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Norwegian abatement targets for 2035

A CGE analysis

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Preface

This analysis is the response to a request from The Ministry of Climate and Environment to Statistics Norway to conduct a macroeconomic analysis of the Norwegian abatement of greenhouse gas emissions by 2035. The request comprises two main tasks. The first task is conducted in the first phase of this analysis. It consists of simulating various policy scenarios for 2035, using the most updated model version of the computable general equilibrium model SNOW-NO of the Norwegian economy. Where beneficial, the simulations have been supplemented and integrated with abatement information from external sources. The purpose of this first task is to show how marginal abatement costs depend on abatement targets under two different policy regimes, one where all abatement is to take place domestically, and another, where buying EU ETS allowances forms part of the abatement options. Phase two of the analysis is devoted to the second task: to analyse and discuss macroeconomic and industry-specific consequences of one of the policy scenarios from the first phase in more detail. This has also involved an analysis of different revenue recycling options.

Statistics Norway, 21 October 2024

Linda Nøstbakken

Abstract

The Norwegian government is in the process of specifying abatement targets applying to the period between 2030 and 2050 and will submit new pledges to the United Nations in 2025. To inform these processes, this report examines and discusses the costs and macroeconomic impacts on the Norwegian economy of introducing different greenhouse gas (GHG) emissions targets and target structures for 2035. A cost-effective implementation is assumed, where the abatement is achieved by replacing the current CO_2-tax system and GHG price in the EU Emissions Trading System (EU ETS) with uniform emissions pricing. The analysis is conducted by means of Statistics Norway's computable general equilibrium (CGE) model SNOW-NO of the Norwegian economy. With a perspective of more than ten years, we consider an equilibrium approach to be relevant to capture the long run adaptation to climate policy. The CGE model allows us to study the interaction among many simultaneous measures and how they interplay with pre-existing distortions. We also study the impacts of recycling the revenue from the emissions pricing in a way that dampens pre-existing distortions, namely reduces the labour taxation.

The analysis is split into two phases. In phase 1, various 2035 policy scenarios are simulated and compared to a common reference scenario, with a focus on constructing economy-wide marginal abatement cost curves for two different target structures. In the first, Policy i), various economy-wide targets for 2035 are to be met solely through *domestic* abatement measures. In the second, Policy ii), the abatement is split into two sub-targets, one for emissions currently covered by the EU ETS, and one for remaining emissions, which are covered by EU's effort-sharing regulation (ESR). The Policy ii) target structure allows for purchases of allowances in the EU ETS, if cost effective. However, it disregards similar cross-border options for the abatement in the ESR-covered sector. This is motivated by limited practical access in the current cooperation with the EU.

In the second phase of the analysis, we examine the macroeconomic and industry-specific implications of *one* of the policy scenarios from the first phase in detail. The selected scenario has a GHG abatement target of 60 per cent compared to the 1990 level which is to be achieved solely by *domestic* abatement, i.e., by conducting Policy i). The selected policy scenario is analysed given two different recycling options for the revenue from emission pricing: a lump sum, non-distortive transfer back to the household sector, and by reducing labour taxation. The latter option illustrates how the revenue from carbon pricing can be used to reduce distortive taxes, thus obtaining a double dividend.

The main results of the analysis are that the uniform emission prices span from 2,900 to 12,300 NOK (in fixed 2022 prices) per tonne of abated GHG emissions across the simulated 2035 policy scenarios. We observe that, for the same economy-wide abatement target of 65 per cent cut relative to 1990, the marginal abatement cost (MAC) is more than doubled if Policy i) is chosen instead of Policy ii). Further, in the detailed assessment of the selected 60 per cent abatement scenario in the second phase, we find that revenue recycling via reduced labour taxation can bisect the social cost as compared with the lump-sum recycling case. This reflects that in the lump-sum case, the interaction between the GHG emission price and the pre-existing labour taxation adds significantly to the social cost. The explanation is that labour taxation encourages households to choose more leisure than socially beneficial, and when an emission price is introduced, even more leisure will be preferred by the households. The driver behind increased leisure is a drop in the real wage and, thus, in the marginal benefit of working.

