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Abating greenhouse gases in the Norwegian non-ETS sector by 50 per cent by 2030

A macroeconomic analysis of Climate Cure 2030

TALL SOM FORTELLER

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Preface

In connection with the Climate Cure 2030 initiative of the Norwegian government, Statistics Norway has a separate mandate to conduct a macroeconomic analysis of Norwegian abatement of greenhouse gas emissions not covered by the EU emission trading system. The mandate specifies an emission target for 2030 not exceeding 50 per cent of the Norwegian non-ETS emission level in 2005. As part of its mandate, Statistics Norway is also asked to assess whether, and in the event how, the partial analyses of abatement measures from the expert group can be utilised in the macroeconomic analysis.

This report is Statistics Norway's response to the mandate.

Statistics Norway, 18 June 2020

Linda Nøstbakken

Abstract

This report is a response to the separate mandate for Statistics Norway (SSB) in the Climate Cure 2030 initiative of the Norwegian government (see footnote 1). SSB was requested to conduct a macroeconomic analysis of a scenario in which the Norwegian greenhouse gas (GHG) emissions not covered by the European emission trading system (ETS) are cut to 50 per cent of their 2005 level by 2030. This is a larger cut than the 40 per cent to which Norway is currently committed.

The analysis examines long-run macroeconomic impacts by means of the computable general equilibrium, multi-sector SNOW model of the Norwegian economy. The abatement is achieved by replacing the CO_2-tax system of today with a uniform price on all non-ETS GHG emissions. Two abatement scenarios are simulated. In the first, we identify the level of the greenhouse gas price necessary to obtain the required abatement responses, where and how the abatement will take place, and the overall cost and macroeconomic implications without any other policy changes. In the second abatement scenario, the same climate policies are introduced. In addition, it is assumed that the extra revenue generated is recycled back to households by reducing the labour income tax rate. This scenario exemplifies how the overall social costs of the climate policy can be reduced by targeted revenue recycling that counteracts existing tax wedges, in this case a significant distortion in the labour market caused by labour taxation.

The macroeconomic impacts are assessed relative to a long-run projection where current policies are extended to 2030. This reference scenario is based on the government's projection of economic trends and emissions in the National Budget for 2020. Since the emission levels already decline significantly towards 2030 in the National Budget projection, the remaining task for the GHG price reforms in our scenarios is to reduce non-ETS GHG emissions by 27.4 per cent, or 5.6 million tonnes of CO_2-equivalent ($MtCO_2eq$) from the reference scenario by 2030.

In the first abatement scenario, the necessary emission price comes to NOK 3 200tCO_2eq in 2030 (real 2013 price). 90 per cent of the abatement takes place within four economic areas: private and commercial road transportation (47 per cent), waste and district heating (19 per cent), agriculture and forestry (17 per cent) and construction (7 per cent). The direct abatement costs facing firms and households that implement abatement measures add up to a total of NOK 7.6 bn by 2030. These direct costs translate into a marked macroeconomic contraction: by 2030, GDP, employment and private consumption have fallen by 0.4, 0.3 and 1.1 per cent, respectively, compared to the reference scenario. The utility of the consumer takes the form of enjoyment of both leisure and consumption. It falls by 0.8 per cent in 2030. The utility loss is a metric for social costs.

Scrutinising this loss further uncovers that it is significantly larger than the direct abatement cost mentioned above. There are indirect costs for society that are primarily attributable to numerous governmental interventions already present in the economy. Many of these have unfavourable impacts on economic efficiency. The considered abatement policies cause activity changes that may either reinforce or counteract these distortions. In this first abatement scenario, two main areas of government intervention become more distortive and explain about 60 per cent of the social costs: i) an increase in the purchase and use of electric vehicles that is already stimulated by implicit subsidies, and ii) a further reduction in labour supply, which is already discouraged by taxes. The latter is a reflection of higher costs and lower private sector demand for labour.

In the second abatement scenario, the cut in the labour income tax rate reduces the labour market distortion directly and dampens the negative impact of the remaining labour taxes. The result is that social costs (utility) are halved compared to the first scenario. This emerges despite higher direct abatement costs in this scenario amounting to NOK 8.0 bn in 2030. This is due to generally higher economic activity, which calls for a more stringent GHG price of NOK 3 500/tCO_2eq. GDP, employment and private consumption all increase compared with the reference scenario, by 0.3, 0.9 and 0.2 per cent, respectively.

The SNOW model's macroeconomic approach complements the analysis in Climate Cure 2030 (2020) in three main respects: it is able to take into account the impacts of many simultaneous measures, it links measures directly to policy instruments via the behavioural responses of modelling agents, and it accounts for the productivity impacts of existing distortions and possible revenue recycling choices that are present in any real economy. Cost metrics in the two approaches are different, both with their respective qualities. The bottom-up methodology used in Climate Cure 2030 (2020) is the most appropriate for examining the details of abatement options This analysis has provided the macroeconomic study with qualitative and quantitative knowledge. It is used most actively to quantify abatement data on agriculture and some commercial transportation.

Sammendrag

Klimakur 2030 er et oppdrag fra regjeringen om å utrede tiltak og virkemidler i klimapolitikken mot 2030; se fotnote 1. Denne rapporten besvarer det særskilte mandatet til Statistisk sentralbyrå om å analysere de samlede kostnadene ved et 50 prosents utslippskutt i ikke-kvotepliktig sektor fra 2005-nivået i 2030. Dette er et større kutt enn Norges foreløpige forpliktelse om 40 prosents kutt. Oppdraget innebærer å gjennomføre en makroøkonomisk analyse av utslippsreduksjoner i et slikt omfang. I den sammenheng skal Statistisk sentralbyrå gjøre en vurdering om og i tilfelle hvordan tiltaksanalysene og tilhørende kostnadstall kan nyttiggjøres i den makroøkonomiske analysen.

Analysen vurderer langsiktige makroøkonomiske konsekvenser ved hjelp av den generelle, disaggregerte likevektsmodellen SNOW av norsk økonomi. Det antas at kuttene oppnås ved at det innføres en utslippspris på alle klimagasser utenfor kvotepliktig sektor. Samtidig fjernes CO_2-skatten som gjelder for disse kildene i dag. Det gjøres to simuleringer av denne politikken. I den første undersøker vi hvor høy utslippspris som trengs for å nå mandatets utslippskutt i 2030, hvordan reduksjonene fordeler seg på utslippskilder og hva de samfunnsøkonomiske implikasjonene blir i tilfellet uten andre politikkendringer. I den andre politikksimuleringen er utslippsmålet og virkemidlet fortsatt det samme. I tillegg lar vi endringen som oppstår i det offentliges budsjetter føres tilbake til økonomien gjennom å redusere skatten på arbeidsinntekt. Dette er et eksempel på hvordan klimapolitikken kan gjøres billigere for samfunnet. Forklaringen er at arbeidsbeskatningen bidrar til å redusere effektiviteten i samfunnet, siden husholdningene velger å tilpasse sin bruk av fritid, arbeidstid og inntekter annerledes enn uten skattekilen. Når provenyendringen brukes til å redusere skattekilen vil arbeidstilbudet bli høyere, og gevinsten det innebærer motvirker kostnaden ved klimapolitikken.

De makroøkonomiske virkningene måles i forhold til en økonomisk framskrivning hvor all gjeldende politikk antas å bli forlenget til 2030. Denne referansebanen er basert på regjeringens nasjonalbudsjett for 2020. I regjeringens framskrivning faller utslippene betydelig mot 2030. Den gjenværende reduksjonen som må til i 2030 i politikkscenarioene er på 27 prosent eller 5,6 millioner tonn CO_2-ekvivalenter i forhold til referansebanen.

I det første politikkscenarioet når utslippsprisen NOK 3 200 per tonn CO_2-ekvivalenter i 2030 (realpris 2013). 90 prosent av utslippskuttene kommer på de fire samfunnsområdene veitransport (47 prosent), avfall, fjernvarme og gassdistribusjon (19 prosent), landbruk (17 prosent) og bygg- og anleggsektoren (7 prosent). De direkte tiltakskostnadene aktørene påføres i form av endret atferd og teknologiske valg som følge av utslippsprisen, beløper seg ifølge beregningene til totalt NOK 7,6 mrd. i 2030. Atferdsendringene bidrar til et markert makroøkonomisk fall: I 2030 går BNP, sysselsetting og privat konsum ned med henholdsvis 0,4, 0,3 og 1,1 prosent i forhold til referansebanen. Nytten til konsumentene faller med 0,8 prosent. Den er knyttet til hvor mye varer, tjenester og fritid som alt i alt kan konsumeres i befolkningen. Nyttetapet kan brukes som mål på de samfunnsøkonomiske kostnadene.

Ved å gå nærmere inn på nyttetapet finner vi at det er betydelig større enn den direkte kostnaden ved utslippskuttene beskrevet ovenfor. Det oppstår indirekte samfunnsøkonomiske kostnader når den klimapolitikken vi analyserer samspiller med annen offentlig politikk som allerede preger økonomien. Mange offentlige inngrep har som bieffekt at de reduserer effektiviteten til økonomien ved å vri ressursbruken. Vridningene som følger av inngrepene som alt finnes, vil enten

forsterkes eller motvirkes av omallokeringer klimapolitikken medfører. I det første politikkscenarioet finner vi at inngrepene på særlig to felt er med på å forsterke de samfunnsøkonomiske kostnadene: (i) For det første innebærer støttepolitikken rettet mot el-biler et ekstra nyttetap når elbiletterspørselen øker ytterligere. (ii) For det andre gir skattene som direkte og indirekte påvirker arbeidstilbudet et økt nyttetap når arbeidstilbudet faller som følge av utslippsprisingen. Disse to effektene forklarer omtrent 60 prosent av nyttetapet.

Når klimapolitikken kombineres med å kutte skatten på arbeidsinntekt i det andre politikkscenarioet, reduserer dette vridningen i arbeidsmarkedet både direkte og gjennom å motvirke de gjenværende skattekilene knyttet til arbeid. Dette bidrar til å halvere den samfunnsøkonomiske kostnaden (nytten) sammenliknet med det første politikkscenarioet, til tross for at den direkte kostnaden ved utslippskuttene er høyere i dette scenarioet – på NOK 7,6 mrd. Grunnen til denne økningen er at utslippsmålet er mer krevende å nå når aktivitetsnivået i økonomien stimuleres av redusert skatt på arbeid. BNP, sysselsetting og privat konsum *øker* fra referansebanen i dette scenarioet – med henholdsvis 0,3, 0,9 and 0,2 prosent. Utslippsprisen når opp i NOK 3 500 per tonn CO_2-ekvivalenter.

Den makroøkonomiske tilnærmingen ved bruk av SNOW-modellen utfyller analysen i Klimakur 2030 (2020) på hovedsakelig tre måter: Den er i stand til å studere hvordan simultane tiltak på mange områder påvirker hverandre og økonomien, den kopler tiltakene direkte til politikkvirkemidler ved å modellere hvordan aktører responderer og den tar i betraktning samfunnsøkonomiske kostnadsendringer pga. effektivitetskiler og provenybruk. Kostnadsbegrepene i de to tilnærmingene har hver sine kvaliteter. Klimakur 2030 (2020) inneholder langt flere detaljer om enkelttiltak og deres kostnader enn SNOW-analysen. Slik informasjon har vært til nytte i tolkninger av den makroøkonomiske analysen. For tiltak i jordbruket og deler av kommersiell transport har vi valgt å bare bruke kvantitativ informasjon fra Klimakur 2030 (2020) heller enn å simulere dem i SNOW.

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1. Introduction

1.1. Background

In May 2019, the Norwegian government established an expert group with the task of analysing feasible measures (behavioural and technological changes that abate greenhouse gas (GHG) emissions), and policy instruments that induce such changes, for meeting the country's GHG emission target for 2030. This project is called Climate Cure 2030 (Klimakur 2030, hereafter abbreviated to KK).[1]

The background to the KK mandate is the world's ambitions for curbing global warming as specified in the Paris Agreement. The Norwegian pledges in the agreement are set out in the Norwegian Climate Act and correspond to the commitments in the country's coordinated climate policy efforts with the European Union (EU). The current national commitment for 2030 is a 40 per cent reduction of emission level in 1990. Norway may raise its ambitions further in forthcoming climate negotiations.

The Norwegian climate policy targets towards 2030 are specified separately for the emission sources covered by the emission trading system (ETS) of the EU and those not covered (non-ETS). The latter are subject to the EU Effort Sharing Regulation (ESR).[2] As part of the ESR, a national GHG emission budget has been established for Norway, with annual targets for the years 2021 to 2030.

The challenge of meeting the non-ETS commitments is the main focus of the government's KK initiative. The first pillar of the KK mandate addresses non-ETS emissions covered by ESR (hereafter non-ETS and ESR are used interchangeably). It issues instructions for the inclusion of measures for obtaining an at least 50 per cent cut in non-ETS emissions by 2030, as compared to 2005 levels. The United Nations (UN) (and EU) definitions of territorial emissions are to be used, and budgets are to be set up for each of the years 2021 to 2030. The budgets are to be consistent with the ESR methodology. The second pillar of the KK mandate addresses emissions and uptake in land use, land use change and forestry (LULUCF).

The expert group was coordinated by the Norwegian Environment Agency (Miljødirektoratet, MDIR) and delivered its report, Klimakur 2030 (2020), hereafter abbreviated to KK (2020), by 31 January 2020. The report analyses 60 different measures for a large variety of non-ETS sources with total abatement potential in 2030 estimated to exceed 50 per cent relative to 2005 volumes. Measures are defined as physical actions by consumers, producers, municipalities or the state that reduce GHG emissions. Each measure is categorised in one of three cost groups designed to indicate the additional costs to society as a whole of implementing the measure. The costs as seen from the point of view of private agents are also assessed, including potential barriers to implementation. Most of the measures consist of producing less emissions for unchanged consumption or production volumes, i.e., providing equivalent services. In many cases, technologies need to be developed in order to become equivalent and cheaper. The methodology ensures consistency across sectors and measures (see KK (2020), Appendix 2).

The KK mandate also contains a separate mandate for Statistics Norway (SSB). SSB is to conduct a macroeconomic analysis of a scenario in which the Norwegian

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[1] For The Climate Cure 2030 mandate, see https://www.regjeringen.no/contentassets/f4af00f2a3184ad383b7b144382e20cc/mandat-klimakur-2030.pdf

[2] https://ec.europa.eu/clima/policies/effort/regulation

non-ETS GHG emission level in 2030 does not exceed 50 per cent of the Norwegian non-ETS emissions in 2005. As part of this, SSB is asked to include an assessment of whether, and in the event how, the partial analyses of the expert group's measures can be utilised in the macroeconomic analysis.

1.2. The present study

The present study is a response to the separate mandate for SSB. It builds on the first pillar of the KK mandate concerning Norwegian non-ETS emissions, which are defined in this report exclusive of (net) emissions related to LULUCF. We examine the impacts on the Norwegian economy of the required 50 per cent reduction (as compared to 2005) in Norwegian non-ETS emissions, including the overall abatement costs and changes in gross domestic product (GDP), industrial pattern, utility, consumption and employment. The macroeconomic study indicates how abatement takes place and is dispersed across sectors. The specifications of the tasks are given in contracts between SSB and the Ministry of Climate and the Environment (Klima- og miljødepartementet) and the Ministry of Finance (Finansdepartementet).

