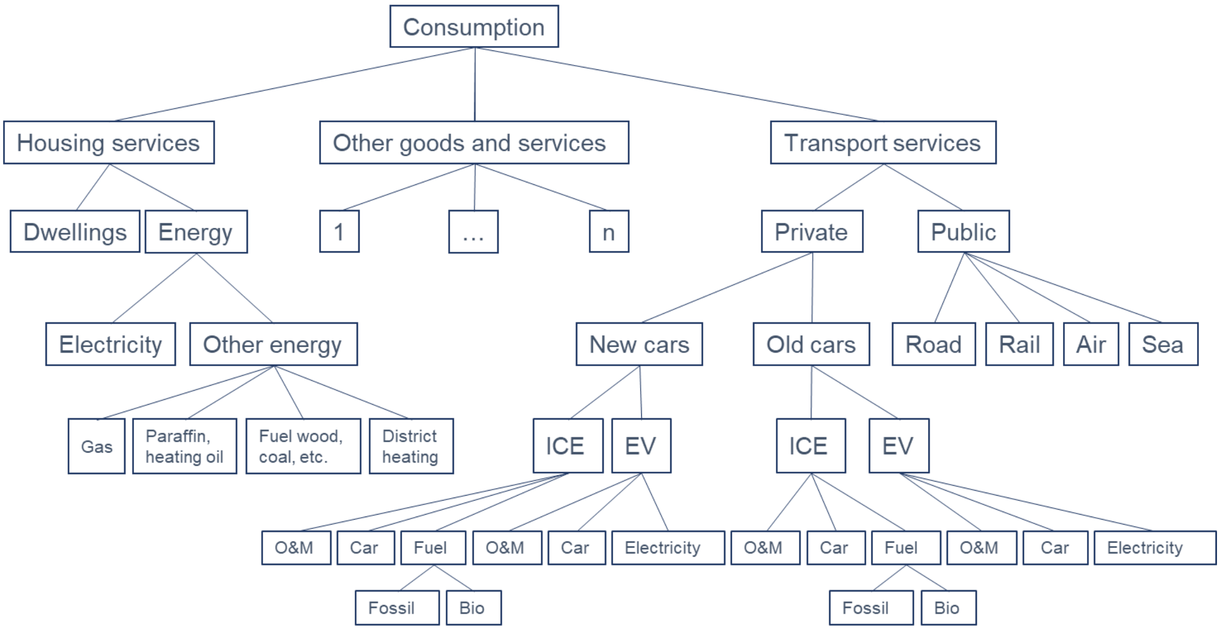
[11] Supply and Use and Input-Output tables - SSB

[12] The annual labour supply is based on population projections from Statistics Norway and employment rate projections from the Ministry of Finance.

[13] The nested CES function (see Varian, 1992) is standard in CGE models. The functions nest inputs and quantify their use according to values for share parameters and substitution elasticities. See Table A 4 in appendix A for the values of the elasticities.

is about 90%.[14] In the transport nest, there are substitution possibilities between public and private transport. Section 3.1.1 describes the household transportation in detail.

Figure 3.1 The CES function of private material consumption in SNOW



See Table A 4 in Appendix A for elasticities in the consumption function.

3.1.1 Private transport and EVs

The representative household's demand for transport services is modelled in detail, see Figure 3.1.[15] First, transport services combine private and public transport. In *public transport*, road, rail, air, and sea transport are specified as substitutable choices. *Private transport* is split into use of old and new cars, and each of them into electric vehicles (EV) and conventional vehicles with internal combustion engines (ICE), to keep track of the development of the stock of each car technology and the resulting emission effects.[16] The elasticity of substitution between EVs and ICEs captures the substitutability between the two types of cars. The higher the elasticity the more similar are the attributes of EVs and conventional cars.

The representative household's spending on cars consists of expenditures for motor vehicles (including parts), retailer's service fee, and all other service costs, and fuel costs (electricity or petrol/diesel costs). Expenses for new cars and old cars are modelled as annual rental values (user cost of capital). Thus, when consumers choose EVs or ICEs, they consider the annual expenses consisting of annual rental

[14] Fuel wood constitutes the largest part of the remaining residential energy consumption. Gas distributed though networks and district heating are very limited in Norway, while use of heating oil is forbidden from 2020.

[15] The equations describing private transport and EVs are provided in Appendix B.

[16] Ordinary hybrid cars are classified as ICE as they use only petrol/diesel, and thus they are simply more efficient ICEs. Plug-in hybrids (PHEV) are currently not taken into account in the model.

values, fuel or electricity costs, and other service costs for each type of car. We keep track of both old cars (purchased before the current year in the simulation) and new cars (purchased in the current year).

Consumption of fossil fuel (petrol/diesel) and electricity is based on the stock of old and new cars. The electricity consumption per EV is based on an exogenous efficiency parameter. The model accounts for the increase in total household electricity consumption associated with electric vehicles as the number of EVs increases as part of the electricity market. As both electricity prices and petrol and diesel prices are endogenous, climate policies that alter the relative prices will influence both the households' choice of vehicle and the level of driving activity, and, ultimately, through households' demand also the energy markets and the production of electricity and petrol and diesel.

Calibration of the EVs in base year and in baseline to 2030

The modelling of private vehicles is calibrated to tally with the 2018 stock of EVs and ICEs. For calibration purposes, we use 2014 figures to account for household EV electricity consumption and the sales share of EVs. The reason for using 2014 data (and not data from the base year 2013) is that it is difficult to calibrate the nested CES structure when the share is very small, as is the case for EVs in 2013.[17]

The EV projections for 2020-2030 in the baseline are fitted to match the official projections for EV shares in Norwegian Environmental Agency (2020). The exogenous world market price of imported EVs falls 20% from 2014 to 2018 and is assumed to fall 5% annually in 2019-2023 and further 2.5% annually in 2024-2030, based on technology projections from Zamorano (2017). The phase-in rate of EVs, EV prices and substitution elasticity are exogenous. We use the implicit subsidy that captures the non-fiscal advantages of EVs as the calibration instrument. The non-fiscal advantages to EV users, e.g., free parking, access to bus lanes, cheaper toll roads etc., are assumed to be extended to 2030, aligning with the official projections in Norwegian Environmental Agency (2020).

Crucially, an increase in the elasticity of substitution between EVs and conventional cars mirrors that the attributes of EVs and conventional cars will become more similar. In the base year, the elasticity of substitution is 0.5. The EV technologies and available EV models have developed a lot over the last few years and are, thus, considered to be much closer substitutes to conventional cars in 2020 than just a few years ago, with substitutability expected to increase further over the next years. In the calibration of the baseline to 2030, the elasticity of substitution increases to 4 in 2020 and to 8 in 2030, as in Fæhn et al. (2020). The literature of relevant elasticities seems to be very scarce, however, some recent contributions fit well with our assumptions: Fridstrøm and Østli (2021) estimate a cross-price elasticity of

[17] The share of EVs was 6% in 2013 and 13% in 2014 (https://elbil.no/elbilstatistikk/).