Sammendrag

Norske myndigheter har satt i gang prosessene for å fastsette sine klimaambisjoner mellom 2035 og 2050, og melde nye løfter inn til FN. Som del av kunnskapsgrunnlaget tar denne rapporten for seg samfunnsøkonomisk kostnader og virkninger av å innføre ulike mål og utslippsstrukturer for utslipp av klimagasser for 2035. Det antas kostnadseffektiv politikk, i den forstand at utslippskutt oppnås ved at dagens CO_2 avgift og kvoteprisen i EUs kvotemarked (EU ETS), fremskrevet til 2035, erstattes med uniform utslippsprising. Analysen er gjennomført ved hjelp av Statistisk sentralbyrås numeriske generelle likevektsmodell SNOW-NO. Likevektstilnærmingen anses som relevant, da tidsperspektivet strekker seg utover ti år. En makroøkonomisk tilnærming er valgt, da det vil få frem hvordan utslippsprising utløser mange simultane tiltak, tiltakenes samspill med hverandre og med allerede eksisterende politikkinngrep, samt hvordan ulike tilbakeføringsalternativer av proveny kan påvirke de samfunnsøkonomiske virkningene.

Analysen består av to faser. I den første sammenlikner vi flere politikkscenarioer med et referanse-scenario uten 2035-mål med. Hovedformålet i denne fasen er å konstruere marginale rense-kostnadskurver gitt to ulike politikktilnærminger. Den første politikktilnærmingen, Politikk i), antar at et overordnet utslippsmål for hele økonomien i 2035 skal oppfylles utelukkende gjennom *innenlandske* utslippsreduksjoner. Den andre, Politikk ii), splitter utslippsmålene inn i to delmål: ett for klimagassutslipp som i dag omfattes av EU ETS og ett for de resterende utslippene, som i dag er dekket av EUs innsatsfordelingsforordningen (ESR). Politikk ii) åpner opp for å kjøpe kvoter i EU ETS om det er mest kostnadseffektivt. Siden det i praksis er begrenset tilgang til å handle på liknende måter i ESR-sektoren, ser analysen bort fra dette.

I den andre fasen undersøker vi nærmere de makroøkonomiske og sektor-spesifikke konse-kvensene i ett av politikkscenarioene fra første fase. Det utvalgte scenarioet har et utslipps-reduksjonsmål på 60 prosent sammenlignet med 1990-nivået og antar Politikk i), det vil si kun *innenlandske* utslippskutt. Vi sammenlikner to alternativer for tilbakeføring av de økte offentlige inntektene fra utslippsprisingen: en lump-sum, ikke-vridende tilbakeføring til husholdningssektoren og en tilbakeføring via redusert arbeidsbeskatning. Sistnevnte gir et eksempel på hvordan de samfunnsøkonomiske kostnadene ved klimapolitikken kan dempes med målrettete kutt i eksisterende skattekiler.

Hovedfunnene fra analysen er for det første at utslippsprisen/marginalkostnaden varierer betraktelig fra scenario til scenario – fra 2 900 til 12 300 NOK (2022-kroner) per tonn redusert klimagassutslipp. Spesielt observerer vi at gitt samme reduksjonsmål på 65 prosent fra 1990-nivå, mer enn dobler utslippsprisen seg om man velger Politikk i) (kun innenlandske kutt) framfor Politikk ii) (åpner opp for kvotekjøp fra EU ETS). I analysens andre fase, der vi går mer grundig inn i ett av scenarioene, der utslippskuttet skjer innenlands og er på 60 prosent, finner vi at det betyr mye hvordan provenyet tilbakeføres. Ved å tilbakeføre gjennom redusert arbeidsbeskatning istedenfor lump-sum til husholdningssektoren, halveres de samfunnsøkonomiske kostnadene. Dette tyder på at det er store effektivitetstap forbundet med at utslippsprisen samspiller med skattekilen i arbeidsmarkedet. Forklaringen er at arbeidsbeskatning oppmuntrer husholdningene til å velge mer fritid fremfor å tilby arbeidskraft. Når utslippsprisen øker, forsterkes denne vridningen; enda mer fritid blir etterspurt. Driveren bak dette er at reallønna faller som følge av utslippsprisingen og det blir mindre inntektsbringende å jobbe.

Contents

1. Introduction

Through its participation in the Paris Agreement, Norway has committed to reducing greenhouse gas (GHG) emissions by 55 per cent compared to the 1990 level by 2030 as part of its Nationally Determined Contribution (NDC)[1]. In 2025, Norway intends to submit a new NDC for a target year beyond 2030. As part of the information basis for determining the structure, ambition level and target year of this pledge, the Norwegian Ministry for Climate and Environment has commissioned an analysis from Statistics Norway, evaluating the costs, as well as the sectoral and macroeconomic impacts of various climate policy structures and ambition levels, implemented by 2035.