The project has made use of Statistics Norway's World (SNOW) model, which is a computable general equilibrium (CGE) model of the Norwegian economy developed by SSB. SNOW is also used for projections by the Ministry of Finance. The effects on the Norwegian economy of the required 50 per cent non-ETS emission cut between 2005 and 2030 are compared to reference projections (the REF scenario) of the economy and emissions to 2030. The REF scenario is a so-called business-as-usual scenario that assumes policies to be unchanged from 2018. The same projections were used as a reference scenario for KK (2020) and are based on the National Budget for 2020 (NB20); see Meld. St. 1 (2019- 2020).[3]

Two abatement scenarios are studied that both attain the required emission target. In the main scenario (the HVD scenario), we identify how abatement will take place and at what cost and with what macroeconomic impacts. We have simulated the abatement measures that will be implemented, given that a uniform price on GHG emissions is introduced for all non-ETS emission sources. This GHG price can be interpreted as a shadow price of the required emission target. It is assumed that the tax on carbon dioxide (CO_2) for non-ETS sources that is in place in REF is replaced. The revenue is recycled as a lumpsum, non-distortive transfer to households. In a stylised economy without market interventions and imperfections, a uniform GHG price imposed on all relevant sources would enable any emission target to be achieved at the lowest possible cost. The SNOW model incorporates many real-world complexities in the Norwegian economy. HVD will indicate how these will interact with the GHG price and influence the social costs of the policy and other macro results.

One important public intervention in this respect is the relatively high taxation of labour, because a tax may distort the supply of labour (Keane, 2011; Mertens and Ravn, 2013). In the second scenario (the PRO scenario) we analyse the case where the extra revenue generated is recycled back to households by reducing the labour tax rate; i.e., the revenue is used to reduce the distortions caused by the income tax. PRO exemplifies how the overall social costs of the climate policy can be reduced by targeted recycling that counteracts existing tax wedges. This is often called a "double dividend" in the economic literature (Goulder, 1995).

Main indicators addressed are the sectoral allocation of emissions and output, GDP, total employment, consumption, private abatement costs and overall social

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[3] Note that this projection was designed before the COVID-19 crisis. The REF does not take account of the economic downturn – national and global - that has occurred since March 2020.

costs. The necessary abatement compared with the 2030 emission level of the reference scenario amounts to 27.4 per cent or 5.6 million tonnes of CO_2 equivalent ($MtCO_2eq$) in 2030.[4] As expected, the sectors with the highest initial emissions, road transportation, waste and district heating, and agriculture, also abate the major part of the amount necessary to meet the target. In the HVD scenario, a GHG price level of NOK 3 200/tCO_2eq result in direct abatement costs borne by the non-ETS emitters of NOK 7.6 bn in 2030. In the PRO scenario, the abatement costs are NOK 0.4 bn higher and the GHG price is NOK 300/tCO_2eq higher. This is explained by a higher activity level in the economy encouraged by the simultaneous labour income tax cut. In contrast to a macroeconomic contraction in 2030 in HVD compared to REF, a small rise in GDP and consumption occurs in the PRO scenario.

In spite of higher direct abatement costs, the social costs in PRO are only half those in HVD. This is explained by the manner in which the GHG price interacts with other distortions in the Norwegian economy. In particular, a large tax wedge distorts consumers' choice of diverting time to labour rather than to leisure. In PRO, where the tax on labour income is reduced, the increase in labour supply contributes to a social gain that counteracts the abatement costs. On the contrary, labour supply drops and reinforces social costs in HVD.

The macroeconomic analysis has benefitted from the analysis and discussions of the expert group in the KK report. In general, a richer picture of the costs and benefits of abatement policies can be obtained by understanding how the partial measure-by-measure approach and the CGE approach complement each other. The two approaches do not overlap. Specifically, their cost metrics capture different aspects, details and components. We compare the different cost metrics of the two approaches in section 5.2.

This comparison forms the basis for responding to the second part of SSB's mandate: assessing how the KK report can support the macroeconomic analysis. Specifically, SSB's analysis has made explicit use of quantifications and discussions from KK in two main respects: First, we have calibrated a module in SNOW for determining the choice to purchase and use of electric vehicles (EVs). This task has, *inter alia*, used information about the reference situation (the so-called zero alternative –*null-alternativet*) in KK. Second, the macroeconomic analysis relies on exogenous information to estimate abatement and the costs of measures in sectors where more detailed technological and behavioural information has been regarded as necessary. KK has been the main source of this information. This applies in particular to measures in commercial road transportation and agriculture. In the case of agriculture, SNOW models only one aggregate output, thus, is not able to reflect abatement through compositional changes or internal reallocations of labour and other production factors. Commercial transportation consists of activities that are currently transitioning fast and that may look very different a decade from now. At the same time, these sectors contribute significantly to the emissions in REF and are therefore pivotal to represent in abatement scenarios that intend to explore the cost-effective options of the economy. See Appendix A for more on these procedures.

The outline for the rest of the report is as follows: Section 2 describes how the task of performing a macroeconomic analysis is approached and section 3 briefly describes the SNOW model. Results are presented in section 4, before uncertainties and methodological considerations are discussed in section 5. Some concluding remarks are given in section 6.

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[4] CO_2 equivalent emissions are measured according to current UN methodology in global warming potentials (GWP100).

2. The design of the analysis

In order to obtain a picture of how the future economy may be affected by the Norwegian non-ETS emission target, we compare scenarios where additional climate policies are implemented with a reference scenario that does not take into account the climate policy target and the shadow price related to achieve the target.

The present analysis features three scenarios: (i) The reference scenario (REF), which is a business-as-usual scenario where only current policy measures aimed at attaining the emission reduction target are assumed to be present, (ii) the main abatement scenario (HVD), where the climate policy emission target is achieved by means of a uniform GHG price (shadow price) on non-ETS emissions, and (iii) a second abatement scenario (PRO). The only difference between HVD and PRO is related to the manner in which the revenue generated by the abatement policies is recycled back to households: whereas HVD assumes that revenue recycling occurs via a non-distortionary lump-sum transfer, the PRO scenario recycles the revenue via lower taxes on labour. In addition to these three scenarios, we run several simulations for use in sensitivity analyses.

We measure the effects of the climate policy as the differences between the REF scenario and the abatement scenarios (HVD and PRO), respectively. The analysis focuses on 2030 results. Note that in both the abatement scenarios we only consider the impacts of a unilateral abatement effort by Norway. The assumptions about the rest of the world are unchanged.

In this section, we describe and explain the choices made when constructing the reference scenario (REF), the main scenario (HVD), the revenue recycling scenario (PRO), and the sensitivity analyses.

2.1. The reference scenario (REF)

The REF scenario represents a projection of the Norwegian economy and emissions for the years 2021 to 2030. It is a business-as-usual scenario, implying no changes in currently implemented policy instruments or future policies already decided and scheduled to be implemented. This applies to all regulatory measures including taxes, subsidies, prohibitions, regulations, information campaigns, etc. Two important climate policy instruments regulating the non-ETS sector are the existing CO_2-tax scheme and the subsidies to EVs that is assumed to be prolonged until 2030.

Even if all policy changes are excluded from REF, projections should reflect likely future changes in trends and external conditions such as technological progress, new production structures, changes in preferences, and price impulses from abroad. These might well affect GHG emissions. Indeed, there are substantial emission reductions in the reference scenario over the next decade.

Our REF scenario is based on the reference scenario for the economic projections in NB20, which are rooted in realistic developments in economic variables and technologies over the next decades. The main vehicle for the emission projections of the Ministry of Finance is the SNOW model (Rosnes et al., 2019), but several exogenous sources are used in order to benefit from expertise in the different fields. For example, SSB’s population projections, MDIR’s road model and the petroleum forecasts of the Norwegian Petroleum Directorate form part of the basis for the projections in REF. Fæhn et al. (2020) describe the methodologies for making business-as-usual projections. The main driving forces in REF are demographic development, natural resources forecasts, where a gradual decline in oil and gas production is anticipated, expected global economic trends, and projected productivity growth for the private and public sectors. This last is based on parallel simulations using the DEMEC model (Bjertnæs et al., 2019), which is designed for projecting public finance and public services. For a more detailed presentation of the economic drivers in the reference scenario, see Meld. St. 29 (2016–2017) and Meld. St. 1 (2019–2020). For the present analysis, we have used a slightly different model version from that in NB20. The model is described in detail in section 3, where we also emphasise how the model deviates from the version used in NB20.

More than 80 per cent of the GHG emissions in Norway are covered by the EU ETS and/or a CO_2 tax, both specified in the model. In addition, direct regulations, emission standards and subsidies, including support for research and technology development, are part of the government's climate policies. These affect technology assumptions and the evolvement of emissions in REF.

Roughly half of the Norwegian GHG emissions are covered by the EU emission trading scheme (EU ETS). This covers crude oil and natural gas producers, manufacturers of chemical and mineral products (including cement), pulp and paper commodities, chemical raw materials (including fertilizers), refined oil products, gas power generation, the metallurgical industries and commercial aviation. Although the emissions in the EU ETS sectors are not covered by the KK mandate, they will be indirectly affected by the introduction of the uniform GHG price in the non-ETS sectors. SNOW models these sectors as well, including their inputs, outputs and tax payments. The EU ETS price development in REF reflects information from MDIR and the KK analysis. It equals NOK 220/tCO_2eq in 2020 and gradually increases towards NOK 330/tCO_2eq in 2030.

Norwegian non-ETS GHG emissions comprise the remaining half of the Norwegian GHG emissions. Roughly three-quarters consist of emissions from transport, agriculture and waste. Almost 70 per cent of the Norwegian non-ETS emissions are subject to an emission tax. The general tax level in 2019 was NOK 508/tCO_2eq (Meld. St. 1 (2019–2020), p. 87). Major exemptions apply in agriculture, while ETS sources in the petroleum and domestic aviation sectors are subject to both the ETS price and a CO_2 tax.[5] Other significant climate policies in REF include a ban on the use of mineral oil for heating enacted with effect from 2020, as well as the lenient tax regime for EVs. In accordance with the reference scenario in NB20, 50 per cent of new passenger cars sold in 2020 are electric in the REF scenario, and the sales share increases gradually to 75 per cent in 2030. This is assumed to be partly a result of the current fiscal and non-fiscal policies for incentivizing the purchase and use of EVs, combined with falling import prices and improved technology. It is also mandatory to blend fuel with biofuel. The required amount is 20 per cent in 2020.[6] Since 2010, landfill of wet organic waste has been banned. KK (2020) describes the GHG emissions along the path in more detail.

Figure 2.1 below depicts the projected non-ETS emissions from 2021 to 2030 in the REF scenario. The downward-sloping trend towards 2030 is due both to the anticipated long-run impacts of already adopted policies and exogenous assumptions about the development of low-carbon technologies and energy efficiency improvements. Underlying these there may be non-negligible costs in the reference scenario that we do not compute. Note that 88 per cent of the total non-ETS emission reduction from 2021 to 2030 in REF takes place in road

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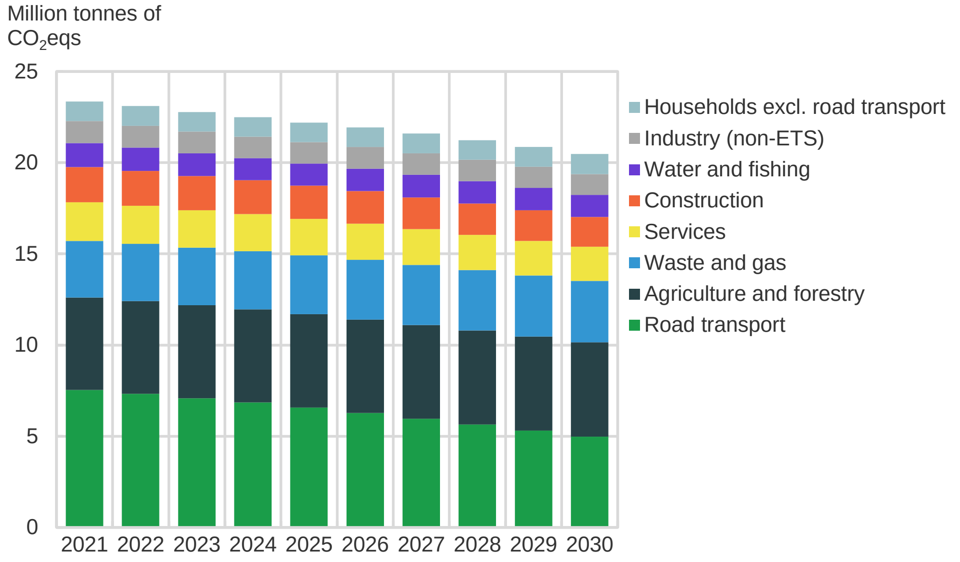
[5] Natural gas and liquefied petroleum gas (LPG) delivered for use in the greenhouse industry are exempted from the CO_2 tax. Further, emissions of methane (CH_4) and nitrous oxide (N_2O) from agriculture and emissions of CO_2 from waste incineration are currently not subject to the emission tax. https://www.regjeringen.no/no/tema/okonomi-og-budsjett/skatter-og-avgifter/veibruksavgift-pa-drivstoff/co2-avgiften/id2603484/

[6] This includes a minimum requirement of 4 per cent advanced biofuels that are double-counted. With 4 per cent advanced biofuels the real blending requirement is 16 per cent.

transport. The main drivers of this emission reduction are increased use of EVs (both private and commercial) and biofuels.

The emission target is defined in terms of emissions in the historical year 2005 and is thus insensitive to the choice of reference scenario. Therefore, the reference scenario determines the magnitude of the emission reductions required to attain the emission target.

Figure 2.1 Projected emissions by sector in the REF scenario. See Table 3.1 for sector definitions



2.2. The main abatement scenario (HVD)

The HVD abatement scenario is identical to the reference scenario, with the important exception of the introduction of a uniform GHG price (shadow price) imposed on emissions from all non-ETS sources that replaces the existing CO_2-tax scheme.[7] This non-ETS emission price in HVD is determined endogenously so as to achieve the required emission reductions in the KK mandate.

The abatement policies introduced generate revenue, which in the HVD scenario is recycled back to the households as lump-sum transfers. Note that all changes in the budget affect the recycled revenue, not only the direct revenue attributable to the uniform GHG price. The lump-sum recycling ensures that household income levels are not affected, and that the only price wedges arising from the policies are caused by the GHG price.