0.36 for EVs and gasoline-driven ICEs, and 0.48 for EVs and diesel-driven ICEs, based on Norwegian data. This corresponds to a CES elasticity of substitution of around 0.5-0.7 in 2018 and 7.2-9.6 in 2030 (assuming increased market share of EVs).[18] Gjerde-Johansen (2021) estimates, also based on Norwegian data, a cross-price elasticity of EVs of 0.71. Both emphasize that the cross-price elasticities are highly context-specific, as they depend crucially on market shares.

3.2 Production

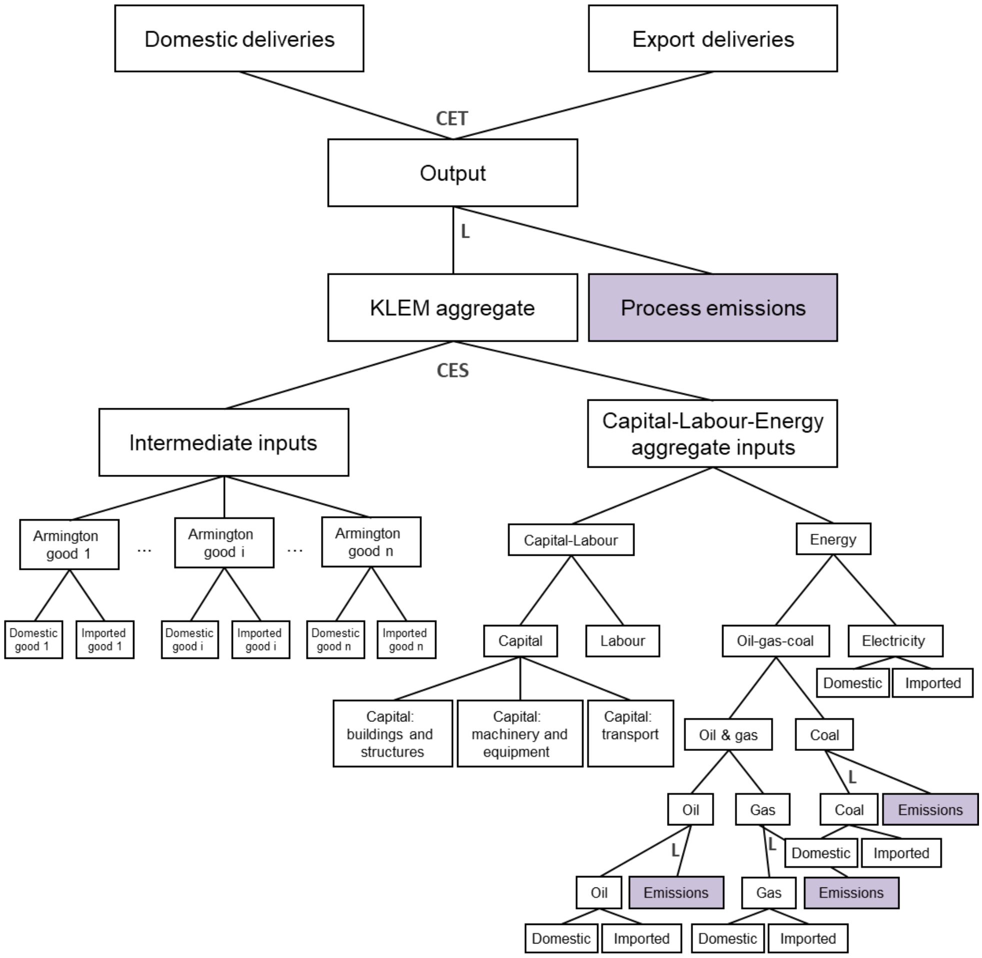
The model specifies 47 production sectors, producing one good each, with one representative producer in each sector. The sectoral disaggregation enables us to study climate policies and emissions from different industries in detail. There are five energy-producing industries: coal, oil and gas extraction, refined coal and oil products, gas distribution, and electricity. Other emission-intensive industries (such as basic metals, cement, etc.) are also modelled as separate industries, as well as three different transport sectors (land, air and water transport), see Table A 1 in appendix A for the full list of industries. In addition, there are 24 final consumption goods (see the list in Table A 2 in appendix A).

The production technologies are described by nested CES functions, where combinations of capital, labour, energy, and intermediate products are inputs in production.[19] Figure 3.2 shows the separability structure of the production functions. Substitution among inputs is possible at all levels, except in the nests marked with L (Leontief) on Figure 3.2. See Table A 3 in appendix A for other elasticities.

[18] See Berck and Sydsæter (1995) ch. 4 for the relationship between price elasticities and substitution elasticities.

[19] The nested CES function (see Varian, 1992) is standard in CGE models. The functions nest inputs and quantify their use according to values for share parameters and substitution elasticities. The quantifications differ among commodities and are based on conventional estimations, see Andreassen and Bjertnæs (2006), in addition to other pertinent literature as collected in the GTAP database, see Narayanan et al. (2012). See Table A 3 in appendix A for the values of the elasticities used in the model.

Figure 3.2 Nested CES production function in SNOW, with emissions highlighted



Note: L on the figure notes Leontief (substitution elasticity equals zero). See Table A 3 in Appendix A for other elasticity values.

3.3 Emissions

Emissions from both energy use and industrial processes are modelled. *Energy-related emissions* are linked to the use of fossil fuels with coefficients differentiated by the specific carbon contents of the fuels, see Figure 3.2. The disaggregation of energy goods into coal, crude oil, natural gas, refined oil products and electricity is essential to differentiate energy goods by emission intensity and degree of substitutability. Similarly, the final consumption goods are disaggregated into petrol and diesel and electricity in transport, and into various fuels in housing (see Figure 3.1). Abatement of the energy-related emissions can be achieved by substitution between energy goods, substitution of capital or other goods for energy, or reducing production in industries and/or final consumption.

Emissions from industrial processes are linked to output level, see 'process emissions' in Figure 3.2. These emissions stem from industrial processes, for instance in aluminium and cement production, and are not related to energy use. Abatement of process emissions can be achieved by reducing output (endogenously) or by introducing new technologies (exogenously). The SNOW model features a more detailed modelling of emissions than most CGE models. In particular, process emissions are absent in most CGE studies, Bednar-Friedl et al. (2012) and Bye et al. (2018) being notable exceptions.

3.4 Government

The government collects taxes, purchases goods and services from domestic sectors and abroad to provide public services and distributes subsidies and transfers to the representative household. Overall government expenditure is exogenous and increases at a constant rate as the general economy grows. The revenue from all taxes accrues to the government, which can use the tax revenues on public goods and services, as deposits in the Government Pension Fund Global or as transfers. [20] Surplus tax revenue over that required to fund (exogenous) government consumption and investment is reallocated to the household sector, so that all tax revenue eventually services households.

The model incorporates a detailed account of government revenue and expenditure. The government revenues in SNOW are from product and production taxes, taxes related to emissions and labour costs including employers' taxes. All taxes and fees are included as percentage (ad valorem) rates in the model, and all taxes are net taxes (taxes minus subsidies).[21]

4 Analysis: Costs of overlapping climate policies

4.1 The scenarios

Our scenarios are based on the Norwegian climate policy goals for 2030, which are part of Norway's road to a low emission society. We analyse the two interacting and partly overlapping climate regulations in transportation and the consequences for the abatement costs and economy-wide welfare costs in 2030 in the non-ETS sectors: the 50% cap on GHG emissions in the non-ETS sectors in 2030 compared to 2005 level (Norwegian Environmental Agency, 2020) and the 100% market share of new EVs for private households in 2030 (Ministry of Climate and Environment, 2021).