In response to this request, we analyse several policy scenarios using SNOW-NO, a macroeconomic model developed at Statistics Norway designed for climate policy analysis (Rosnes and Yonezawa, 2024). Abatement measures in the model constitute the behavioural responses of its agents: firms and households. Emissions decline if agents substitute away from emission-generating energy, or other inputs, or scale down emission-intensive industrial production processes. The abatement behaviour of the model gives somewhat scarce technological detail. Moreover, as abatement technologies develop fast, all relevant options are not captured by simulations of the SNOW-NO model. For these reasons, we supplement the abatement represented in the SNOW-NO model with external information that we integrate into the analysis ex-post.

The analysis is performed in two phases. Phase 1 compares different NDC targets for 2035 that vary in ambition levels and policy structures, with a focus on marginal abatement cost (MAC). For a given policy structure and ambition level, each scenario assumes uniform MACs across all emission sources covered by the same target, representing the cost minimising implementation of emissions abatement. The MACs can be interpreted as uniform GHG emission price levels and reflect how costly it is to abate one more tonne of GHG, measured in CO_2 equivalents (CO_2e). By simulating different abatement targets, we can construct a MAC curve that shows the accumulated abatement on the X-axis and the uniform, necessary GHG emission price on the Y-axis.

We construct MAC curves for two distinct policy structures. The first policy structure, Policy i), assumes that a new economy-wide target for 2035 will be solely fulfilled by domestic abatement. Currently, Norway is part of the EU Emissions Trading System (EU ETS) that allows firms in some sectors to buy emissions allowances. In Policy i) this option is removed, and the resulting emission price needs to encourage firms covered by the EU ETS to undertake domestic measures rather than buy allowances in the ETS market. The second policy structure analysed, Policy ii), splits Norwegian emissions into two sectors: those covered by the EU ETS (t*he ETS emissions sector*), and remaining emissions covered by the EU's effort sharing regulation (*The ESR emissions sector*). The two emissions sectors have separate targets for 2030 according to an agreement with the EU, and we assume that this structure is prolonged to 2035. Within these two policy structures, we simulate different ambition levels for the 2035 NDC.

In phase 2, we analyse the sectoral and macroeconomic implications of *one* of the scenarios, characterised by an economy-wide target of reducing GHG emissions by 60 per cent compared to the 1990 level. The reduction is assumed to be met by domestic abatement only (Policy i)). By interpreting the uniform MAC as a GHG emission price, we also study two different recycling alternatives – one where revenue is paid out to the household sector as a lump-sum transfer and one where the revenue is used to simultaneously reduce labour taxation.

[1] https://unfccc.int/node/620976

Section 2 gives a brief introduction of the SNOW-NO model and presents key methodological choices made in the analysis. Section 3 outlines the approach and presents the results related to Phase 1. Similarly, Section 4 addresses Phase 2. Section 5 provides some methodological reflections, interpretations, and uncertainty considerations, while Section 6 concludes.

2. The SNOW-NO model and methodological choices

2.1. The SNOW-NO model

SNOW-NO is a multi-sector Computable General Equilibrium (CGE) model developed by Statistics Norway. The model represents Norway as a small open economy with 46 industries, a representative household, and the government. The model computes a set of equilibrium prices that clears the market for factor and final consumption, given the production technology of firms, import and export opportunities, government policies and household preferences. GHG emissions are modelled as a byproduct of industrial processes and energy use. SNOW-NO is a recursive-dynamic model, in which each individual year is linked to previous years via households' savings decisions and companies' investment decisions. It is used both for making projections of the Norwegian economy, and for studying relative changes between reference and policy path projections. The present analysis is an example of the latter purpose. The projection used as the reference path coincides with the emission projection trajectory in the National Budget for 2023 (Ministry of Finance, 2022). The reference path is described further in section 3.1.