In HVD we have introduced the GHG emission budgets as defined in KK (2020) for the years 2021 to 2030. The 48 per cent emission reduction analysed in this report corresponds to the annual budget allocation in KK (2020). It is required in KK that the non-ETS emission level in 2030 is 48 per cent lower than the level in 2005. The deviation from the 50 per cent target as stated in the KK mandate reflects an anticipation that part of the emission budget for the initial years will be saved for use in the latter part of the period. This adjusted target for 2030 is the meaning of the notion ‘required target’ used in the following. It implies that emissions in 2030 in HVD are capped to 14.9 $MtCO_2$eq, which is a 27.4 per cent –

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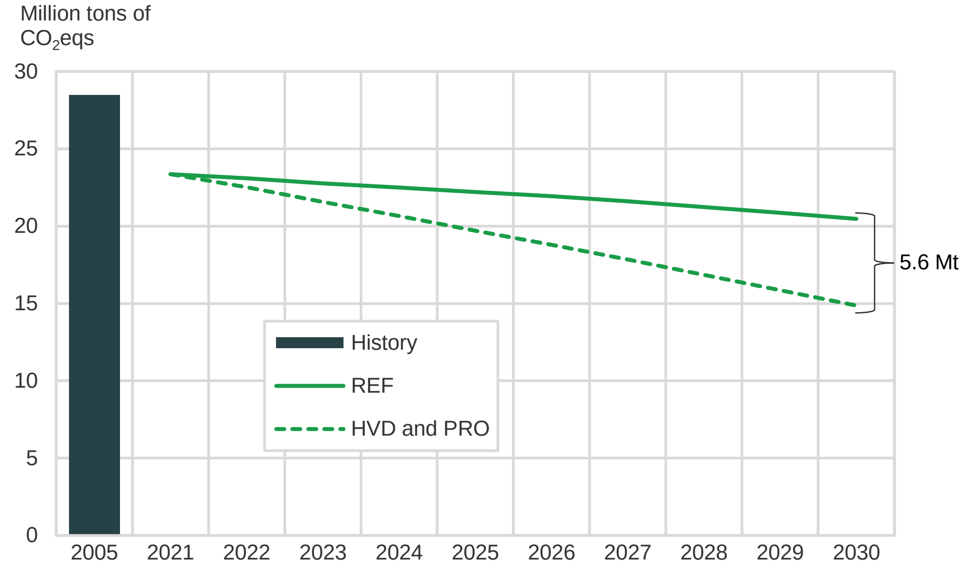
[7] Note that the GHG price is not imposed on agricultural emissions in the SNOW simulations. Here, only the current level of CO_2-tax is maintained. The reason is that the sector is modelled as exogenous and would only end up paying large GHG price revenues to the state without any scope for abatement response. We take account of some of the measures described in KK (2020) for agriculture exogenously; see appendix A.

or a 5.6 Mt – reduction compared with 2030 emissions in REF.[8] In the following, this is the meaning and specification of the 50 per cent target.

Figure 2.2 shows the annual emission levels in the abatement scenarios (represented in the figure by HVD) and the REF scenario. The abatement taking place is shown graphically as the distance between the solid 'REF' line and the broken 'HVD and PRO' line.

Figure 2.2 **Non-ETS emissions along the reference scenario REF and the abatement scenarios HVD and PRO**



In HVD the emission target is met by introducing a uniform GHG price that also replaces the existing CO_2-tax system in REF. This is done by removing the CO_2 taxes as they appear in the input-output (I-O) system underlying the model. Note that the introduced GHG price thereby changes both the level and the design of the climate policies, since the system in the base year 2013 was more differentiated (Meld. St. 1 (2012-2013)). This ensures a uniform GHG price for all non-ETS emission sources, in accordance with the recommendation of the Green Tax Commission (Ministry of Finance, 2015) to facilitate cost-effective emission reductions. Note, however, that all other policy instruments in the reference scenario remain in place, both those directly affecting GHG emissions and all other distorting taxes and subsidies. The full system of public interventions will affect cost-effectiveness.

The removal of the existing CO_2-tax system in the abatement scenarios has two counteracting effects on social costs. On the one hand, it is expected to reduce the social costs as the tax system becomes more uniform. On the other hand, the existing tax system had an impact on emission sources that must be compensated for by the GHG price in the abatement scenarios, which contributes to a higher GHG price and higher social costs necessary. Section 4.4 presents a sensitivity analysis of this assumption.

While the modelled economic behaviour and macroeconomic mechanisms of the SNOW model are exploited to determine which measures are implemented in response to the GHG pricing in the abatement scenarios, the current model version is not yet sufficiently adapted to capture realistic technological adaptations within

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[8] Norwegian non-ETS emissions in 2030 are projected to be 20.5 $MtCO_2eq$ in REF, and non-ETS emissions in 2005 were 28.5 $MtCO_2eq$. A 50 per cent target implies an emission level equal to 14.2 $MtCO_2eq$ in 2030. We follow KK and reduce by 48 per cent, which gives an emission level equal to 14.9 $MtCO_2eq$ in 2030 in our abatement scenarios.

two important fields of emissions: commercial transportation and agriculture. Information about technological abatement measures within these sectors is therefore gathered from other external sources. Note that technological in this context incorporates all abatement that change emissions for a given output volume in the sector. Thus, all behavioural changes that change input composition within a technology, output composition or introduces completely new technologies, will be relevant technological options.

The model is modified and iterated so as to consistently incorporate this knowledge in the analysis. The procedure implies that the technological measures resulting from the model simulations only constitute part of the measures necessary to attain the required target, while the remaining abatement is recursively added to the simulated abatement. The analysis in section 4 clarifies what this implies for the results and their interpretation. The procedure is explained in detail in Appendix A.

2.3. The revenue recycling scenario (PRO)

In the HVD analysis, we neutralise the budget by giving the additional revenue generated by the abatement policies to households as lump-sum transfers. In the second abatement scenario, the revenue recycling case PRO, we instead allow a decrease in the income tax on labour to neutralise the public budget. In other respects, HVD and PRO are identical.

The motivation for including PRO is that in a complex economy with many distortions the uniform GHG price might not enable the target to be attained at the lowest possible cost. In PRO, we examine how social costs might become lower when the tax on income, which distorts households’ choice between consumption and leisure, is reduced as a result of the revenue recycling.

Because the only difference between PRO and HVD relates to how the revenue is recycled back to households, we refer to section 2.2 for more details about the PRO scenario.

2.4. Sensitivity analysis

The costs of implementing the necessary GHG abatement of domestic non-ETS emissions by 2030 are uncertain. The level of future emissions in the reference scenario is unknown and directly determines the residual abatement necessary to attain the emission reduction target. Furthermore, the abatement commitment for the Norwegian non-ETS sources in 2030 is for the time being equivalent to a 40 per cent reduction compared with 2005, i.e., 10 percentage points smaller than the 50 per cent emission reduction target in KK. However, Norway may raise its contribution above this level in forthcoming international climate negotiations. On the other hand, the Norwegian non-ETS climate policies are tied to the EU policies and the ESR. This system incorporates several flexibility mechanisms that can reduce domestic commitments for 2030. First, it makes it possible to use a limited amount of ETS allowances for offsetting emissions in the non-ETS sectors and, to some extent, to swap non-ETS abatement for a reduction in net LULUCF emissions. Second, flexibility applies across time periods. In years when a nation’s emissions are lower than its annual emission allocation, it can bank any surplus for use later. When emissions are higher than the annual emission allocation, limited borrowing from the following year is allowed. Finally, there will in principle be full access to buy and sell allocated non-ETS allowances among all the ESR-participating states. If mechanisms for such transfers are established and function well, paying for emission cuts outside of Norway may be an option.

To quantify the abatement costs of different 2030 targets, we have simulated different non-ETS targets, both higher and lower than the required target. We construct a marginal abatement cost (MAC) curve by plotting pairs of targets and corresponding GHG prices. On the margin, agents are indifferent between paying the GHG price or abating another tonne of CO_2eq. Thus, the simulated GHG price for a given target is equal to the cost, as seen from the perspective of the agents, of the marginal, most expensive implemented measure to attain that target. The area under the MAC curve up to a target reflects the private abatement cost of that target.

The MAC curve can be used to illustrate how private abatement costs vary with the amount of abatement required to attain the required target. For example, suppose REF underestimates the emission levels along the business-as-usual path. Then we must abate more in HVD and PRO. The (private) abatement cost of this adjustment can be read off the MAC curve. Similar arguments apply, for example, to a change in the non-ETS emission target or changed rules for swapping non-ETS abatement for a reduction in net LULUCF emissions.

As mentioned, we have decided to overrule the model when it comes to measures in commercial transportation and agriculture. Besides the uncertainty related to the KK cost estimates per se, it is not obvious how to use this external information in our overall cost estimates. Because of the high uncertainty of these costs, and the corresponding abatement potentials, we run a sensitivity analysis with respect to the costs of these exogenous measures.

Finally, a sensitivity analysis investigates the isolated impact on social costs of our removal of the existing CO_2-tax system imposed on non-ETS sources in HVD and PRO. In principle, the impact is ambiguous and will depend on the stringency of the system as well as the distortive influence of its differentiated rates.

3. The SNOW model

SNOW is a multi-sector CGE model developed by Statistics Norway. It models Norway as a small, open economy in the world. The model describes how the market behaviour of economic agents determines annual production, government and household spending, labour supply, input factor use in each industry, cross-border trade for all goods, domestic prices of all goods and input factors (such as labour, capital and resources), and emissions to air, including pollutant compounds and GHGs. Emission coefficients are calibrated to the base year. Besides estimates describing behavioural characteristics, the main exogenous factors driving the sectoral and macroeconomic results are demographic assumptions, international market prices and sector- and factor-specific productivity growth rates. These, and also the emission coefficients, can be exogenously adjusted to represent technological improvements.

This report uses the dynamic recursive version of the model. The base year of the model is 2013. SNOW is used for simulating long-run projections by the Ministry of Finance and a slightly different version was used for making the projections in NB20. The main differences between the two versions will be emphasised where relevant.

3.1. Producers

The model specifies 46 production sectors, producing one good each, with one representative producer in each sector. The producers minimize their costs subject to technological constraints by combining the input factors. The technologies are described by nested Constant Elasticity of Substitution (CES) functions, where combinations of capital, labour, energy and intermediate products are input factors in production; see Appendix D. The substitution possibilities of different inputs are represented by the substitution elasticities. The elasticity determines how the relative use of inputs changes as the relative input prices change. The larger the elasticity value, the easier it is to substitute one good (input) for another. These elasticities are important for the analysis as they determine the technological abatement taking place in response to policy changes. Since each sector is represented by an aggregate technology that is modelled by an abstract production function, the model cannot bring information about exactly which technological changes take place. The substitutions can represent a variety of different adjustments. For example, an investment in a new, low-carbon technology can be one interpretation of a substitution taking place of capital for fossil fuels. Electrification will turn up as a substitution of electricity for fossil fuel energy. An increase in intermediate inputs at the expense of fossil fuels and be interpreted as a substitution of bioenergy for fossil energy, as bioenergy constitutes part of intermediate inputs.

It is possible to specify different substitution elasticities at all levels in the nested CES function. At the outset, they are set in accordance with estimates from the econometric literature; however, the model user can set the substitution elasticities that are considered relevant. For example, in fields with rapid technological change, new substitution possibilities may emerge, or old ones become less relevant.

In this analysis we have also exploited the option to eliminate energy use substitution in the main sectors providing commercial transportation services. This is intended to avoid any overlap with abatement measures we have included in this analysis from external sources. In agriculture, we have set all substitutability across factors, as well as output changes, at zero, for the same reason. While most sectors are private, there are also several government production sectors (state or municipality/region) providing public goods. Their outputs and inputs are modelled as exogenous (like agriculture).

Labour and capital are mobile across domestic sectors. 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. Total labour supply is endogenous in the model and will depend on the real wages received by employees – see the description of households below. This is in contrast to the version used in NB20, where total labour supply is exogenous.

3.2. Trade

SNOW models Norway as a small open economy, where world market prices are exogenously given. Goods used in the domestic market in intermediate and final demand correspond to a CES composite, that combines the domestically produced good and the imported good from abroad. This is in line with Armington modelling (Armington, 1969). The heterogeneity between domestically produced and imported goods depends on constant elasticity of substitution. Similarly, production in each sector consists of goods sold to the domestic and international market with a constant elasticity of transformation (CET) function. Factor prices and prices for domestic deliveries are all determined by equilibrium in domestic markets. All prices are real prices, since the model has the consumer price index as numeraire.

3.3. Households

SNOW features a representative household that owns and receives net-of-tax income from labour, capital and natural resources. Tax revenue (net of subsidies) is collected by the government, but reallocated to the household sector, so that all tax revenue also eventually goes to households. There are two options for household savings behaviour. It can be held exogenous or determined endogenously by means of a (Cobb Douglas) split between consumption and savings (for consumption in future periods).[9] The representative household substitutes time between labour and leisure and maximizes utility subject to the income constraint. This implies that the labour supply from households is endogenous and reacts to changes in income, saving and prices, including the net-of-tax wage rate, which is in effect the price of choosing one more hour of leisure at the expense of labour. External effects, e.g. environmental benefits, on the utility of households, are not modelled. Furthermore, household consumption demand is determined by means of a nested CES function as depicted in Figure 3.1. As for the production functions described above, the adjustments going on in response to changes in the model, for example climate policies, are largely results of substitution and give little technological and behavioural detail.

In case of private driving, the model is recently improved to bring in more detail on household choices. The module of households' private transportation was not present in the version used in NB20. The transportation services for a representative household consist of public transport (which includes road, rail, air and sea) and private driving (see Figure 3.1). Private driving consists of driving new cars (purchased in the same period) and old cars (purchased in previous periods). We consider two types of car: conventional internal combustion engine vehicles (ICEs) and EVs. Thus, we keep track of the stock of cars in the economy as well as cars purchased in teach period. For example, the sales share of EVs in 2018 is more than 30 per cent, whereas the stock share of EVs is still only 7 per cent, and the EV stock share will increase more slowly than the EV sales share. Accordingly, the car-related operational expenses (e.g., energy cost, insurance, service) are associated with the stock of the cars.