We analyse the effects of the climate policies as compared to a *baseline*. Our baseline is based on the government's projection prepared for Klimakur 2030 (Fæhn et al., 2020; Norwegian Environmental Agency, 2020). This is a business-as-usual path, based on standard assumptions about demographic and

[20] The fiscal policy rule is adhered in each year by assumption.

[21] All quantity-based taxes, such as taxes on alcohol, petrol etc., are transformed to average ad valorem tax rates by using base year tax income divided by base year tax base, see Rosnes et al. (2019) for more details. This is standard procedure in MSPGE-based CGE models, see Rutherford (1999).

technology development and current climate policies in Norway. The rest of the world (most importantly the trade partners and the EU) are supposed to follow a similar path, with no additional climate policies. The EV projections in the baseline are fitted to match the official projections for EV shares in 2030 in Norwegian Environmental Agency (2020), as described in section 3.1.1.

With these assumptions, Norwegian GHG emissions are projected to approximately 47.3 M ton CO_2-eq in total in 2030, distributed on 20.3 M ton in non-ETS sectors and 27 M ton in ETS sectors. A 50% cap on GHG emissions in the non-ETS sectors relative to 2005 implies a gap of approximately 5.6 M tons CO_2-eq in 2030 which gives the emission reduction target. [22]

We implement the climate policy scenarios in the model as follows:

- *Cap-only scenario*: a cap on GHG emissions in non-ETS sectors (amounting to approximately 14.8 M ton CO_2-eq in non-ETS sectors in 2030) that is reached by imposing a uniform carbon price in the non-ETS sectors. The carbon price applies to all GHG emissions and is measured in EUR/ton CO_2-eq. The uniform carbon price also replaces today's differentiated CO_2 taxes.
- *Cap and EV target scenario*: The emission cap in the non-ETS sectors is *supplemented* with the specific EV target, requiring that all new cars sold to private households are EVs by 2030.[23] The carbon price modelling and replacement of differentiated CO_2 taxes are identical to the cap-only scenario.

We also analyse the effects of *the EV target only*, to isolate the effects of an EV target without emission cap or emission pricing. In this case, all new cars sold to private household are EVs by 2030, and the CO_2 taxes are kept at the same level as in the baseline. Since there are no additional regulations in the other non-ETS sectors, the emission reduction in this scenario is much smaller.

The nominal deficit and real government spending are required to follow the same path in the policy scenarios as in the reference scenario, implying revenue neutrality in each period. The excess tax revenue (negative or positive) from the emission pricing and changes in other governmental revenues in the policy scenarios are distributed as lump-sum transfers to the representative household. Household savings are exogenous, equal to the savings in the baseline, in the policy scenarios.

In addition to the policy scenarios, we perform several sensitivity analyses. These are discussed in section 5.

[22] The ETS-industries subject to the cap in the EU ETS market.

[23] The target is implemented as 99.9% in the simulations to solve the model.

4.2 Macroeconomic effects

Since the climate policies are defined and targeted for 2030, we concentrate our analysis on the effects in this year. By using the dynamic recursive version of the model, we can calculate the results in 2030 for the different scenarios, even though 2030 is not necessarily characterised as a long run (steady state) solution, but rather as a point on the path to a new, long run equilibrium.[24] We measure the effects in the scenarios as relative (percentage) changes from the baseline. The relative changes are not sensitive to the number of periods in the simulations.

4.2.1 Cap-only scenario

In the cap-only scenario, the carbon price that is necessary to close the emission gap in non-ETS sectors reaches 419 EUR/ton CO_2-eq in 2030.[25] This is almost seven times higher than the current carbon tax that most non-ETS sectors pay in the baseline.[26] The higher carbon costs imply higher production costs in all non-ETS industries. Higher costs lead to lower production in many industries, and to lower demand for labour and capital in these industries. Labour and capital are reallocated to other industries and both real wage rate and the real rate of return to capital fall by 1.7% and 2.2% respectively (see Table 4.1, first column).

Lower labour and capital prices benefit labour and capital-intensive industries. Capital-intensive non-ETS industries, such as production of machinery and metal products and other manufacturing (leather goods, textiles and food products), expand. Likewise, labour-intensive industries, such as business services, expand. For these industries, lower capital and labour costs outweigh the increase in emission costs.

The ETS-industries (aluminium, iron and steel and cement) also benefit from lower capital and labour prices. (Recall that carbon prices in the EU ETS market are the same in all scenarios.) They substitute labour and capital for intermediates and energy, while their output level is approximately unaltered, suggesting that they become relatively more capital and labour intensive. Output of energy-producing industries (refineries and oil/gas extraction) declines, as a response to lower demand for fossil fuels from other industries.

[24] We have tested the stability of the results in the baseline by extending the simulation period. The results are robust to the number of periods.

[25] The EU ETS price is exogenous and equal in all scenarios, 42 EUR/ton CO_2-eq in 2030 (increasing from 28 EUR/ton CO_2-eq in 2020). Exchange rate of 0.128 EUR/NOK is used (2013 value).

[26] Note that since the original carbon tax was not equal, some industries experience relatively larger cost increase than others.

GDP falls by 0.2%. The exchange rate appreciates to adjust to the fixed current account, benefitting especially industries that import intermediates.

Table 4.1 Main macroeconomic results, 2030. Change (%) from baseline; absolute values for carbon price

	Cap-only	Cap and EV target	EV target only
Carbon price for non-ETS industries, (EUR/ton CO_2-eq)[a]	419	228	Same as in baseline [b]
GDP	-0.2	-0.4	-0.3
Utility	-0.8	-2.3	-2.0
Real wage rate	-1.7	-0.3	0.7
Real return to capital	-2.2	-1.2	0.2
Capital use	-0.1	-0.2	-0.2
Exchange rate (NOK/foreign currency)	-0.3	0.2	0.4

[a] *The EU ETS price is exogenous and equal in all scenarios.*

[b] *In the EV target scenario, all industries have the same non-uniform CO_2 tax as in the baseline.*

The household sector ultimately receives all income in the economy and here this income falls, with consequent reductions in consumption of all goods and services. Price increase is substantial for transport activities, following the sevenfold increase of the carbon price, and this leads to large substitution effects in consumption. The consumer price of petrol and diesel increases more than 50% because of the carbon price increase, and there is a large substitution from ICEs to EVs in households. Use of petrol and diesel for transport purposes by households falls by 31% while electricity used for EVs increases by almost 10% (Table 4.2). The market share of new EVs to households increases to 88% (from 75% in the baseline), see Table 4.3. Consumption of housing and residential energy use are reduced, including households' demand for electricity for housing purposes, which falls by 1.9%. The cap-only policy leads also to substitution from public transport to private EV transport. The price of public transport increases (except air transport) and consumption of both road, rail, and water transport, are reduced by 0.5 to 1.2%.