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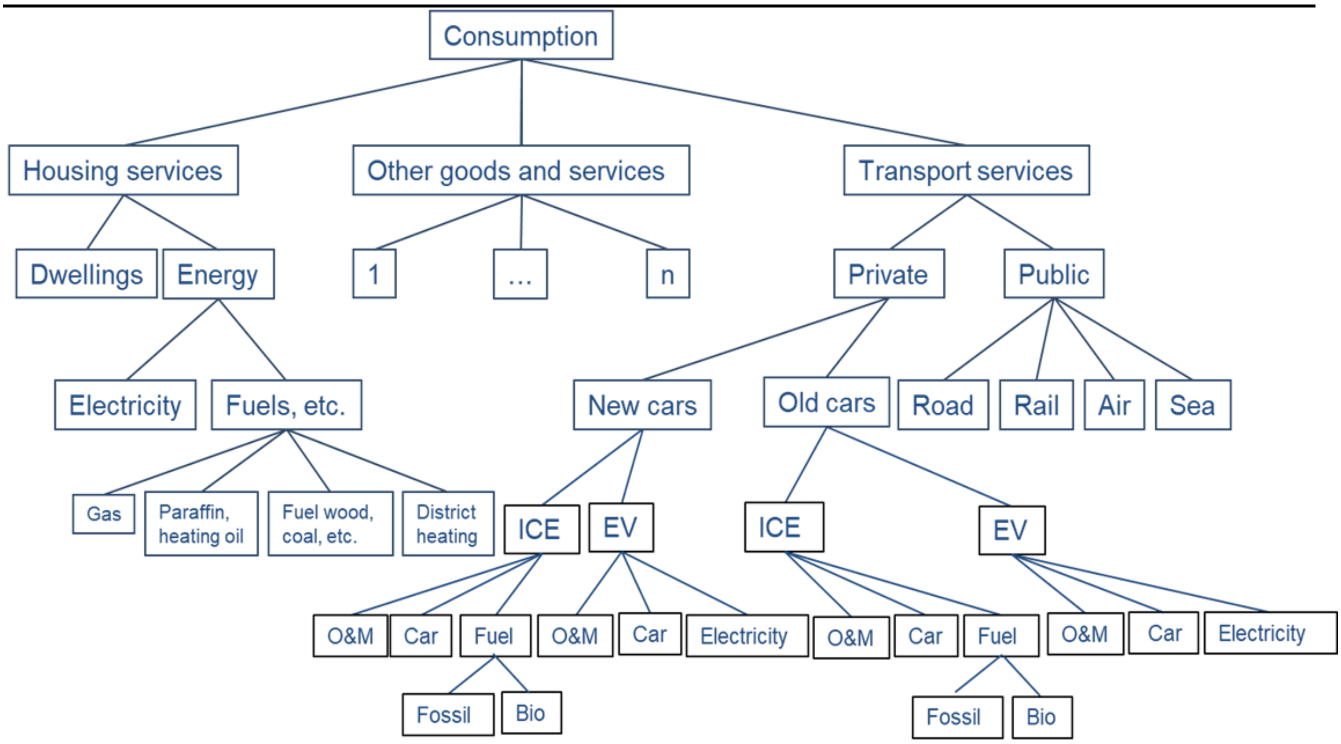
[9] In our simulations we have let saving be endogenous in the reference scenario and assumed that it is equal to the reference level in the analysis of abatement policies.

Figure 3.1 Consumption activities in SNOW



When the GHG price increases in the abatement scenarios, petrol and diesel prices increase accordingly, and the cost of driving ICE cars increases. Thus, EV purchase is encouraged and petrol and diesel consumption is discouraged. Public transport is also encouraged as a substitute for the use of ICE. In sum, the representative household can reduce transport emissions by using less transport services, switching from ICE cars to EVs, using the car more energy-efficiently or switching to public transport.

The model parameters are calibrated in REF so as to achieve the EV sales share projected in the KK (2020). We explicitly model the main drivers: developments in relative import prices of ICEs and EVs, improved substitutability between new EVs and ICE cars, and a continuation of fiscal and non-fiscal incentives promoting EVs., Quality-adjusted prices are used for import price estimates. Thus, even if the price is the same, the relative import price of EVs is considered to be reduced if the quality improves (e.g., longer driving range because of better batteries). We have projected an annual import price decrease of 5 per cent from 2020 to 2023 and of 2.5 per cent from 2024 onwards. Note that the retailer’s profit is not affected, and thus the decrease in the EV purchase price is more modest. The elasticity of substitution between EV and ICE captures the comparability of the EV and ICE services, and we assume that it increases over time so that the two types of vehicles become close to perfect substitutes by 2030. Non-fiscal incentives are particularly hard to quantify and project. Given the fiscal incentives and the other parameters, the non-fiscal incentives for EVs relative to ICEs are calibrated to attain an EV sales share of 75 per cent in 2030. For details, see Appendix B.

3.4. Government

The government collects taxes, distributes transfers and purchases goods and services from domestic sectors and abroad to provide public services. Overall government expenditure is exogenous and increases at a constant rate as the general economy grows. The model incorporates a detailed account of government revenue and expenditure. In the presented abatement policy analysis, it is required that the nominal deficit and real government spending follow the same paths as in the reference scenario, implying revenue neutrality in each period. This is achieved either by lump-sum transfers (as in the HVD scenario) or through changes in other taxes (such as tax revenue recycling via lower taxes on labour in PRO).

The existing public interventions in SNOW are product and business taxes, subsidies and labour costs including employer's tax. All taxes and fees are included as percentage (ad valorem) rates in the model, and all taxes are net taxes (taxes minus subsidies). 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.

3.5. Emissions, abatement and climate policy instruments

The GHG emissions include CO_2, methane (CH_4), nitrous oxide (N_2O) and fluorinated greenhouse gases (HFC, PFC, SF_6 and NF_3). The model also includes other emissions to air (NOx, SO_2, NH_3, NMVOC, PM_{10} and $PM_{2.5}$). The model represents emissions from both energy use and industrial processes. Energy-related emissions are linked in fixed proportions to the use of fossil fuels, with coefficients differentiated by the specific carbon content of the fuels. The emission coefficients are basically determined by base year values but can be adjusted by changing productivity parameters. Abatement of energy-related emissions can be brought about by fuel switching, substitution of other goods for energy, or by scaling down production and/or final consumption. Abatement of process emissions by means of existing production technologies can only be brought about by reducing output.

The description of the government’s climate policy instruments is relatively detailed. It includes differentiated and uniform CO_2 taxes, national and international quota systems, as well as free quotas, subsidies and compensation schemes for companies.

In the present study it is essential to distinguish between ETS and non-ETS emissions. We have based the classification on information from the KK expert group. However, the aggregation level in SNOW prevents an accurate distribution between ETS and non-ETS sources. For example, all waste incineration is classified as non-ETS in SNOW (although industrial co-incineration plants are actually subject to the EU ETS). We have classified according to the dominant source classification of the emissions from each sector. The result is listed in Table 3.1.

Table 3.1 Aggregated sectors in SNOW

Description	Code	Sectors (see Rosnes et al., 2019)
Agriculture and forestry	ag_fr	Agriculture; Forestry
Industry (non-ETS)	indu	Minerals nec (not elsewhere classified); vegetable oils and fats; food products nec; beverages and tobacco products; metal products; dairy products; textiles, wearing apparel; leather products; wood products; motor vehicles and parts; manufactures nec; transport equipment nec; machinery and equipment, incl. electronic equipment; fuel wood, coal etc.
Road transport	road	Transport nec; consumption of petrol and diesel
Services	serv	Water; trade; business services nec; defense; public administration (central) education, health, etc; recreational and other services; communications; private education, health, etc; insurance; financial services nec; dwellings
Construction	cns	Construction
Waste and district heating	wa_ga	Gas manufacture, distribution; waste (public); waste (private)
Water transport and fishing	wt_fi	Water transport; fishing
Other household consumption	othhh	Paraffin and heating oil; furnishings & household equipment and routine household maintenance; gas; fuel wood & coal etc.
ETS sectors	ets	Crude oil and gas; refined oil products & chemicals industry; non-metal minerals; iron and steel; non-ferrous metals; paper products, publishing; air transport; electricity

3.6. Cost of climate policies

Private abatement costs

Normally, agents facing changes in climate policies will bear the costs, since producers will find new input compositions and output levels and households new consumption patterns and real income levels that they would not have chosen in the absence of the new policy instruments. These costs are the private abatement costs. How behaviour is changed will depend on the type and dimensioning of the policies – in our case a GHG price per tonne of mitigated GHG. On the margin, these private costs will equal the GHG price. That is, the last mitigated tonne of GHG within a period will represent an abatement cost equal to the GHG price.

SNOW can be used to construct MAC curves. An example of this is shown in section 4.1 for the year 2030. It is obtained by running different GHG targets for 2030 and reading off the resulting GHG price. All possible pairs, consisting of a given GHG emission level and its associated GHG price, are points that together construct a curve. All measures implemented for a given target have a private cost equal to or below this MAC; only the most expensive ones reach the MAC cost level.

We can use this MAC curve to derive the total private abatement cost. We do this by calculating the area under the curve, which is approximated by a triangle:

(1) *Private abatement cost = ½ GHG target x GHG-price*

We know the abatement target for the whole non-ETS sector, T. However as explained in section 2.2. above, we do not let the model compute abatement behaviour in the agricultural sector, but rather rely on external information. The same is true for parts of the abatement in commercial transportation sectors. We include abatement measures from these sectors as exogenous GHG reductions, T_x, if the externally available estimates of their private abatement costs are lower or equal to the computed GHG price. This price is the result of the abatement options modelled in SNOW, given that the abatement target is set at $(T\text{-}T_x)$. It equals the MAC, as explained in section 2. Clearly, T_x depends on the GHG price which is determined by $(T\text{-}T_x)$, so that T_x and GHG price computations have to be iterated. See Appendix A for details of exogenous measures in agriculture and commercial transport.

Let the sum of the private abatement costs of the externally obtained GHG abatement measures in agriculture and commercial transportation be A_x. This should be added to the calculated private abatement costs derived from the model simulations. Denote the latter, which is given in equation (1) above, A_m. The total abatement costs (A), including those of the modelled measures (A_m) and those of external measures (A_x), become:

$$A = A_m + A_x = \tfrac{1}{2}\,(T\text{-}T_x)*P_c + \Sigma T_{xi}*c_i \qquad (2)$$

where P_c is the GHG price and c_i is the externally obtained abatement cost of measure i. Combining cost information from different sources in this way has serious caveats. While the cost computations based on the model simulations are built up from the same economic context and thus are internally consistent, the exogenous information relies on various assumptions that are not necessarily internally consistent, nor calibrated to the modelled context. Section 2.2. discusses the available information and how we use it. We also refer to sources given in Appendix A for more information. We perform a sensitivity analysis to check the impact of varying the cost inputs into the calculation of total private abatement costs in equation (2). See also the discussion of social costs below.

Social costs

The sum of private abatement costs will differ from total social costs. Since the private abatement costs derived from the model are based on the prices faced by agents, their sum takes into account changes in prices that take place in the model. And these are many, since the model represents the whole formal economy in contrast to analyses of individual measures (*tiltaksanalyser*), project analyses or partial equilibrium models. For example, electrification of many activities simultaneously will push up the electricity price and affect the electrification cost faced by each agent. Note, however, that such endogenous price changes, e.g., in the electricity price, are not brought into the external abatement cost information that we use for agriculture and part of commercial transportation.

In a very stylized general equilibrium model where markets are not characterized by imperfections and where there are no governmental price distortions, such as taxes, subsidies, or restrictions on quantities other than the imposed GHG target, the social costs of introducing the target will be equal to the sum of all agents' private abatement costs (Paltsev, 2013). However, a major virtue of CGE models like SNOW is their ability to take account of relevant market imperfections and public interventions. In their presence, productivity differences on the margin between sectors arise and social resources, like labour and capital, will be used inefficiently. When climate policies are introduced in an economy with distortions, it can reinforce or counteract such inefficiencies, depending on where the interactions with the existing policy instruments occur. Some distortions can be counteracted. For example, the existing electricity tax dampens demand for electricity. In the presence of the electricity tax, the introduction of a GHG price may partly correct for overly low electricity consumption from an efficiency point of view. The GHG price will encourage the use of electricity (which is a substitute for GHG-intensive fossil fuels) and result in an extra efficiency gain for society not reflected in private abatement costs. Some pre-existing distortions may also be reinforced. A relevant example is labour tax, which in principle discourages labour supply. When households face increased consumption costs because of the GHG price, it may be tempting to spend their time on even more leisure at the expense of labour supply, causing social costs.

We base the simulations on the premise that changes in climate policies do not alter net public expenditure. All publicly borne abatement costs will have to be funded by tax income. Conversely, all GHG price revenue to the government when GHG prices are imposed on production and consumption will be recycled. Such transfers take place between the household sector and the government. They may also cause distortions, to the extent that they involve changes in taxes and subsidies. Section 2 describes how our two abatement scenarios differ in this respect: while HVD uses non-distortionary transfers (lump-sum subsidies) for recycling revenue, PRO recycles through reduced labour taxation, which affects households' choice of time devoted to labour and leisure. We will come back to the effects in section 4. In order to be able to capture such contributions to social costs, the model should have a rich representation of public interventions, including funding and recycling options, as well as market imperfections. Whereas SNOW takes account of public interventions, funding and revenue recycling options, it does not take account of market imperfections like asymmetric information, market power and externalities (like pollution). We discuss this further in section 5.1.

In each period, the total social costs of abatement will be measured in the model by the utility loss of the consumer. All changes in all agents' behaviour will eventually be reflected as changes in the representative household's ability to consume goods, i.e., products, services and leisure. This follows from the fact that the household receives all net income from the endowments of labour, capital and natural resources and thus faces all income adjustments. It also faces all consumer price changes on goods. Moreover, it eventually also receives the changes in public budgets, since the balance is fixed in every period (see section 3.4).

In addition to these modelled social costs, we must account for the social costs of the abatement measures that are brought into the analysis exogenously. As already mentioned, estimates are added from external sources for measures in the agriculture and commercial transportation sectors of both their abatement potentials and their costs. We use the same estimates for private and social costs for these exogenous abatement measures; see section 2.2. This has some important implications and rationales. We lose the difference between social and private costs due to the interactions of external measures with existing policy interventions, as well as their interactions with the modelled measures that take place endogenously in the simulations.

The cost measures and simulated values obtained from the model also have some major deficiencies. The simulated total abatement cost and social cost in a given year consistently measure the private and social costs, respectively, of the policy. However, it is unsatisfactory to look at annual costs without weighing them together in overall cost concepts. The conventional method is to discount the annual estimates of all future years to a current value. The current value can also be converted into annual, equal costs (annuities). This has not been possible in the present analysis, since the data for the simulations are restricted to the KK period 2021-2030. In order to be able to derive current values, we would need cost simulations not only for the years up to 2030, but for all future years. The post-2030 years will impact current values significantly, to an extent depending on the level of relevant (private and social) discount rates. In practice, the larger the rate, the shorter the post-2030 period that would be necessary, since contributions will become rapidly smaller. Given the KK perspective, input has not been available for simulations beyond 2030. This analysis therefore restricts the simulations to the KK period and focuses on 2030 costs, in particular.

4. Results

This section reports the main changes in relation to REF of the abatement scenarios, HVD and PRO. Recall that the difference between the two abatement scenarios is that generated revenue is recycled in a non-distortionary way in HVD, i.e., transferred as a lump sum to the representative household. In PRO, the recycling takes place through reduced tax on labour income.

4.1. GHG price, emissions and abatement costs

The uniform GHG price

MAC is the cost of an additional unit of abatement. It is equal to the GHG price level necessary to attain the target. In HVD, the MAC amounts to NOK 3 200/tCO_2eq.[10] This is the price when the abatement potentials of the external measures are taken into account. In PRO the corresponding GHG price is NOK 3 500/tCO_2eq.

The GHG price is higher in PRO than in HVD (see Table 4.1 below) The reason is that the simultaneous reduction in labour income tax stimulates activity (see 4.2) and makes it correspondingly harder to keep emissions below the given target. Thus, a higher price on emissions is necessary to attain the same target.