Overall, household utility falls by 0.8% (Table 4.1). This is the welfare cost of the cap-only scenario. The carbon price interacts with other policies and distortions in the economy which are represented in our model, so the welfare cost is a mix of the direct abatement costs of the carbon cap and the carbon price's interaction effects with other policies and distortions. Fæhn et al. (2020) identify that the direct abatement costs make up approximately 40% of the total welfare cost of the cap, and the favourable EV policy as one of two other main sources for interaction effects with the carbon pricing that causes welfare loss.[27] A rule of thumb is that increasing consumption of goods that are heavily taxed initially (as ICEs and petrol and diesel) contributes positively to welfare, while increasing consumption of goods that are heavily subsidised initially (as purchase and use of EVs) will contribute negatively to welfare, as is confirmed in this scenario with increased purchases and use of EVs and a substantial reduction in purchases and use of ICEs.

Table 4.2 Household consumption of energy and transport goods, electricity production and trade, 2030. Change (%) from baseline

	Cap-only	Cap and EV target	EV target only
Electricity production	-4.5	-4.7	0.0
Electricity net import	14.6	14.2	2.3
Household consumption:			
Purchases of EVs	18.6	57.0	55.0
Purchases of ICEs	-53.1	-98.0	-98.0
Petrol and diesel	-30.9	-49.8	-42.9
Electricity use for EV charging	9.6	22.7	22.6
Electricity use for residential purposes	-1.9	-3.5	-1.9
Public road and rail transport	-1.2	-3.1	-2.9

4.2.2 Cap and EV target scenario

When the cap and EV target are combined the carbon price is 228 EUR/ton CO_2-eq, about half of that in the cap-only scenario. As the total cap for emissions from the non-ETS sectors is the same in all scenarios, less abatement is needed from other non-ETS sectors when households replace the rest of their new fossil-fuelled cars with EVs. Hence, the most expensive abatements in other sectors can be avoided, and this transforms into a lower emission price for the whole non-ETS segment.

The lower emission price benefits all other non-ETS sectors by reducing production costs, and the decline in output level in most industries is smaller than in the cap-only scenario. The fall in demand for labour and capital is smaller than in the cap-only scenario, consequently, wage rate and return to capital are reduced less than in the cap-only scenario (Table 4.1).

However, GDP declines 0.4% compared to baseline, twice as much as in the cap-only scenario. This illustrates that the economy is less efficient in reducing the emissions when such overlapping policies are present. Even though the most expensive emission abatements in the non-ETS production sectors are avoided, the total costs to the society are higher. In particular, household utility is reduced by 2.3%

[27] The other wedge is taxes that influence the real wage rate, interfering with the labour-leisure choice. With exogenous labour supply this effect is absent from our model. The wedges and imperfections in the current version of the SNOW model in climate policy analysis are thoroughly discussed in Fæhn et al. (2020).

compared to the baseline, so the additional target on new EVs comes at a cost. That utility falls three times more than in the cap-only scenario leads to a considerable negative income effect on consumption of all goods and services. The only exception is the increase in the number of EVs and accordingly also consumption of electricity used for charging EVs, which is almost 23% higher than in the baseline (compared to the 10% increase in the cap-only scenario). Households' spending on EVs is nearly 60% higher than in the baseline and 30% higher than in the cap-only scenario (Table 4.2).

Net imports of electricity increase to meet the higher demand for charging EVs. The exchange rate depreciates to keep the current account fixed, making imports, including more import of EVs, more expensive.

The increased roll-out of EVs is achieved by an implicit subsidy to EVs (see section 3.1.1 and appendix B for more details on modelling). This subsidy represents a **shadow price** on EVs to households. The shadow price of increasing the market share of new EVs to 100% amounts to 34%, an increase of 50% compared to the baseline and cap-only scenario where the shadow price is 23% (Table 4.3). This illustrates that more incentives (in the form of more benefits to EVs and higher GHG price/restrictions on ICEs) are needed to reach the EV sales target of 100%. This is also confirmed by our cap-only scenario, which demonstrated that an EV market share of 100% new EVs in 2030 was not reached with the carbon price of 419 Euro/ton CO_2-eq (see Table 4.3). We find that the 100% market share of new EVs comes at a considerable welfare cost – the utility loss is tripled in the cap-and-EV target scenario compared to the cap-only scenario.

Table 4.3 EVs in private transport, 2030

	Baseline	**Cap-only**	**Cap and EV target**	**EV target only**
EV sales (share of total car sales for households)	75	88	100	100
EV stock (share of total private vehicle stock)	59	64	69	69
Shadow price of EVs to households (rate)	**23**	**23**	**34**	**36**

4.3 Emissions

The cap on emissions in the non-ETS sectors implies a nearly 15% reduction in emissions from the baseline in 2030. In the cap-only scenario, transportation contributes most to the emission reduction, followed by gas and district heating, agriculture and forestry, and construction industries (see Figure 4.1). Emissions from commercial transport are reduced by 85%, while emissions from private transport are reduced by 31%, compared to baseline (Table 4.4). However, the share of emission reductions is approximately 30% in both scenarios for commercial transport (Figure 4.1).

In the cap-and-EV target scenario emissions from private transport are 30% (0.5 M ton) lower than in the cap-only scenario, while emissions from the other industries are 0.5 M ton higher (particularly emissions from commercial transport, construction, water transport, food products and fisheries). The cap, combined with the EV target, implies that households take a larger share of the emissions reductions compared to the cap-only scenario.

Figure 4.1 Emission reduction (as share of total CO_2 emission reduction in scenarios)

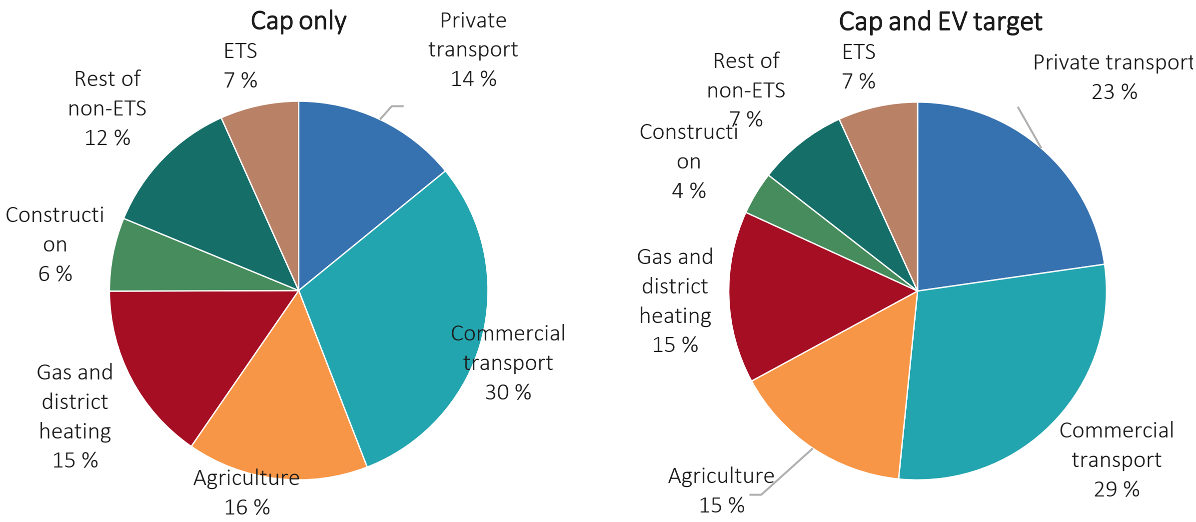


Table 4.4 Emissions from non-ETS sectors, 2030. Change from baseline

	Cap-only	Cap and EV target	EV target only
Emissions (relative change from baseline, %):			
Total emissions in non-ETS sectors	-27.5	-27.5	-5.7
- Private transport	-31	-50	-43
- Commercial road and rail transport	-85	-82	3
- Road transport in total	-54	-63	-23
Emissions (change from baseline, M ton CO_2):			
Total emissions in non-ETS sectors	-5.6	-5.6	-1
- Private transport	-0.9	-1.4	-1.2
- Commercial road and rail transport	-1.8	-1.7	0.1