Allocation of abatement

In Figure 4.1, we depict the allocation of emission abatement by non-ETS sector in 2030 in the HVD scenario.[11] We split sectoral abatement into two contributions: abatement caused by changing output volumes *for given technology* (*_vol*), on the one hand, and, changes in production technologies that reduce emissions *per unit output* from the sector (*_tech*), on the other, according to the following decomposition:

$$\text{(3)} \qquad GHG\ emissions = Output * GHG\ emissions/Output,$$

where changes in the first factor reflect emission changes in the sector driven by changes in output volumes, while changes in the second, unit emissions, would explain the residual emission changes. This implies that abatement caused by changes in sectoral output volumes can be inferred from the simulated percentage changes in outputs, while the remaining abatement in the sector is caused by changes in production technologies that in the model results from substitution of emitting input factors, primarily fossil energy. The sectors' emission abatement usually consists of a combination of both these types of behavioural responses, but significantly more of the abatement takes the form of technological adaptations; this is where the flexibility of the model is the larger.[12] The differences in allocation of emissions between HVD and PRO are insignificant (see Table 4.1).

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[10] The GHG price is a real price, i.e., deflated by the change in the consumer price index (CPI) since 2013. If a more recent base year is used, the real price becomes higher. For example, the CPI increased by 15.5 per cent from 2013 to 2019 (SSB).

[11] For an explanation of the sector names, see Table 3.1 (in section 3.5).

[12] Note that both *_vol* and *_tech* abatement in agriculture are based on external sources, as is the *_tech* abatement taking place in the two main commercial road transportation sectors, TRD and OTP. In Figure 4 agriculture is combined with forestry in *agr_fr*, while commercial transportation is combined with private transportation by households in *road*.

Figure 4.1 The per cent share of abatement across sectors and between change in volume (_vol) (shaded colour) and technology (_tech) (non-shaded colour) for each sector in 2030 (HVD)

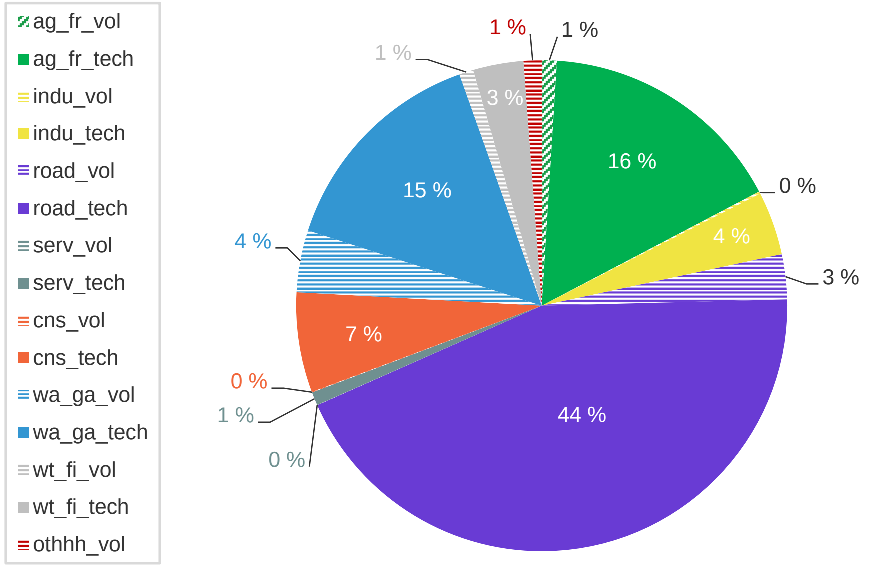


Figure 4.1 first presents the volume change (*_vol*) for each sector with a shaded colour, and then the technology change (*_tech*) with the corresponding colour non-shaded. Four sectors account for 90 per cent of the abatement measures: *road* (private and commercial road transport), *wa_gas* (waste and district heating), *ag_fr* (agriculture and forestry) and *cns* (construction). As seen from Figure 4.1, three per cent of the total non-ETS emission abatement is a result of reduced road transport volume, while 44 per cent is due to new available technologies in the sector. The latter mainly reflects the simulated shift in the use of vehicles from ICEs to EVs and to new input structures and technologies with less fossil fuels in business sectors that use vehicles. EVs for private use contribute to 15 percentage points of this, while electrification, hydrogen and bioenergy for commercial freight and passenger vehicles constitute the rest. *Wa_gas* contributes 19 per cent of the total required non-ETS reduction. This sector is relatively large in the REF scenario in terms of 2030 emissions, and it responds relatively flexibly in the SNOW model. Again, most take the form of technology adjustments. The results are consistent with an electrification taking place in waste incineration and district heating.

Emission abatement in *ag_fr* consists almost exclusively of technological abatement. The one per cent share of total abatement due to volume change in *ag_fr* is attributable to the forestry sector; agricultural output is assumed to be unchanged in relation to REF, as explained in section 2.2. However, even if agricultural output is assumed to be unchanged, the composition might well change. This is included as part of technological abatement in Figure 4.1. It reflects measures that are taken account of by means of external data. The abatement in the construction sector (*cns*) amounts to seven per cent of total non-ETS abatement and consists primarily of reduced fossil energy input shares. Electrification and increased share of biofuels for machines used in construction will be modes of reducing fossil energy use, measures that KK (2020) points out as central for the sector. Abatement in the remaining non-ETS sectors is relatively limited.

In Table 4.1 we present an overview of emissions in each sector in the REF, HVD and PRO scenarios. It also includes ETS emissions and indicates indirect, though limited, emission cuts also in this sector, in spite of unchanged policies targeting ETS emission sources. The ETS sectors suffer from increased costs for inputs with

GHG content and lower demand from sectors affected by the GHG price. A noteworthy feature of Table 4.1 is that the sectoral emission allocations in HVD and PRO are virtually identical, since they have to meet identical targets and in practice, the same options will be cost-effective.

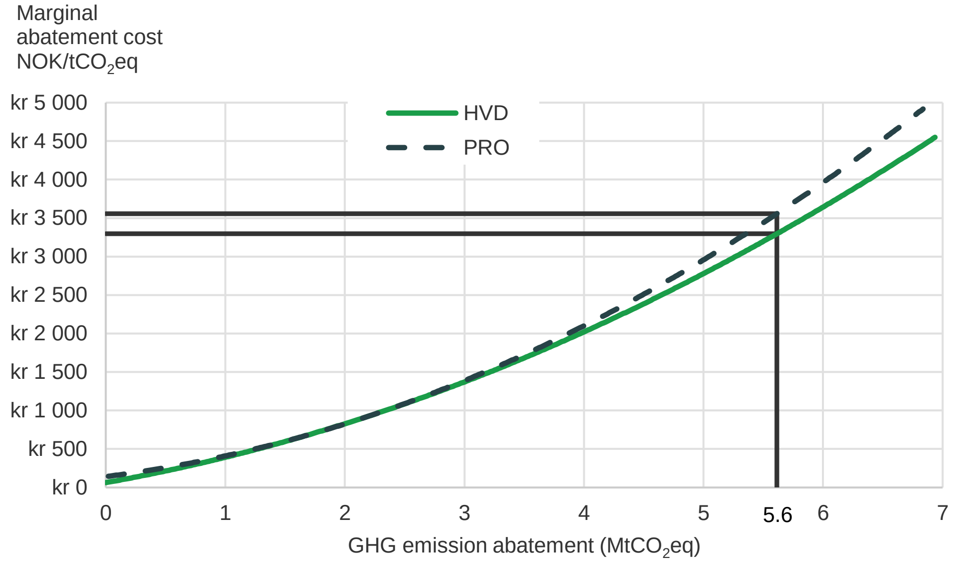
Table 4.1 GHG emissions per sector in scenarios REF, HVD and PRO (MtCO$_2$eq)

Sector	Abbrev.	REF	HVD	PRO
Non-ETS sectors		20.5	14.9	14.9
Agriculture and forestry	ag_fr	5.2	4.2	4.2
Construction	cns	1.6	1.3	1.3
Industry (non-ETS)	indu	1.1	0.9	0.9
Other household consumption	othhh	1.1	1.0	1.0
Road transport	road	5.0	2.4	2.4
Services	serv	1.9	1.8	1.8
Waste and district heating	wa_ga	3.4	2.3	2.3
Water transport and fishing	wt_fi	1.2	1.0	1.0
ETS sectors	ets	27.0	26.6	26.6
Total GHG emissions		47.5	41.5	41.5

Abatement costs

The cost of all the reductions taking place from non-ETS emission sources can be approximated by constructing a MAC curve. In Figure 4.2 we present the MAC curves for the two abatement scenarios HVD and PRO. They are constructed by simulating different abatement ambitions from REF, reading the resulting GHG prices and fit a continuous regression curve.[13]

Figure 4.2 The marginal abatement cost (MAC) curve in non-ETS for the main scenario (HVD) and revenue-recycling scenario (PRO) in 2030



The vertical axis shows the marginal cost per tCO$_2$eq (MAC) and the horizontal axis shows the corresponding accumulated GHG emission reductions achieved by all abatement measures taking place if the GHG price is set at that MAC. The required target for 2030 corresponds to a GHG reduction relative to REF of 5.6 Mt. The MAC is NOK 3 200/tCO$_2$eq in 2030 in HVD and NOK 3 500 in the PRO scenario.[14] For any lower (higher) target, the MAC decreases (increases).

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[13] The figure is constructed by including the abatement potentials estimated externally for agriculture and commercial transportation if and only if the measure cost is below the MAC. Hence, the exogenous abatement levels are increasing in the abatement volume.

[14] Observe that the removal of the CO$_2$ taxes in the abatement scenarios causes the MAC to be positive for (approximately) zero abatement. The exact level is not identifiable because the curve is an approximated regression.

Based on the MAC curve, we can approximate the direct abatement costs in the HVD and PRO scenarios as viewed by agents affected by the GHG price. It will be equal to the area under the MAC curve in line with equations (1) and (2) presented in section 3.6. In HVD it is equal to NOK 7.6 bn, and in PRO somewhat higher, NOK 8.0 bn, as shown in Table 4.2.

4.2. Macroeconomic and sector-specific impacts

Table 4.2 lists changes in main macroeconomic indicators in 2030 in relation to REF to the abatement scenarios HVD and PRO.

Table 4.2 Macroeconomic changes from the reference scenario, 2030[1]

	Unit	HVD	PRO
Direct abatement cost[2]	NOK bn	7.6	8.0
GDP	per cent	- 0.4	0.3
Private consumption	per cent	- 1.1	0.2
Leisure	per cent	0.5	- 1.5
Utility loss/social costs[2]	per cent	0.8	0.4
Employment/labour supply	per cent	- 0.3	0.9
Ad val. labour income tax	per cent	0.0	-12.9
(Pre-tax) real wage rate	per cent	- 1.4	- 2.5
Marginal abatement cost, non-ETS[2]	NOK/tCO_2eq	3 200	3 500
Non-ETS emissions[2]	MtCO_2eq	- 5.6	- 5.6
ETS emissions	MtCO_2eq	- 0.4	- 0.4

[1] Changes in all economic values are in real terms, i.e. measured at base-year prices.

[2] The estimates for these indicators include the impact of the external abatement measures. See footnote 15.

The HVD scenario with lump-sum recycling reflects how the introduction of the abatement target and uniform GHG price affect the economy. The direct abatement cost translates into a marked macroeconomic contraction; GDP, private consumption and employment/labour supply all fall. The utility of the consumer, that consist of leisure and consumption, declines considerably in spite of the minor leisure increase.[15] The reduction in employment does not reflect higher unemployment in the model; it is unchanged by assumption. Rather, it follows from a decrease in the household labour supply, because real wages fall. Thus, it becomes more beneficial to increase leisure at the expense of labour income and consumption.

In the PRO scenario, recycling by means of reduced labour income tax has a strong impact on macroeconomic outcomes. The ad valorem labour income tax rate falls by 12.9 per cent because of the recycling of the revenue generated. This pushes down the pre-tax real wage to some extent, but all in all the net-of-tax wage of employees increases. This encourages labour supply, which causes GDP to increase slightly by 0.3 per cent in the PRO scenario in contrast to the 0.4 per cent decrease in HVD. This reflects augmented resources available for the economy when labour supply increases and that the resources are allocated in more productive ways; see next section. Private consumption is higher in PRO than in HVD, as is utility. The marginal abatement cost is higher in the PRO than in the HVD scenario. This reflects higher macroeconomic activity levels, which calls for a higher GHG price in order to meet the emission target for non-ETS sources.

The differences in activity levels between the HVD and PRO scenarios are reflected in the sector-wise results of Tables 4.3 and 4.4. Both production and employment in PRO are generally greater than in HVD, since the lower labour tax stimulates economic activity. In the PRO scenario, non-ETS *industry*, *services* and *construction* increase in terms of production volumes and employment. These are

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[15] Note that among the macroeconomic indicators, only the direct abatement costs and the utility indicator take account of the costs estimated for the external measures. If external measures are excluded, abatement costs in HVD and PRO will be NOK 4.7 bn and 5.1 bn, respectively. The percentage changes in social costs in relation to REF would amount to 0.3% in HVD and 0.7% in PRO.

relatively labour-intensive sectors, which benefit most from the increase in labour supply.

Table 4.3 Activity[1] volume per sector, 2030, percentage change relative to REF

	HVD	PRO
Agriculture and forestry	- 1.1	- 1.1
Construction	- 0.1	0.0
Industry (non-ETS)	- 0.7	0.5
Other household consumption	- 2.8	- 1.5
Road transport	- 3.3	- 2.4
Services	- 0.1	0.9
Waste and district heating	- 6.8	- 6.2
Water transport and fishing	- 4.3	- 4.0
ETS sectors	- 1.5	- 1.3

[1] Activity is measured in real terms (at base-year prices) and consists of production in sectors and consumption in households.

Table 4.4 Employment[1] per sector, 2030, percentage change relative to REF

	HVD	PRO
Agriculture and forestry	- 0.8	- 0.6
Construction	1.0	1.8
Industry (non-ETS)	0.2	2.0
Road transport	- 2.5	- 0.8
Services	0.0	1.1
Waste and district heating	- 5.7	- 4.7
Water transport and fishing	- 3.0	- 1.8
ETS sectors	- 1.9	- 0.7

[1] Changes in employment are in real terms, i.e., measured at base-year prices and can be interpreted as percentage change in man-years employed.

4.3. Social costs

Social costs in the abatement scenarios are measured by the change in utility by 2030 compared with REF. In the HVD scenario, the social cost of the uniform GHG price introduction amounts to 0.8 per cent of the REF utility; see Table 4.3. The private abatement costs facing agents in the form of the high uniform GHG price will be a major explanatory factor. However, the direct impact of the GHG price only explains but around 40 per cent of the social costs.[16] The reason for additional social costs is that there are numerous reallocations taking place in the economy as a response to the GHG price that contribute to the welfare impacts. As a rule of thumb: If there are distortive taxes that discourage any activity, increases in this activity will contribute positively to welfare, and vice versa. Existing public interventions in market prices will interact with the GHG price because the tax bases of the existing interventions, and thus their distortion, will change. As mentioned in section 3, the interventions modelled will in some cases be intended to correct market failures that are not modelled. In that case their distortive impacts will be exaggerated. It is nevertheless useful to try to identify and discuss the main contributions to the utility change in the model. We discuss the uncertainty of the outcomes further in 5.1.

In a complex model like SNOW, identifying how each public intervention contributes to the total net social costs is a cumbersome task. See Paltsev et al. (2004) and Fæhn and Holmøy (2000) for decomposition methods that can approximate the distortive impacts of some specific interactions of this kind. Estimations show that in both HVD and PRO the social costs can largely be explained by adding the impacts of two major reallocations to the abatement cost results: the switch from ICE to EV cars and changes in labour supply.

In the REF, which is a business-as-usual scenario, several current EV incentives are represented. They are also, by assumption, retained in the abatement scenarios. This is, of course, a policy question. Given that the GHG price comes on top of the

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[16] It is not unusual to see small contributions of the direct policy shift to the social cost; see, e.g., Paltsev (2004).

EV incentives, the reallocation from ICEs to EVs in the abatement scenarios implies social costs. First, this is due to substantial tax exemptions for EVs. Even when the existing CO_2 tax is removed in the simulations, as in the abatement scenarios (where it is replaced by an endogenous GHG price), about 95 per cent of the taxes on purchase and use of ICE cars remains. These consist of registration and re-registration fees, weight tax, annual vehicle duty, in addition to the petrol and diesel taxes. By comparison, EV purchases are exempted from value added tax (VAT) and registration fees and face but a small annual vehicle duty. In addition, their tax on energy use, the electricity tax, is relatively low. The ICE taxes partly have the purpose of raising public revenues and partly of correcting externalities associated with driving, externalities that in most cases also result from use of EVs (Fridstrøm, 2019). Therefore, the switch that takes place from ICE to EV cars causes a loss to society, as the impact of this tax wedge becomes larger.[17]

In addition, there are a variety of national and local advantages enjoyed by EV users as opposed to ICE users. These include measures like access to bus lanes and rebated or eliminated road tolls, parking fees, charging and ferry prices. Quantifications of shadow subsidies of this type are difficult to find.[18] However, in the model they appear as a calibrated wedge between the annual costs of owning and using EVs and ICEs, respectively; see section 3.3. This modelled wedge is nearly as large as the formal tax wedge described above in 2030.

In both HVD and PRO these cost elements come on top of the direct abatement cost. Their social cost contribution is nearly as large as the direct abatement costs.

The other main area in which tax interventions matter for social costs is in the market for labour. As explained, time is a resource that can be devoted to labour or leisure, and its allocation will be affected by various tax wedges. In addition to the labour tax imposed on employees' –ordinary income tax –firms pay payroll tax on their use of labour. In addition to these two wedges, taxes on consumer goods and services, particularly VAT, also affect labour supply. This is because VAT encourages the choice of enjoying leisure at the expense of consumption. These three distortions of households' choice and labour supply contribute about 1/3 each to the labour-tax wedge based on the base-year rates.

In the HVD scenario, labour supply is negatively affected; see Tables 4.2 and 4.4. This is partly attributable to the relative increase in household demand for leisure as opposed to consumer goods as a result of the GHG price. This substitution increases the social costs of the abatement policies. In the PRO scenario, the labour supply increases (see Table 4.4). The driver is the reduction in the labour tax rate. This prompts substitution of consumption for leisure. In addition to the direct, rather small, gain due to the lower income tax rate, this reallocation reduces the efficiency distortion of the other still existing taxation of labour which is still in place. These reallocations contribute to a significant reduction in social costs that leaves total social costs in PRO about half those in HVD.

To sum up, in HVD the direct abatement cost explains about 40 per cent of the social costs. Most of the remaining social cost is attributable to the two reallocations described above, substitution of EVs for ICEs and the increase in leisure at the expense of labour supply.

The lower social costs in PRO than in HVD occur despite higher costs associated with both the direct abatement cost and the increase in EVs, which are even more

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[17] Another argument used for the implicit subsidies to EVs is that they are there to correct market failures in the dispersion of new technologies and should therefore not be modelled as a distortion.
[18] See Fridstrøm (2019).

marked in the PRO scenario. The lower social costs are attributable to the labour tax reduction. The tax cut in itself gives rise to a small direct gain. The indirect social gain due to stimulating the labour supply and thereby counteracting the distortion already present in the consumers' labour/leisure choice, is more important.

4.4. Sensitivity analysis

We perform a sensitivity analysis of some of the key assumptions made in the main analysis.

First, even if we know the emission budget that is allocated to Norway's non-ETS sources in the effort-sharing agreement with the EU, there is uncertainty as to how much effort will be needed to comply with it. The necessary policy implementation relies both on what a business-as-usual policy will achieve in terms of GHG mitigation and on how restrictive the emission budget turns out to be. As outlined in section 2.4, there will potentially be access to several flexibility mechanisms in the EU system.

We have examined cost variations in relation to the abatement ambition for domestic non-ETS emissions by means of the constructed MAC curve; section 4.1. For any selected target, the y-axis shows the MAC or necessary GHG price while the area under the MAC curve reflects the abatement cost of that target. Since the MAC curve is convex, lower abatement ambitions will reduce costs more than proportionally. It should be borne in mind here that the abatement costs only reflect part of the cost picture; see section 4.3. The relative impacts of the cost components will not be stable. Simulations show that the higher the abatement ambition, the more of the social costs that are accounted for by the abatement costs. The MAC curve can also easily be used to visualise and calculate the abatement cost implications of systematically higher or lower marginal abatement costs, which would move the MAC curve vertically and change the abatement cost integral. Further, the MAC curve can be used to visualise changes in abatement costs following different assumptions about, e.g., emissions in REF or the exogeneous emission reduction potentials in commercial road transport and agriculture. For example, the GHG price in HVD increases from 3 200 to around 3 700 if the abatement necessary to achieve the required emission reduction increases from 5.6 MtCO$_2$eq to 6.0 MtCO$_2$eq.

We have performed a sensitivity analysis of the cost estimates for the external measures in commercial transportation and agriculture. The cost of the different external measures determines whether they should be included in our simulation or not. However, the costs of implementing necessary GHG abatement of domestic non-ETS emissions by 2030 are uncertain. We now assume that the abatement costs for external measures in commercial transportation and agriculture sector are 100 per cent higher than our estimates based on external sources. The simulation results suggest that some external measures will not be cost-effective to implement.[19] Leaving them out, raises the marginal abatement cost to NOK 4 100/tCO$_2$eq. In other words, given a 100 per cent higher abatement cost for external measures, the large majority of the measures are still cheaper than the marginal, most expensive measure needed to attain the target according to the SNOW simulations. Total abatement costs will increase by 67 per cent. This is driven not only by the increase in the costs of measures added externally, but also results from more and costlier abatement taking place in the modelled sectors.

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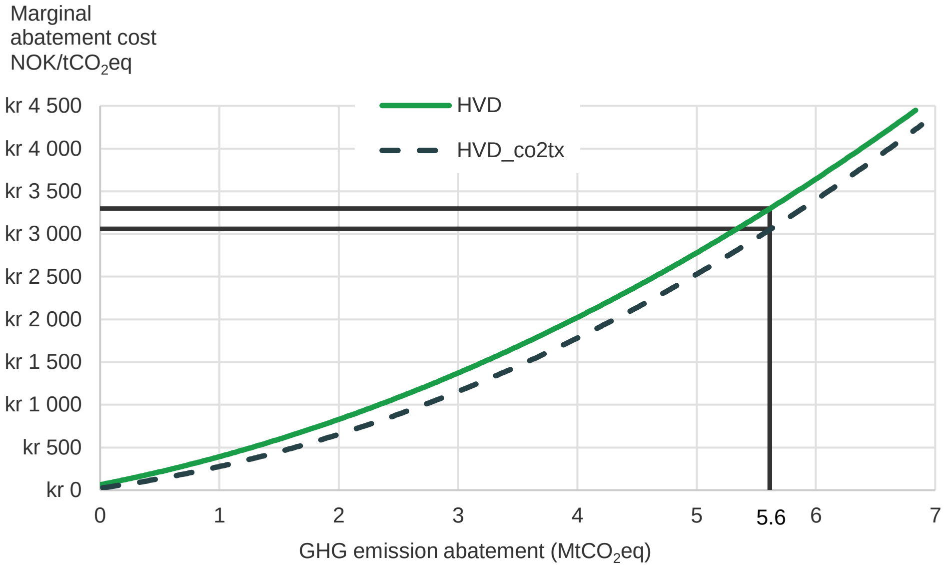
[19] Particularly, the most expensive measure in agriculture, *J04*, *AT02* and *O02*, and approximately 40 per cent of the measures from *T12* and *T13* are excluded (see Appendix A.2 and A.3). This implicitly assumes that the abatement cost of T12 and T13 are convex functions of abatement volume.

Our last sensitivity analysis examines the impact of the CO_2 taxes for non-ETS sources that were excluded from the abatement simulations. In this sensitivity analysis, we keep the same assumptions for CO_2 taxes as in REF and also keep them in the abatement simulations. As stated earlier, the exclusion of the existing CO_2 tax system from the abatement scenarios has two, counteracting, effects on social costs. The GHG price will be higher since it has to compensate for the abatement of the CO_2 tax. This influences social costs positively. On the other hand, social costs are lowered by a uniform, more cost-effective policy design. The former effect is seen in Figure 4.3. Here, HVD is the main scenario in our benchmark simulations while HVD_co2tx is the scenario where the existing CO_2 taxes on the non-ETS sources are included. The result suggests that a lower GHG price is needed in the economy when the CO_2 tax is maintained. In HVD excluding existing CO_2 taxes, the GHG price is NOK 3 200/tCO_2eq, while in HVD_co2tx including existing CO_2 taxes the GHG price is NOK 3 000/tCO_2eq. However, in spite of a higher GHG price, social costs in 2030 are slightly lowered (by 1 per cent) by removing the differentiated CO2-tax system and replacing it with a more cost-effective one.

Figure 4.3 Marginal abatement cost (MAC) curve for main scenario (HVD) and scenario including existing CO_2 taxes in the non-ETS sector (HVD_co2tx) in 2030



The GHG price gap in Figure 4.3 of NOK 200/tCO_2eq in 2030 is based on the impact of the 2013 CO_2-tax system. However, the emission projection in NB20 that we follow assumes a prolongation of the 2018 CO_2-tax system, which was both less differentiated and more stringent. The SNOW-projected emission impact of the 2018 CO_2-tax system in NB20 is obtained not by adjusting CO_2 taxes and relying on model responses but rather by adjusting technological parameters. The CO_2 taxes that we exclude from our abatement scenarios are therefore lower than in the 2018 system assumed in NB20. If, hypothetically, the CO_2-tax system was fully uniform in 2018, the 2030 gap between the two GHG prices in Figure 4.3 would approximately double to NOK 400/tCO_2eq (and the social cost impact most likely slightly positive).

5. Uncertainty and methodological considerations

5.1. The CGE method

The results of the model analysis must be interpreted with caution, since both the data used as input to the model and the mechanisms of the model are uncertain. The uncertainty inherent in the mechanisms also includes the uncertainty introduced by omitting mechanisms and effects from the model.

Data

The model consists of a large number of parameters that need to be exogenously quantified. Many of them are behavioural parameters. They can generally be regarded as more permanent and structural and are estimated by means of backward-looking statistical methods. Only occasionally are studies specifically designed for the model structure and case at hand. Moreover, studies based on Norwegian data are scarce. Most parameter estimates in SNOW rely on international studies; the data sources are referred to in Rosnes et al. (2019). It is not entirely true that behavioural parameters are stable. In a changing world, particularly in light of the massive attention to and progress of knowledge in the field of climate change and environmental policies, objectives and preferences may well change among the population. Examples are changing attitudes to consumption of different kinds of food and transport services. In some cases (as in the EV module) we therefore allow for preferences that change in the course of scenarios (see section 3.3), on the basis of assumptions from experts, including the KK expert group. Information from experts also forms the basis for projections about sectoral developments, productivity change and emission intensities; see Fæhn et al. (2020) and NB20.

In addition to exogenous estimates, the quantification of the model relies on a detailed input-output system based on the national accounts and the SSB emission inventory. The virtue of the I-O system is that it is consistently calibrated or “adds up”, so that activities and components on the detailed level can be regarded consistently from both the supply and the demand side, and so that macroeconomic conditions are obeyed. The last update of the model uses 2013 as its base year and the scope of this project has not allowed for further updating. 2013 is a well-chosen year for a CGE model calibration, since the CGE analysis requires data that can represent a trend situation. The economy was not characterised by large cyclical deviations from trend in that year (Statistics Norway, 2019).

A couple of issues related to the I-O system contribute to uncertainty. First, the KK data and projections use 2018 data as the starting point, and the modelled developments from 2013 to 2018 need to fit the observations. Conventional calibration procedures for fitting observed data and KK’s projection have been used for this task (Fæhn et al., 2020). One complication has been that the emission inventory has recently undergone considerable revision. We have adjusted the projection from 2013 to fit new data, but it is no small matter to adjust consistent 2013 data to fit partial adjustments in data for 2018. This contributes to the uncertainty of the analysis.

Another general challenge associated with old I-O data is that in the field of climate policies large changes have been made in recent years. In 2013, although policies were already in place to encourage EV phase-in, the impacts were still modest and virtually invisible in the data. Moreover, the impacts (because they are small) are often merged into averages and not identifiable. One particularly important example is that I-O data do not identify different vehicles and cannot be used for projecting the strong impacts of EVs on private transport today and going forward. We have therefore used external data for developing a module in SNOW where the choice of purchasing and using EVs is determined. As can be seen from the description of this module in section 3 and Appendix B, several sources of uncertainty are present. Its introduction exemplifies the fact that the inclusion of novel trends, that cannot be based on backward-looking methods and current facts, adds uncertainty. However, we do include novel trends when we believe that neglecting obvious trends will involve even greater misrepresentation.

Another related problem is how to represent new or reinforced policies that were not in force in the base year. NB20 has adjusted parameters affecting emissions in order to reflect this as a substitute for adjusting policy variables and relying on the model's mechanisms. Our REF scenario adopts this approach, causing some difficulties in connection with interpretation of the impacts of the REF's CO_2-tax system, for example. As described, we have replaced the CO_2-tax system with the uniform GHG price in HVD and PRO. However, the current CO_2-tax system is more uniform and more stringent than the 2013 system that we have replaced. See section 4.4 for a discussion.

Model mechanisms

The present SNOW version does not include externalities or other market imperfections. The Norwegian economy is fairly well-functioning, and markets can be expected to produce relatively effective outcomes. However, we know that activities like road transportation and industrial processes have externalities and that market power can occur in industries or niches with few actors. Such market failures are omitted, mainly because they are difficult to quantify. A wide range of activities have impacts on health and nature. One obvious caveat is that local and regional air pollution is not evaluated with respect to its social harm in terms of health, corrosion etc. Nevertheless, the model can identify the direction of impact, as several pollutive emissions have been quantified. These include SO_2 NO_X, CO (carbon monoxide), PM, NMVOC and NH_3. These quantifications can constitute the basis for calculating environmental damage. Other externalities that are omitted are other social costs of road transport, like noise, congestion and accidents.