4.4 Decomposition of the effects: EV target only

In this scenario we study the effects of only imposing the EV target of a 100% market share of new EVs in 2030, without the cap and uniform emission pricing in the non-ETS sectors. Rather, the CO_2 taxes are kept as in the baseline, which implies that there are non-uniform CO_2 taxes. This scenario highlights the effects of imposing a particular regulation on private transport without regulating carbon emissions by an additional cap.

Some interesting results emerge as we consider the tables above. Firstly, the emission reduction goal is not reached in this scenario: emissions are only reduced by 1 M ton CO_2, not 5.6 ton, as is the goal for non-ETS sectors. Emissions from private transport fall, but, with no cap on non-ETS emissions, the other industries have no incentives to reduce emissions. Second, private consumption is 2% lower than in the baseline, a slightly smaller reduction than in the cap-and-EV-target scenario (see Table 4.1).

The crucial conclusion is that the welfare costs of the 100% EV target are large, and the emission reductions are small. Subsidising EVs to such an extent, without pricing carbon emissions to reach a more stringent emission cap, is a very costly policy. The non-ETS sectors benefit from insufficient emission pricing, however, higher real wage and capital costs outweigh the lower carbon cost and GDP falls 0.3%, see Table 4.1.[28]

5 Sensitivity analyses

The results of the policy analyses rest particularly on the assumptions about EV technologies in the future. We test the robustness of the costs of the climate policies to these assumptions in sensitivity analyses. First, we test how the costs of the policies depend on EV technology development, particularly the price of the EVs at the world market (section 5.1). Second, we look at the importance of the assumptions of the relative attributes of EVs and ICEs, i.e., the extent to which households perceive EVs and ICEs to be close substitutes (section 5.2). Third, we test how increased annual driving distance for EVs, approaching the average driving distance for ICEs, will impact the electricity market (section 5.3).

5.1 EV technology development and world market prices

The first sensitivity exercise analyses how the costs of the policies depend on EV technology development: how much cheaper or more expensive it would be to reach the same emission reduction target with different technological development of EVs. Norway has no car production, so EVs are all imported. The prices of EVs at the world market are sensitive to technology development and world market demand effects. As other countries are considering EV policies, this will also influence world market demand and technology development.

[28] CES functions have limitations for analyses of corner solutions. We have tested the sensitivity of the results with a share of new EVs of 95% and find that the welfare effect for EV target only scenario is -0.7% compared to BAU, less than half the loss with 100% EV target. Recall that the share of new EVs in the baseline is 75%.

The world market price development of EVs in our baseline closely follows the projection of Bloomberg (Zamorano, 2017) suggesting a price fall of more than 50% from 2020 to 2030. The prices of EVs have declined substantially in the past, even more than the projections by Bloomberg, see e.g., IEA (2020b); Kittner et al. (2020); Norwegian Environmental Agency (2020). On the other hand, Ghandi and Paltsev (2019) also show battery cost projections with lower reduction rate over time. Hence, we test the robustness of the results by performing two sensitivities for world market prices for EVs: a more moderate price development, implying 50% higher price for EVs in 2030, and an even more optimistic price development, leading to 50% lower price for EVs in 2030.

We implement these alternative EV price assumptions in the *cap-only* and *cap and EV target* scenarios discussed above. Table 5.1 summarises the key results (measured as relative change from the relevant main policy scenario, that is, change from c*ap-only* and c*ap and EV target* scenarios, respectively).

In the **cap-only scenario,** with 50% higher EV price, there is now less substitution from ICEs to EVs than in the main scenario. Emissions from private transport are higher, and the carbon price that is necessary to reach the emission cap is 3% higher than with the baseline EV price projections (Table 5.1). The welfare cost in terms of loss in household utility is 0.4%. The GDP effect is also slightly negative since other non-ETS sectors than households must take a larger share of the emission reduction at a higher cost (higher carbon price). This includes commercial road transport where production and emissions are lower than in the main cap-only scenario.

The effects in the cap-only scenario with lower EV prices are symmetric, but with opposite signs: there are more EVs and less ICEs and the households take a larger share of the emission reduction, at a lower carbon price.

In the **cap and EV target** scenario, world market prices of EVs have a different effect. With the 50% higher EV price, the costs of reaching the 100% market share of new EVs in 2030 increases. Consumption of private transport falls. Purchases of both EVs and ICEs fall by 3.3%, following the higher costs of private transport and the negative household income effect, while GDP is only 0.04% lower. The carbon price is almost 2% lower than in the main policy scenario, reflecting lower consumption and production activity. The welfare costs of reaching the additional EV target, measured by change in utility, are especially sensitive for the technological development of EVs.

On the other hand, when the world market price of EVs is 50% lower, the costs of private transport fall considerably, and purchases of both EVs and ICEs increase by 3.1%.[29] Household income increases, giving a positive income effect for all goods and services. Consumption of all energy goods increases, especially electricity for charging EVs, but also petrol and diesel. This results in higher emissions from private transport. Production of commercial road transport also increases, contributing to higher emissions.

From this sensitivity exercise, it is especially interesting to note that with the additional EV target, the improved (cheaper) EV technologies stimulate private transport activities of both EVs and ICEs, and the emissions from private transport increase. The carbon price is higher and more of the emission reductions take place in other sectors than private and commercial road transport, at a higher emission reduction cost.

Table 5.1 Sensitivities with alternative EV world market price assumptions, 2030. Change (%) from the main policy scenarios

	Cap-only [a]		Cap and EV target [b]	
	50% higher EV price	50% lower EV price	50% higher EV price	50% lower EV price
Carbon price in non-ETS industries	3.0	-3.0	-1.9	2.0
Emissions from private transport	2.1	-2.1	-0.4	0.4
Emissions from commercial road and rail transport	-4.7	5.0	-2.1	2.1
GDP	-0.02	0.01	-0.04	0.04
Utility	-0.4	0.4	-0.5	0.6
Electricity production	0.00	0.00	-0.02	0.02
Electricity net import	-0.7	0.7	-0.9	0.9
Household consumption:				
Purchases of EVs	-3.6	3.0	-3.3	3.1
Purchases of ICEs	10.8	-10.3	-3.3	3.1
Petrol and diesel	2.1	-2.1	-0.4	0.4
Electricity use in households for EV charging	-3.5	3.7	-1.7	1.8
Electricity use in households for other purposes	-0.2	0.3	-0.4	0.4

[a] *Measured as relative change from the main Cap-only scenario.*

[b] *Measured as relative change from the main Cap and EV target scenario.*

[29] Note that the EV target is implemented as 99.9% requirement in 2030; hence, there is a small number of new ICEs also in the cap and EV target scenario.