In many cases, however, such features are acknowledged by policymakers and counteracting policy regulations are implemented. For example, the road tax and NO_x tax systems have been introduced to counteract phenomena like congestion, infrastructural depreciation and pollution. The paradox of the model is that while these instruments are modelled because they constitute part of the I-O system, their market failure counterparts are not. The result is that the policies will appear as distortions. When a GHG price is introduced into an economy with distortions, it may lessen or increase inefficiencies, depending on where interactions with the existing policy instruments occur; see section 4.3. The GHG tax does not have a climate impact counterpart either, because it is not based on an explicit valuation of the emission reductions caused by the climate policy.

Such counteracting policies are, however, not introduced for EVs, which generate nearly the same externalities as do ICEs (Fridstrøm, 2019). This is why it will be relevant to include the social costs of substituting EVs for ICEs; it will have a negative effect in the real economy because activities without corrections for externalities replace activities that are corrected. Also in the model will the discriminatory treatment of ICEs and EVs imply a negative social cost, as shown in Section 4.3.

When the results of CGE model simulations are interpreted, they should be regarded as impacts on the long-run development trend when transitional costs have ended. They describe the new state of equilibrium when resources that are no longer in demand in some sectors find new uses. This implicitly assumes that resources like capital and labour are generic and can move freely across sectors and types of use. Moreover, it is assumed that agents can invest and disinvest smoothly or, interpreted alternatively, that they can rent capital goods by paying rent for each year they are wanted. Possible interpretations are that there are effective rental markets and second-hand markets for capital and durables, that unemployment is fairly constant and that the impacts of retraining programmes and reorientation of the educational system come fast and at a low cost. These assumptions obviously underestimate costs. The scale of the underestimation will depend on how long the transition takes. The analysis looks ten years ahead, and a significant part of that period will be characterised by unused resources, like unemployment, unused capacity and premature scrapping of capital goods. Scaling down or shutting down enterprises can have serious repercussions, not only for individuals but for whole economic and social communities. Some loss of resources may be permanent.

Distributional costs are another omission from the CGE model. It cannot distinguish between households in terms of income, size or place of residence. The social cost metric of the model is that of the average, representative household. We cannot construct a cost metric capable of reflecting distributional preferences that assign different weights to different population groups. However, the model reflects impact differences across sectors of the economy, that also include indirect effects. Sector-specific and to some extent regional distributional impacts can thus be captured. Who will carry the burden also depends on the policy instruments chosen.

It is also worth mentioning that the choice of programming tool for the model imposes some restrictions. The functional forms are pre-defined (CES functions, see section 3) In particular, it should be noted that income elasticities in CES functions have the value 1, per definition. In other words, in isolation, a marginal relative increase in consumers’ income generates the same percentage increase in all consumption goods. All else being equal, demand for goods like food, transport services and electricity arguably follows the income trend. Likewise, in production the isolated impact of increasing the scale of output by one per cent increases demand for each input by the same amount.

5.2. The use of the Climate Cure expert group’s material

The KK mandate of SSB includes a request to assess whether, and in the event how, the analysis of individual measures by the KK expert group – both their abatement potentials and costs – can benefit the macroeconomic analysis.

First, the macroeconomic approach supplements the KK approach by taking into account the impacts of many simultaneous measures and by linking measures directly to policy instruments: in the present analysis a uniform GHG price for all non-ETS sources. The abatement measures in SNOW constitute the behavioural responses of the agents. They are typically modelled in a rather abstract way that does not identify specific technologies or modes of servicing. This provides the users of the results with some freedom of interpretation but will fail to capture specific characteristics of the measures; see Section 3.1 and 3.3. In this respect, the measure-by-measure analyses in KK (2020) comprise complementary information and using the two approaches in tandem can give a more complete picture of potential abatement measures. We, thus, use the information about abatement measures from the KK expert group to identify reasonable interpretations of what can be specific technological adjustments in the coming decade that are consistent with the SNOW results.

The two approaches deviate in important respects in their cost concepts. The present macroeconomic study computes two types of cost metrics, both of which differ from those in KK. The first, denoted *abatement costs*, is the sum of the costs directly borne by the agents facing the introduced GHG price. Conceptually, it resembles the sum of private costs in KK. However, in contrast to the partial measure analyses in KK, the model computations account for cost changes and income changes facing agents when all react simultaneously to the sector-overarching GHG price. The representation of the agents' behaviour is richer in that household demand for consumer goods and household labour supply, as well as the business sector's demand for production factors and sector's output supply react continually to the changes taking place. This implies that it is more meaningful to sum the private, direct abatement costs. Another difference is that behaviour is not explicitly modelled in KK. As a result, some cost elements are left out of the calculations. (See Teknisk beregningsutvalg for klima (2019) for a discussion.) Specifically, the private costs in KK normally do not reflect the fact that the marginal cost tends to increase with the stringency of the environmental policy target. In contrast, the CGE approach inherently accounts for the manner in which the cost of one specific measure *i* is affected by increasing the scale of that measure *i*, or by introducing another measure *j*, for example via changes in prices, activity levels and labour supply. In SNOW, increasing marginal costs follow from the behavioural assumptions and market interactions that take place in response to a policy change. In KK, some unquantified barriers can be interpreted as accounting for increasing marginal costs.

To grasp the overall *social cost*, another metric from the computations is used: the loss of utility of the representative consumer. This cost modifies the abatement costs: first, by excluding pure transfers between the government and private agents and second, by taking into account the fact that interventions already exist in the economy. The reallocations taking place in response to the GHG pricing will interact with those interventions, as already explained, involving costs or gains. The social costs will take all these interactions into account and may deviate substantially from the direct abatement costs, in any direction, depending on the other distortions in the economy. KK calculations of social costs include no such interaction effects. Note that, in principle, this is also how market imperfections like externalities will modify social costs. However, the SNOW model does not include any such market imperfections. So, whereas the KK analyses try to quantify some externalities, e.g. health implications, the macroeconomic simulations exclude them, by assumption. Another difference between the social cost concepts of KK and SNOW is that, in contrast to KK, SNOW will also take account of the cost of funds in the event of government measures and recycling effects in the event of taxation. The GHG price in the macroeconomic study represents such a tax instrument.

The cost metrics in KK and the present report do not overlap and measure different aspects and components. The generic approach taking everything into account is not available, but a richer picture can be obtained by understanding how the two approaches complement each other. One main purpose of the macroeconomic analysis is to assess total social costs for the economy. The cost of each abatement measure cannot easily be extracted from the analysis.[20] For this information, one must refer to the KK analysis. A major drawback of KK social cost estimates is that very rough cost categories are usually presented. Particularly rough is the category for the most expensive measures (above NOK 1 500/tCO_2eq).

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[20] The simulations for constructing the MAC curve can, however, provide a guide as to how sectoral abatement differs in composition when abatement ambitions are increased from different initial levels, thereby indicating which measures are more and which are less costly.

In the present analysis, we have benefitted particularly from the KK quantifications in two respects:

First, as mentioned above, we have calibrated a module in SNOW for determining the choice of purchasing and using EVs by, *inter alia*, making use of the reference (the so-called zero alternative - *null-alternativet*) in KK. Some other sources are also used for this quantification; see Appendix A.

Second, for some economic sectors the measure-by-measure data in KK are assessed as providing better estimates of abatement potentials, and we have substituted KK's estimates for SNOW's. This is true for measures in agriculture as well as technological transformations within commercial road transportation. When relying on external information on abatement potentials, we also need cost estimates that can guide us to their marginal abatement cost. The conceptual information for this is the direct, private costs. KK (2020) presents private costs for these measures – see Appendix A. The cost estimates used are tested in a sensitivity analysis – see section 4.4.

6. Concluding remarks

The analysis indicates that a substantial rise in the marginal abatement costs (MAC) would be necessary to meet the required target for greenhouse emissions (GHGs). The simulated GHG price levels of 3 200 and 3 500 NOK/tCO_2eq in the two abatement scenarios, HVD and PRO respectively, apply to all GHGs and are in 2013 prices. By comparison, the ordinary CO_2 tax level in 2019 would amount to NOK 440/tCO_2eq in 2013 prices, though varying with respect to emission sources and GHG gases.

The 2030 MACs found in the present study are fairly in line with previous macroeconomic studies of Norwegian climate policies. In particular, SSB conducted a comparable analysis as part of the Climate Cure 2020 government initiative (Climate Cure 2020, 2010). In that study, the national abatement ambition for 2020 was 12 MtCO_2eq from a reference scenario, and ¼ would be met as a response to the allowance price in the ETS sector. When the remaining cut of 9 MtCO_2eq was restricted to take place in the non-ETS sector, the resulting MAC level became NOK 4 000/tCO_2eq.[21] The study of the Climate Cure 2020 ambition considered the recycling case similar to our PRO scenario, where NOK 3 500/tCO_2eq is the computed MAC level. Both analyses rely partly on information from the bottom-up measure analyses administered by MDIR, which have been substantially updated during the last decade. On the one hand, access to low-emission technologies will most likely be higher in the coming than in the previous decade, pushing abatement costs downwards. On the other hand, many of the low-hanging fruits will already be picked along with increasing ambitions.

The tug of war between these two opposing trends can be illustrated by comparing with a third study, made with many of the technological assumptions of the Climate Cure 2020 study but with the ambitions for 2030. As can be expected, this study of Aune and Fæhn (2016) found a significantly higher MAC than the present, of NOK 5 700/tCO_2eq. It can also be partly explained by a larger required emission cut than in the present study. Even if the political targets of the two simulations are the same, the gap from the reference scenario was significantly larger in Aune and Fæhn (2016) – almost the double (10.8 vs. 5.6 Mt), because of significantly higher emissions in the reference scenario. In the present study, the MAC curve is found to be convex, indicating that higher levels become successively more challenging. It is also worth mentioning that, contrary to the present study, none of the previous studies included abatement options for agriculture, where the KK material reflects a significant cost-effective abatement potential.

A main finding of the present analysis is that existing distortions have a major impact on the social costs of climate policies. In particular, the implicit fiscal and non-fiscal relative subsidies currently encouraging the purchase and use of EVs are diverting abatement efforts away from other alternatives and causing harmful external effects that are not corrected by taxes. Our study indicates that targeting policies more uniformly across emission sources would benefit the economy at large. A main argument for promoting EV phase-in has been positive technological externalities, effects that the SNOW model does not take into account. However, arguments in this vein will weaken over time as we move towards the flatter part of the learning curve for EV technologies.

Whereas the 50% reduction target for non-ETS emissions formulated in the KK mandate may become reality, the current policy commitment is only 40%. Moreover, Norway’s association with EU policies for the non-ETS sectors will in

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[21] For comparison, the prices found in previous studies mentioned in this section are deflated to real 2013 NOK.

practice alleviate the abatement cost burden by giving access to several flexibility mechanisms, including a limited amount of ETS allowances that can be used for offsetting emissions in the non-ETS sectors and permitted access to non-ETS allowances from EU states. If mechanisms for such transfers become attractive, paying for emission cuts outside of Norway may be an option. The MAC curve constructed for Norwegian non-ETS emissions in this report can guide us to cost levels for less ambitious domestic cuts. However, a reduction in domestic cuts must be paid for somehow. If it takes the form of buying allowances in the EU, several studies show that EU MAC estimates for the non-ETS sector are lower, often considerably lower, than the MACs computed for Norway in the present study. In a regime with full internal non-ETS flexibility, no LULUCF or ETS flexibility, and all other energy policies unchanged, Aune and Fæhn (2016), Bye et al. (2019), and Aune and Golombek (2020) indicate EU MAC levels between NOK 600 and NOK 2 000/tCO_2.

As pointed out earlier, the CGE methodology tends to disregard transitional costs. This can be a serious omission. The ten years between now and 2030 is not a long time, and transitional costs must be expected to constitute a large part of the abatement cost up to then. How serious the omission is will depend on the economic situation. The world is now in an unfamiliar state of crisis because of the COVID-19 pandemic. On the one hand, the transitional costs of tightening GHG prices may be substantial and further deepen the crisis. For both the private and the public sector, other priorities will naturally move up on the agenda. On the other hand, emissions will decline and take the pressure off the GHG price for any given target. A state of unused capacity and unemployed labour may also be an opportunity for cost-effective climate initiatives when the recovery eventually comes. There are currently ongoing discussions in Europe about whether and in the event how the vision for a European Green Deal should be pursued in the current situation, and Norway is involved in this dialogue.[22]

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[22] https://www.regjeringen.no/no/dokumenter/forelopig-norsk-innspill-til-eu-og-european-green-deal/id2696101/

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Appendix A: Measures from external sources

A.1. The method

The simulation model does not include all measures that are relevant for reaching the required target. Main examples are changes in agricultural output compositions and technologies as well as technology changes in commercial road transportation. We have allowed for including the mitigation potentials of such measures as assessed in KK (2020) if they have estimated private costs lower than the simulated MAC in SNOW. These are included exogenously in the HVD and PRO scenarios in SNOW (and some of the sensitivity simulation runs).

The external source of additional measure information is mainly KK (2020). To ensure that we do not double count, we have modified the SNOW model to omit emission changes due to technological adjustments in the two main commercial road transportations sectors, other transport (OTP) and detail and retail trade (TRD). We do this by imposing Leontief production functions (i.e., no substitution across input factors) in the relevant parts of the CES structure. Likewise, we use Leontief functions in all parts of the input structure for agriculture (AGR); see Appendix D for the input structures. The estimated costs of the measures in commercial road transport and agriculture are added to the abatement cost and utility cost estimates from SNOW.[23]

In OTP and TRD, only emission changes caused by adjusting the output scale are part of the simulated measures. Hence, the SNOW model endogenously captures emission reductions caused by changes in commercial road transport volume but allows the production technology used in commercial road transport to be given exogenously. In the agriculture sector (AGR), emission changes due not only to technological adjustments but also to rescaling output are excluded from the simulations. AGR output as well as input is kept unchanged from REF. Note, also, that since no measures, by definition, can take place in AGR, we have not imposed the GHG price on that sector in the simulations. Here, only the current level of CO_2 tax is maintained. Otherwise, the sector would end up paying large GHG taxes to the state without any scope for abatement response.

The inclusion of the external measures in the analysis takes place as follows: We first simulate an abatement scenario (HVD or PRO). Then we identify the relevant measures in agriculture and commercial transportation in KK (2020) that are estimated to have lower private costs than the simulated GHG price. We now add the abatement potential of these KK measures to the emission target in the abatement scenario and simulate again. Some KK measures might need to be excluded because the GHG price will now be lower. We repeat this iteration procedure until the sum of measures in the analysis, both endogenously simulated and externally included, reaches the abatement needed to attain the required target.

Note that this procedure does not capture the indirect impacts of the external measures on the macroeconomy. For instance, we will not be able to take account of the pressures they cause in markets for production factors like labour, capital, electricity or other intermediates. However, we include their estimated costs in our two cost metrics: the direct, private abatement cost and the social costs, the former by adding them to the total abatement costs, the latter by deducting them from the simulated utility of households.

The cost and emission reduction potential of the exogenous measures we introduce are subject to uncertainty; see KK (2020). We do sensitivity analysis w.r.t the cost of these measures to illustrate the impact.

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[23] These are costs in real terms.