5.2 What if EVs and ICEs are not perceived as close substitutes?

In the main scenarios, it is assumed that the attributes of the EVs and ICEs become more similar in the future and the consumers perceive them as close substitutes. This is reflected in the model by assuming a gradual increase of the substitution elasticity between ICE and EVs from 4 in 2020 to 8 in 2030 (as discussed in section 3.1.1). In this sensitivity exercise, we test the effects of the ICEs and EVs *not* becoming as similar by assuming that the substitution elasticity remains constant at 4, and we simulate the two policy scenarios with this lower elasticity. We find that lower substitution elasticity impacts the two policy scenarios in different ways (see Table 5.2 for results, measured as relative change from the relevant main policy scenario, with baseline elasticity).

In the **cap-only scenario** purchases of EVs are reduced by 15.2%, while purchases of ICEs increases considerably (but from a very low level, since the majority of car sales is EVs). The market share of EVs (both of sales and of stock) is 1 percentage point lower. Consumption of electricity for charging EVs is reduced, while consumption of petrol and diesel for ICEs increases, leading to higher emissions from private transport.

Utility increases by 0.5%, which may seem counterintuitive given that reduced options for substitution may be expected to reduce welfare. However, the welfare effects depend on initial tax wedges and imperfections in the economy, as discussed in section 4.1. In this sensitivity exercise, purchase and use of EVs is reduced, while purchase of ICEs and petrol and diesel increase, and both effects contribute to increased welfare, since the favourable EV policy is identified as one of the major contributors to the welfare loss of the carbon policy. Since households abate less emissions, the carbon price increases and other industries (commercial transport and the other carbon-intensive industries in non-ETS) must contribute more to the emission reduction to reach the cap, but the higher carbon price is not enough to outweigh the welfare gain of less use of EVs.

In the **cap and EV target scenario** the EV target implies that the household cannot substitute away from EVs. Therefore, the lower substitutability implies higher costs of EVs and private transport for the household, and purchases of both EVs and ICEs are reduced. The reduction in consumption of ICEs and fuel for ICEs (petrol and diesel) contribute to a welfare loss that is not offset by the slight reduction in consumption of EVs. In total, utility falls by 0.3%. Lower emissions from private transport contribute to lower the carbon price that is necessary to reach the emission cap, and less abatement take place outside the household sector. However, the lower carbon price is not enough to outweigh the welfare loss of even less use of ICEs.

Table 5.2 Sensitivity with lower substitution elasticity between EVs and ICEs, 2030. Change (%) change from the main policy scenarios

	Cap-only [a]	**Cap and EV target** [b]
Carbon price in non-ETS industries	24.0	-27.6
Emissions from private transport	12.3	-14.8
Emissions from commercial road and rail transport	-17.5	3.2
GDP	0.1	0.01
Utility	0.5	-0.3
Electricity production	0.1	0.0
Electricity net import	0.3	0.5
Household consumption:		
Purchases of EVs	-15.2	-0.6
Purchases of ICEs [c]	116.6	-0.6
Petrol and diesel	12.3	-14.9
Electricity use in households for EV charging	-13.4	-0.4
Electricity use in households for other purposes	0.9	0.1

[a] *Measured as relative change from the main Cap-only scenario.*

[b] *Measured as relative change from the main Cap and EV target scenario.*

[c] *The share of ICE purchases is initially low in the baseline. The 116.6% increase in the Cap-only scenario is in fact the same sales share as in baseline.*

5.3 Increased driving distance of EVs

In our modelling of EVs we assume that the average driving distance is constant. However, over the last years we have seen a considerable increase in the annual average driving distance for EVs; it is reasonable to assume that the annual driving distance will continue to increase over time as EV batteries and the infrastructure for charging improves.[30] Hence, in this scenario we assume that the annual driving distance for each EV is doubled, to approximately the same driving distance as for ICEs, to investigate the effects of higher electricity demand.

The results of this sensitivity, compared to the two main policy scenarios, are given in Table 5.3. The effects are largest in the electricity market as expected, while the macroeconomic effects are minor in both policy scenarios. With a longer driving distance, the households' electricity demand for charging the EVs is nearly doubled.[31] However, this doubling is from a very low absolute level, as electricity for charging accounts for a small share of total household electricity consumption. The total electricity consumption for charging EVs with the 100% EV target has been estimated to less than 4 TWh in 2030,

[30] https://www.ssb.no/en/transport-og-reiseliv/statistikker/klreg (table 12577). See also: https://www.ssb.no/transport-og-reiseliv/artikler-og-publikasjoner/mindre-bilkjoring-i-koronaaret.

[31] Since the shift results in slightly more driving, the cost of driving EVs increases for the household, and there is a small substitution effect towards ICEs.

which is less than 3% of Norway's total electricity consumption (NVE, 2017). In our simulation, the electricity market effects are minor: production of electricity only increases by 0.1% and the electricity net import increases by 2–2.8% (Table 5.3). However, the initial level of electricity import to Norway is moderate, around 1% of total electricity consumption.

Table 5.3 Sensitivity with increased EV driving distance, 2030. Change (%) from the main policy scenarios

	Cap-only [a]	**Cap and EV target** [b]
Electricity use in households for EV charging	98.5	99.6
Electricity use in households for other purposes	-0.2	-0.3
Electricity production	0.1	0.1
Electricity net import	2	2.8

[a] *Measured as relative change from the main Cap-only scenario.*

[b] *Measured as relative change from the main Cap and EV target scenario.*

6 Concluding remarks

We have analysed the abatement costs and economy-wide welfare effects of interacting and partly overlapping climate regulations in private transportation and in the non-ETS sectors in general. We show that the combination of policies – when the uniform carbon price is supplemented with a specific EV target – triples the welfare costs (compared to only capping emissions by a uniform carbon price).

In the **cap-only** scenario, the high uniform carbon price (that is needed to reach to cap) implies that the emission-intensive non-ETS industries experience high costs. In the **cap and EV target** scenario, a lower carbon price is needed to reach the cap, since the larger number of EVs in private transportation reduces emissions from households (and hence the necessary emission reduction from other sectors). One key outcome is that all non-ETS industries benefit from the lower carbon price. Hence, for the non-ETS industries there are incentives for overlapping climate regulations, as the EV policies reduce the marginal carbon price for these industries.

Until now, Norway has been an international leader in decarbonising private transportation, with its generous support schemes and relatively high share of EVs. As EV technologies become mature, other countries are likely to introduce more policy focus on promoting, enabling and incentivising EV uptake. Our findings suggest that the cost of these policies is high in Norway but may be even higher in other countries. The effects of the interacting regulations and especially the EV policies depend on a range of factors and conditions prevailing in the national context: the degree of the initial electrification of the society, the share of electricity in household energy use, the electricity production and grid capacity and investment needs. Technological improvements and productivity effects will benefit both exporting and importing countries. Further, the economy-wide effects will also depend on whether it is a car-producing nation, potentially benefitting from new market options related to EVs, or whether these benefits accrue to foreign nations. Thus, the implications and lessons emerging are likely to be characterised by a combination of country-specific and more generic effects. Still, even though the magnitude of the effects depends on country-specific conditions, the key conclusion remains: a combination of partly overlapping policies increases the abatement costs, since the additional EV policy puts the most efficient emission abatement policy – uniform carbon price – partly out of action. Crucially, the novel CGE model developments introduced here enable investigation of the features of ambitious EV and climate policies, a highly electrified economy and EV technologies in private transportation in an economy-wide consistent framework.

The large improvements in EV technologies that have taken place the last few years will contribute to reduce the costs of electrification through EVs, as our sensitivity of technological development shows. Here we note a caveat in that our model does not include positive technology externalities, such as learning effects, technology spillovers, or network externalities, each of which may result in EV support turning out to be less expensive in reality than in our analyses. However, independent of the source or size of technology externalities, it is likely that support schemes for climate technologies should still be combined with sufficient carbon pricing to reach the emission reduction goals. To gain more knowledge of technology externalities, development of markets for new climate technologies and effects of policy instruments, with insights informing modelling economy-wide impacts thereof, should be at the research agenda in the years to come, given the myriad of policy instruments and technologies that are used.

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Appendices

A Industries, final consumption goods and elasticities in SNOW

Table A 1 Industries in SNOW

Agriculture	AGR
Forestry	FRS
Fishing	FSH
Coal production	COA
Oil & gas extraction	CRU
Minerals nec	OMN
Food products – meat	MEA
Vegetable oils and fats	VOL
Dairy products	MIL
Food products nec	OFD
Beverages and tobacco products	B_T
Textiles	TEX
Wearing apparel	WAP
Leather products	LEA
Wood products	LUM
Paper products, publishing	PPP
Petroleum, coal products	OIL
Chemical, rubber, plastic products	CRP
Mineral products nec	NMM
Ferrous metals	I_S
Metals nec	NFM
Metal products	FMP
Motor vehicles and parts – conventional internal combustion engine (ICE) vehicles	MIE
Motor vehicles and parts – electric vehicles (EV)	MEV
Transport equipment nec	OTN
Machinery and equipment, incl. electronic equipment	MEE
Manufactures nec	OMF
Electricity	ELE
Gas manufacture, distribution	GAS
Water	WTR
Construction	CNS
Trade	TRD
Transport nec	OTP
Water transport	WTP
Air transport	ATP
Communication	CMN
Financial services nec	OFI
Insurance	ISR
Business services nec	OBS
Recreational and other services	ROS
Public sector (defence)	OSG
Dwellings	DWE
Public sector – central government (administration, education, health services, culture)	OSS
Public sector – local government (admin., education, health services, culture, water)	OSK
Private education and health services	OSP
Waste management (public)	AVK
Waste management (private)	AVP

Table A 2 Final consumption goods in SNOW

Food and non-alcoholic beverages	CFAB
Alcoholic beverages and tobacco etc.	CABT
Clothing and footwear	CCAC
Housing & water	CHAW
Electricity (for heating)	CELE
Gas (for heating)	CGAS
Paraffin and heating oil (for heating)	CPAH
Fuel wood, coal etc. (for heating)	CFAC
District heating	CDHE
Furnishings, household equipment and routine household maintenance	CFHR
Health	CHEA
Transport equipment – conventional internal combustion engine (ICE) vehicles	CTEQ
Transport equipment – electric vehicles (EV)	CTEV
Fuel in private transport – Petrol & diesel	CPAD
Fuel in private transport – Electricity for EVs	CEEV
Public transport (rail)	CRAI
Public transport (road)	CROA
Public transport (air)	CAIR
Public transport (boat)	CBOA
Communication	CCOM
Recreation and culture	CRAC
Education	CEDU
Restaurants and hotels	CRAH
Miscellaneous goods and services	CRAH
Final consumption expenditure of central government	GS
Final consumption expenditure of local government	GK
Final consumption expenditure of NPISHs	GF
Gross fixed capital formation – private	I
Gross fixed capital formation – central government	IG
Gross fixed capital formation – local government	IG
Changes in stocks and statistical discrepancies	ST

Table A 3 Elasticities in the CES function for production and trade

Parameter	Explanation	Value
Elasticities in production function:		
esub_kle_m	Elasticity of substitution between aggregate intermediate inputs (M) and other inputs (KLE)	0.5
esub_m	Elasticity of substitution between non-energy intermediate inputs (M)	0.25
esub_e_va	Elasticity of substitution between capital-labour aggregate (KL) and energy aggregate (E)	0.5
esub_va	Elasticity of substitution between capital (K) and labour (L)	0.75
esub_k	Elasticity of substitution across capital types	0.25
esub_elec	Elasticity of substitution between electric and non-electric energy in the energy aggregate	0.5
esub_c_go	Elasticity of substitution between coal and the oil-gas aggregate	0.5
esub_g_o	Elasticity of substitution between oil and gas	0.5
Elasticities in trade:		
esub_dm	Armington elasticity - domestic versus imports	4
etrn	Elasticity of transformation	4
Elasticities for emissions:		
	Elasticity between energy-related emissions and energy goods	0
	Elasticity between process emissions and output level	0

Table A 4 Elasticities in the CES function for final consumption

Parameter	Explanation	Value
esubh_nele	Substitution between non-electric energy inputs in housing	0.5
esubh_ele	Substitution between electricity and the non-electric energy aggregate in housing	0.5
esubh_hou	Substitution between energy and other inputs in housing	0.5
esubh_trnt	Substitution between public and private transportation in final consumption	0.75
esubh_trpu	Substitution between alternative public transportation in final consumption	0.5
esubh_on	Substitution between old and new cars in private transportation in final consumption	10
esubh_trpr	Substitution between EVs and ICEs in transportation in final consumption	0.5 – 8[a]
esubh_cpad	Substitution between fuel and the composite of car and O&M for conventional cars in transportation in final consumption	0.5
esubh_ceev	Substitution between electricity and the composite of car and O&M for electric cars in transportation in final consumption	0
esubh_m	Substitution between all other consumption goods (except those transportation and housing)	0.5

[a] *Substitution elasticity between EVs and ICEs is 0.5 in 2013 (base year), increasing gradually to 4 in 2018 and to 8 in 2030, see section 3.1.1.*

B Modelling private transport and EVs in the SNOW model

We describe the cost function of private transport service (P_{PRV}), which is part of the private consumption nest in the SNOW model, as described in section 3.1 and Figure 3.1. The values for the relevant elasticities are reported in Table A 4.

At the top nest of private transport, we combine services of new and old cars following the constant elasticity of substitution (CES) function:

(B.1) $$\frac{P_{PRV}}{\bar{P}_{PRV}} = \left[\theta_{NCAR}\left(\frac{P_{NCAR}}{\bar{P}_{NCAR}}\right)^{1-\sigma_{on}} + \theta_{OCAR}\left(\frac{P_{OCAR}}{\bar{P}_{OCAR}}\right)^{1-\sigma_{on}}\right]^{\frac{1}{1-\sigma_{on}}}$$

where P_{NCAR} and P_{OCAR} are the prices of the composite of the services of new and old cars. The parameter θ represents the value share of corresponding input in the benchmark. Note that the benchmark values are represented with bar (e.g., $\overline{P}_{PRV}$). The parameters σ represent elasticities of substitution in CES functions.