A.2. Commercial road transport

The KK report provides a detailed account of measures assessed to reduce emissions from road use (see measures T01 to T13 on p. 54 in KK (2020) Del A). We classify these measures as technology- or output-induced reductions, respectively. The measures classified as output-induced (i.e., the zero-growth goal for passenger vehicle traffic (T01), the transfer of goods transport from road to sea and rails (T02), and some of the measure dealing with improved logistics for goods transportation by van (T03)) are not considered further, because they are already taken into account in SNOW. Moreover, we do not consider the personal EV measure (T05), because private EVs are modelled in SNOW, as well. The remaining measures in commercial transport, that mainly consist of electrification and biofuels blending, are included in HVD and PRO as exogenous measures.

The abatement potential and cost of each of these measures included into the macroeconomic analysis for the year 2030 are listed in Table A.1. This is not done in the REF scenario. Remember that the exogenous emission reductions are included if and only if their marginal costs are below the endogenous price on non-ETS GHG emissions. Hence, the emission reductions and costs given in Table A.1 are valid for the HVD and PRO scenarios given the 50 per cent requirement, but not for lower emission targets along the MAC in Figure 4.2, nor the sensitivity analysis where the measure costs in Table A.1 are doubled; see section 4.4.

Table A.1 Exogenous abatement and measure costs in commercial road transport. Figures for 2030 in HVD given the 50% emission requirement, in NOK (2013)[1]

	Exogenous abatement ($MtCO_2eq$)	Measure cost (mill. NOK)	Cost per tonne emission reduction in SNOW (NOK)
Improved truck logistics (T03)	0.01	5	633
Improved logistics and increased efficiency of trucks (T04)	0.20	127	633
100% of new light vans are electric by the end of 2025 (T06)	0.12	132	1 066
100% of new heavier vans are electric by the end of 2030 (T07)	0.11	70	633
50% of new trucks are electric or hydrogen vehicles in 2030 (T08)	0.36	384	1 066
100% of new city buses are electric by the end of 2025 (T09)	0.30	320	1 066
75% of new long-distance buses are electric or hydrogen vehicles in 2030 (T10)	0.08	85	1 066
45% of new motorcycle (MC) and moped sales are electric in 2030 (T11)	0.01	7	633
10% of new tractors run on biogas in 2030 (T12)	0.06	119	1 985
Increased interference with biofuels in road traffic (T13)	0.51	985	1 932
Sum	1.76	2 233	

Source: Own calculations based on Klimakur 2030 (2020)[24]

Whereas these emission reductions are added exogenously in the HVD and PRO scenarios, they do not come for free. We use information in KK (2020) to evaluate the private costs of the relevant measures. In 2030, the estimated cost of the included measures amounts to 2.2 bill NOK (2013). We also use this cost estimate for the social costs of the measures.

The KK method also provides social cost estimates. However, they do not provide information about policies nor direct or indirect behavioural responses to the policies, including tax interaction effects, which are shown to be considerable in the present study. On the other hand, we exclude some market failures that are considered by KK; see also section 5.2. As emphasised in KK (2020), the actual

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[24] The emission reduction figures in Table A.1 are based on slightly older estimates than those presented in KK (2020). The differences are very small, except for T09 which are 0.22 $MtCO_2eq$ in KK (2020). Note that we have added the non-ETS CO_2 tax present in REF to the cost of the exogenous measures (this tax is removed in HVD and PRO to achieve a uniform price on non-ETS emissions).

private costs of these measures are highly uncertain and, in many cases, there are barriers to their implementation not reflected in the cost estimate. We run a sensitivity analysis of their cost estimate; see section 4.4. It is also possible to use the MAC curve presented in section 4 to reason about consequences of removing or adding measures based on other cost assumptions.

A.3. Agriculture

For the agriculture sector (AGR) in SNOW, AGR output as well as input is kept unchanged from REF. When supply is completely inelastic, we leave out abatement through output contraction that would reduce emissions both by decreasing the volume of fossil energy (for a given fossil fuel intensity) and by decreasing process emissions. Processes are the dominant emission source in SNOW’s AGR sector. They account for significant emissions of CH_4 from animal husbandry and of N_2O from the use of fertilizers. Even if the supply of agricultural products is completely inelastic, that does not rule out the possibility that the output composition of agricultural products can be changed. This type of adjustments as well as adjustments in technologies/production processes will have to be included as external information.

KK (2020) presents a detailed account of measures that reduce GHG emissions from the agriculture sector (see the measures J01 to J11, AT02 and O02, in KK (2020)). In particular, the report refers to several studies that have tried to estimate the measures in terms of both quantity and cost. For our purpose, we evaluate the measures J01 to J11 to determine whether they can be relevant as external measures in the macroeconomic analysis. We do this mainly by considering the private cost estimates and the uncertainty related to the different measures. As in the OTP and TRD sectors, we only include emission reductions that have a private cost lower than the GHG price in non-ETS sectors in the relevant SNOW scenario in the years 2021-30.

We fully include only one measure from KK (2020) in the AGR sector, J01, which is transition from red meat to plant-based diet and fish. For measures J02 to J05, AT02 and O02 we scale down the abatement potentials by 50% since we interpret these measures as more uncertain (see Table A.2). The private cost estimates for all external measures are drawn from KK (2020). The cost estimates for particularly AT02 and O02 hare highly uncertain with a big range of possible private cost estimates. Thus, for the latter we use the middle values reported from KK (2020) for private cost estimates. These measures have costs well below the simulated GHG price in the non-ETS sectors in SNOW and account for a substantial amount of emission abatement from the sector. When comes to the output impacts of the measures, J01 suggests a higher production volume while the rest may indicate a lower production volume. Thus, they can be assumed to more or less cancel each other out in terms of production volume. Hence, we retain the assumption of inelastic aggregate supply of AGR products when we implement the external measures. The emission abatement figures for the sector in 2030 is 0.93 $MtCO_2eq$, listed in Table A.2.

Table A.2 Exogenous abatement and measure costs in agriculture. Figures for 2030 in HVD given the 50 per cent emission reduction requirement, in NOK (2013)

	Exogenous abatement ($MtCO_2eq$)	Measure cost (mill. NOK)	Cost per tonne emission reduction in SNOW (NOK)
Transition from red meat to plant-based diet and fish (J01)	0.72	456	633
Reduced food waste (J02)	0.10	63	633
Livestock manure for biogas (J03)	0.02	26	1 500
Various fertilizer measures (J04)	0.02	37	2 050
Stop in new cultivation of marshes (J05)	0.01	6	633
Replace use of fossil natural gas for permanent heating of buildings (O02)	0.03	58	2 538
70% of new non-road machines and vehicles are electric by 2030 (AT02)	0.03	65	2 858
Sum	0.93	758	

Source: Own calculations based on Klimakur 2030 (2020)

The implemented cost of the included agricultural measures is estimated to be 0.76 billion NOK in 2030. We adjust the simulated private abatement costs and social cost estimates for 2030 accordingly when including the agricultural measures. Specifically, we do not include the health impacts of dietary changes in either the social or the private costs. Because of the uncertainty related to the measures, inter alia, identified, unquantified barriers in KK (2020), we run a sensitivity analysis of the cost estimate – see section 4.4.

Appendix B: Private EV modelling in SNOW

At present, only the representative households' transport is split into electric vehicles (EV) and conventional vehicles with internal combustion engines (ICE). We refer to Appendix A above for details about commercial road transport. Normal hybrids 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.

The representative household's spending on cars consists of expenditures for motor vehicles (including parts), retailer's service fee, and all other service costs. In the CES nesting structure, the activity of private driving is split into the use of old and new cars, which in turn are split into EVs and ICEs (see section 3.3, Figure 3.1). Thus, 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 and electricity is based on the stock of old and new cars.

Expenses for new cars and old cars are modelled as annual rental values. Thus, when consumers choose EVs or ICEs, they consider the annual expenses consisting of annual rental values, fuel or electricity costs, and other service costs for each type of car. The elasticity of substitution between EVs and ICEs captures the substitutability between the two types of new cars; i.e., an increase in this elasticity means that the attributes of EVs and conventional cars have become more similar. In other words, it will be easier to switch from conventional cars to EVs in future years. The exogenous price of imported EVs decreases by 20% in 2018 and then by 5% each year from 2019 to 2023 and by 2.5% from 2024 to 2030.

To match the reference information from KK (2020) on EV phase-in in REF by 2030, the substitution elasticity, EV sales prices and the implicit non-fiscal advantages given to EV users are treated as calibration instruments. Our EV sales shares for the years 2020-2030 therefore equal the EV sales shares in the KK reference scenario. The implicit subsidy is intended to represent the advantages of EVs that are not modelled (e.g., free parking, access to bus lanes, cheaper toll roads etc.) and the improved attributes of the EVs ("more car for the same price"). We fix the substitution elasticity, the import prices and the implicit subsidy at the reference scenario level in the abatement scenarios, so that the EV sales share becomes endogenous.

We make the rather conservative assumption that electricity consumption per EV is exogenous. However, consumption of refined oil (petrol and diesel) is endogenous. When petrol and diesel prices increase in the abatement scenarios (HVD and PRO) as the GHG price increases households drive less and consume less diesel and petrol (compared with REF).

The modelling of private vehicles in SNOW is calibrated to tally with the 2018 stock numbers of private EVs and ICEs. For calibration purposes, we use 2014 figures to account for household EV electricity consumption and the sales share of EVs (13%). The reason for using 2014 data, as opposed to data from the SNOW 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.

On the supply side, domestic production and import of the good "motor vehicles including parts" is split into conventional ICE vehicles and EVs, respectively. Note that Norwegian production of private vehicles and parts is modest. The model accounts for the increase in household electricity consumption associated with electric vehicles as part of the electricity market.

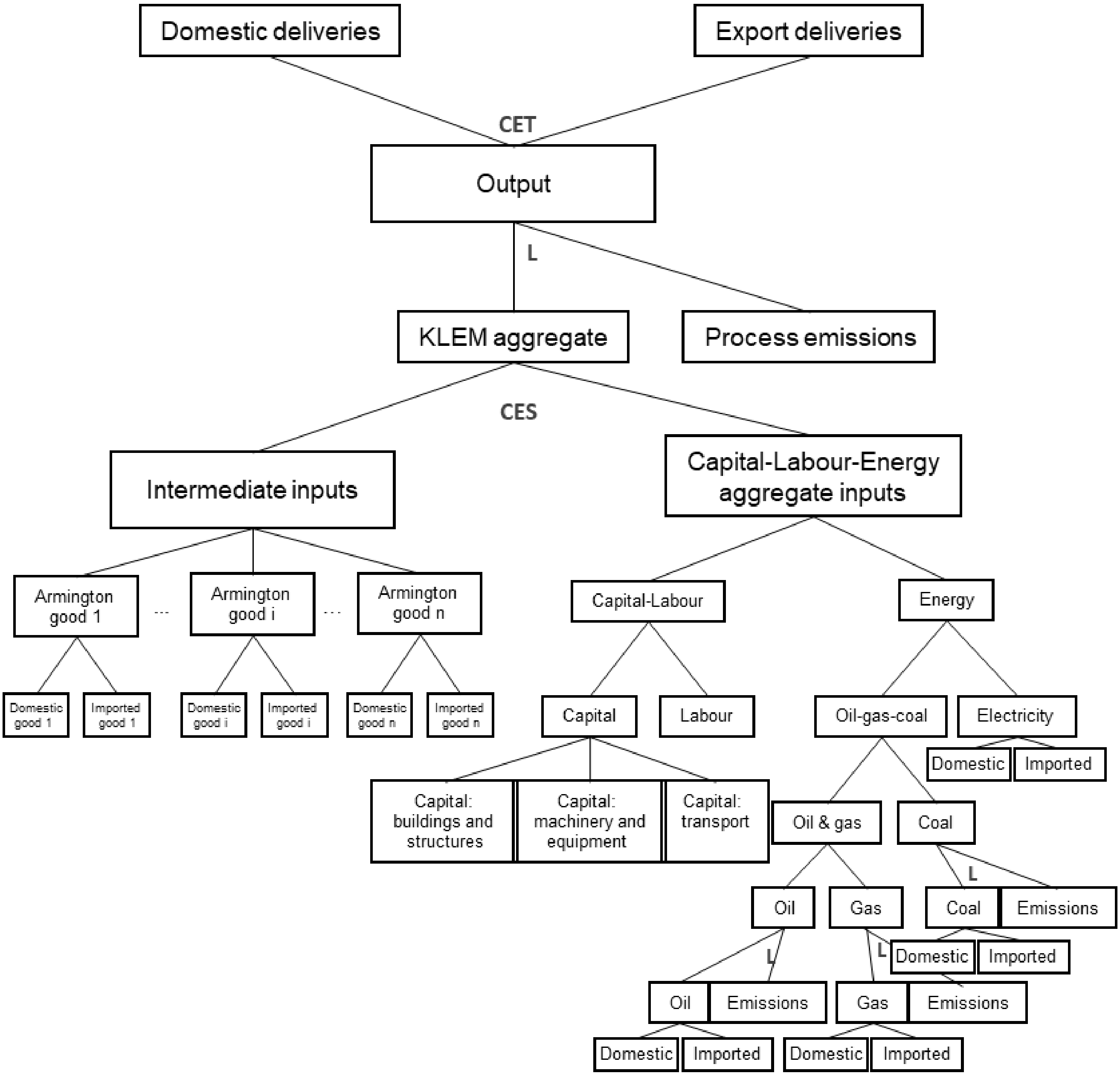
Appendix C: List of abbreviations

Table C.1 Abbreviations used in the report

Abbreviation	Description
CES	Constant elasticity of substitution
CGE	Computable general equilibrium
CH4	Methane
CO_2	Carbon dioxide
CO_2eq	CO2 equivalent
CPI	Consumer price index
ESR	Effort Sharing Regulation
ETS	Emission Trading System
EU	European Union
EV	Electric vehicle
GDP	Gross domestic product
GHG	Greenhouse gas
HFC	Hydrofluorocarbon
HVD	Main scenario
ICE	Internal combustion engine vehicle
I-O	Input-output
KK	Climate Cure 2030
LPG	Liquefied petroleum gas
LULUCF	Land use, land use change and forestry
MAC	Marginal abatement cost
MDIR	The Norwegian Environment Agency
Mt	Million tonnes
N_2O	Nitrous oxide
NB20	National Budget for 2020
Nec	not elsewhere classified
NH_3	Ammonia
NMVOC	Non-methane volatile organic compound
NOK	Norwegian kroner
NOx	Nitrogen oxides (generic term)
PFC	Perfluorocarbons
PHEV	Plug-in hybrid electric vehicle
PM_{10}	Particulate matter 10 micrometres (μm)
$PM_{2.5}$	Particulate matter 2.5 micrometres (μm)
PRO	Revenue recycling scenario
REF	Reference scenario
SF_6	Sulphur hexafluoride
SNOW	Statistics Norway’s world model
SO_2	Sulphur dioxide
SSB	Statistics Norway
UN	United Nations
VAT	Value Added Tax

Appendix D: The production technologies in SNOW

Figure D.1 The CES production functions of SNOW sectors[1]



[1] In resource-based sectors (Crude oil and gas, Agriculture and Electricity), the natural resources are also modelled as a non-substitutable input factor in the upper part of the CES tree.

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