The composite of services of new cars consists of services of new EVs (electric vehicles) and new ICEs (internal combustion engine vehicles), and EVs and ICEs are substitutable. In other words, when the households buy a new car, they can decide which type of car they buy with relative prices including the subsidy on EV (s_{EV}) and tax on ICE (t_{ICE}):

(B.2) $$\frac{P_{NCAR}}{\bar{P}_{NCAR}} = \left[\theta_{NEV}\left(\frac{P_{EV}^{new}(1-s_{EV})}{\bar{P}_{EV}^{new}(1-\bar{s}_{EV})}\right)^{1-\sigma_{trpr}} + \theta_{NICE}\left(\frac{P_{ICE}^{new}(1+t_{ICE})}{\bar{P}_{ICE}^{new}(1+\bar{t}_{ICE})}\right)^{1-\sigma_{trpr}}\right]^{\frac{1}{1-\sigma_{trpr}}}$$

The composite of services of old cars follows a similar equation, while the difference is that the number of vehicles is determined in the past in this case:

(B.3) $$\frac{P_{OCAR}}{\bar{P}_{OCAR}} = \left[\theta_{OEV}\left(\frac{P_{EV}^{old}(1-s_{EV})}{\bar{P}_{EV}^{old}(1-\bar{s}_{EV})}\right)^{1-\sigma_{trpr}} + \theta_{OICE}\left(\frac{P_{ICE}^{old}(1+t_{ICE})}{\bar{P}_{ICE}^{old}(1+\bar{t}_{ICE})}\right)^{1-\sigma_{trpr}}\right]^{\frac{1}{1-\sigma_{trpr}}}$$

The price of services of EVs consists of the rental value of EV (P_{EV}^{r}), electricity consumption (P_{ELE}) and other costs ($P_{i,EV}$) (where the set *r* represents old or new vehicles and the set *i* represents the good or service):

(B.4)

$$\frac{P_{EV}^{r}}{\bar{P}_{EV}^{r}} = \left[\theta_{ceev}^{r}\left(\frac{P_{ELE}}{\bar{P}_{ELE}}\right)^{1-\sigma_{ceev}} + (1-\theta_{ceev}^{r})\left(\theta_{evcar}^{r}\left(\frac{P_{EV}^{r}(1+t_{EV}^{r})}{\bar{P}_{EV}^{r}(1+\bar{t}_{EV}^{r})}\right) + \sum_i \theta_{i,EV}^{r}\left(\frac{P_{i,EV}}{\bar{P}_{i,EV}}\right)\right)^{1-\sigma_{ceev}}\right]^{\frac{1}{1-\sigma_{ceev}}}$$

Similarly, the price of services of ICEs consists of the rental value of ICE (P_{ICE}^{r}), petrol/diesel consumption (P_{CPAD}), and other costs ($P_{i,NICE}$).

(B.5)

$$\frac{P^r_{ICE}}{\bar{P}^r_{ICE}} = \left[\theta^r_{cpad}\left(\frac{P_{CPAD}}{\bar{P}_{\mathrm{CPAD}}}\right)^{1-\sigma_{cpad}} + (1 - \theta^r_{cpad})\left(\theta^r_{icecar}\left(\frac{P^r_{ICE}(1+t^r_{ICE})}{\bar{P}^r_{ICE}(1+\bar{t}^r_{ICE})}\right) + \sum_i \theta^r_{i,ICE}\left(\frac{P_{i,ICE}}{\bar{P}_{i,ICE}}\right)\right)^{1-\sigma_{cpad}}\right]^{\frac{1}{1-\sigma_{cpad}}}$$

C A stylized version of the recursive dynamic model SNOW

Assumptions: One representative firm that use labour and capital for input, we disregard other intermediates and natural resources. One household that receives all income, net taxes and transfers, and all imports, while all investments take place in the firm. Emissions are omitted in the stylized model.

	Equations:	Corresponding endogenous variable:
(1)	$p^Y = c(w,r)$	p^Y
(2)	$p^Y = \left[\phi^{-\eta}(p^H)^{(1+\eta)} + (1-\phi)^{-\eta}\left(v\overline{p}^W\right)^{(1+\eta)}\right]^{1/(1+\eta)}$	p^H
(3)	$p = \left[\theta_A^{\sigma_A}(p^H)^{(1-\sigma_A)} + (1-\theta_A)^{\sigma_A}(v\overline{p}^W)^{(1-\sigma_A)}\right]^{1/(1-\sigma_A)}$	v (and p, but p is numeraire)
(4)	$K^D = \left(\frac{r}{\theta p^Y}\right)^{-\sigma} Y$	K^D
(5)	$L^D = \left(\frac{w}{\theta p^Y}\right)^{-\sigma} Y$	L^D
(6)	$M = \left(\frac{v\overline{p}^W}{\theta_A p}\right)^{-\sigma_A} C$	M
(7)	$A = \left(\frac{v\overline{p}^W}{\varphi p^Y}\right)^{\eta} Y$	A
(8)	$H = Y - \overline{G} - \overline{D}$	H
(9)	$Y + M = C + A + \bar{G} + I$	Y
(10)	$K = (1-\delta)(K_{-1} + I_{-1})$	K
(11)	$L = \overline{L}$	L
(12)	$K^D = K$	r
(13)	$L^D = L$	w
(14)	$S = S(H,p)$	S
(15)	$C = C(H,p)$	C
(16)	$I = S$	I

Eq. (1) is the first-order condition for the cost minimising firm. Eq. (2) production is a CET-aggregate of domestic and foreign deliveries. Eq. (3) consumer price is an Armington-aggregate of a domestic and foreign variety. Eq. (4) and eq. (5) are demand for capital and labour. Eq. (6) and (7) denote demand for import and export, Eq. (8) is consumer budget balance. The aggregate of savings and consumption *H* is determined residually in this dynamic, recursive model. Eq. (9) is the equilibrium condition in this one product economy. From eq. (8) and (9) savings is determined by trade balance surplus: $\overline{D} = A - M$. Domestic savings and consumption are distributed by a CES-function, see eq. (14) and (15), and savings determines real investments, (eq. (16)).

The stock of capital is given in the base year and develops along with domestic real investments, while labour supply is exogenous. There are 17 endogenous variables (p^Y, p^H, v, p, K^D, L^D, K^S, L^S, M, A, H, C, Y, r, w, S, I), and p is numeraire that determines the model. All prices are defined in real prices in terms of the consumer good. All variables with bar and parameters with Greek letters are exogenous.

Variables in the stylized model:

w	Wage rate
r	Rate of return to capital (user cost)
$c(\cdot)$	Unit cost
p^Y	Unit income
p^H	Price of domestic delivery
$\overline{p}^W$	World market price (export and import) measures in foreign currency
v	Exchange rate
p	Consumer price
Y	Production
C	Consumption
M	import
A	export
K^D	Capital demand
L^D	Labour demand
K	Capital stock
L	Labour stock
G	Government consumption
$\overline{L}$	Exogenous labour supply
$\overline{D}$	Exogenous foreign savings
S	Savings (in real terms)
I	Private investments
H	CES-aggregate of S and C
$\theta, \theta_A, \varphi$	Share parameters
η, σ_A, σ	Transformation elasticity, Armington elasticity, factor substitution elasticity
δ	Depreciation rate