Production

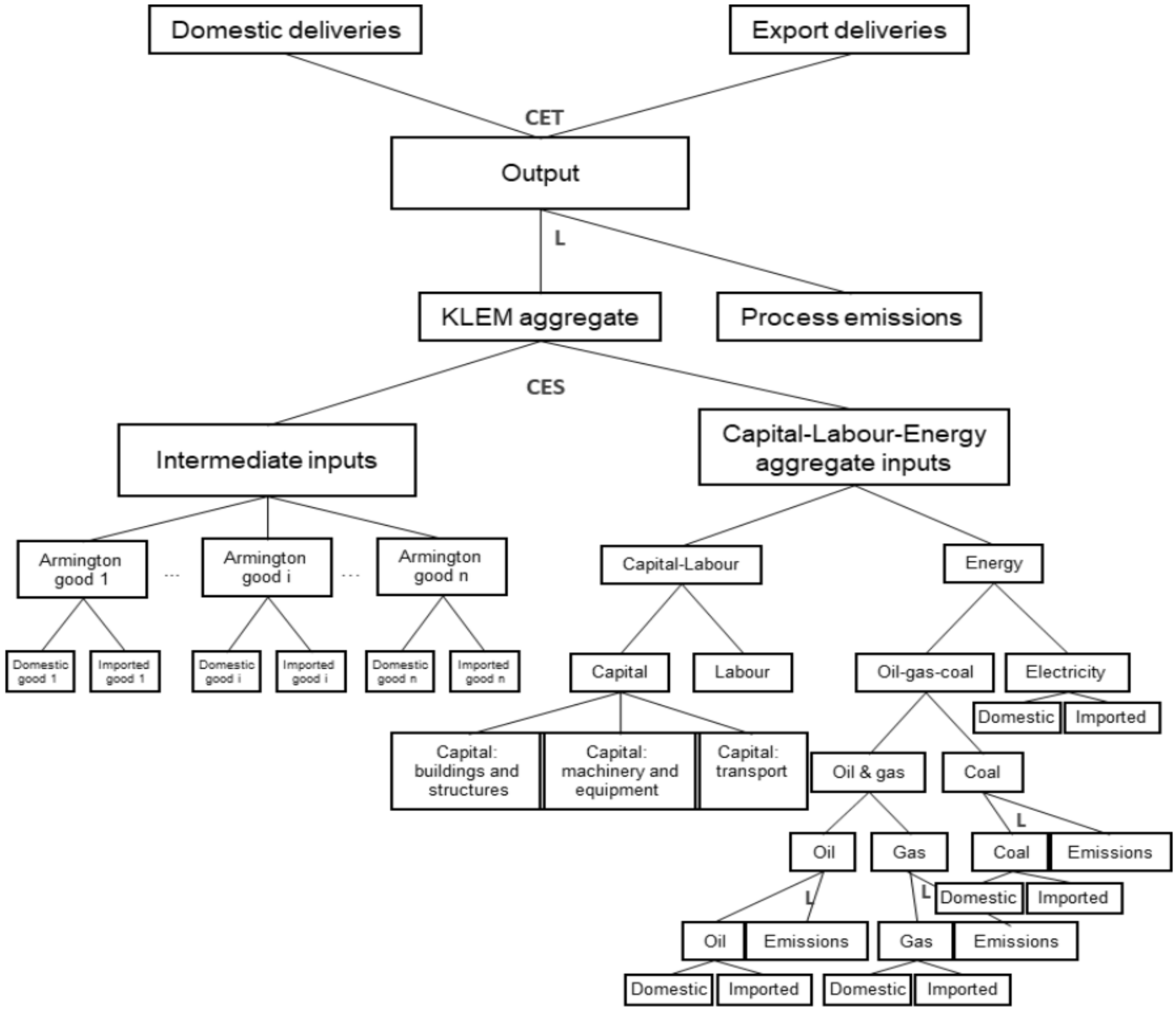
The production side of the SNOW-NO model consists of 46 industries, each with its own representative producer, equipped with a nested constant elasticity of substitution (CES) production function. Each of these minimise their cost of production. The production function describes the industry-specific combination of capital, labour, energy and other intermediate goods that are combined to produce the industry-specific output; see Figure 2.1. The elasticity of substitution parameters of CES functions describe the substitution possibilities across inputs when the relative input prices change. A high elasticity of substitution between an input pair implies that it is relatively easy to substitute one input for another. The substitution elasticities are therefore important for the analysis, as they determine how flexible the sectors are to changes in relative factor prices.

Many of the elasticities of substitution can be interpreted as abstract representations of the technological abatement options of the sectors; see also the description of abatement below. For example, substitution from fossil fuels to capital can represent investment in more fuel-efficient machinery as the relative price of energy increases. Likewise, an increase in other energy inputs at the expense of fossil fuels reflects substitution to less emission-intensive energy forms like bioenergy or electricity. This will take place as fossil fuel prices increase relative to other energy goods. It is important to note, however, that input compositions as well as output levels are fixed for some industries: Crude oil and gas, Electricity and Agriculture. The motivation for this modelling is that they are heavily reliant on scarce natural resources, and governmental decisions and regulations.

It is possible to specify different substitution elasticities at every level of a nested CES function. While the default elasticities are based on econometric estimates from the literature, the model user has the flexibility to adjust these values according to the context of the analysis. For example, in sectors experiencing rapid technological advancements, new substitution possibilities may emerge, while older ones become less relevant.

Labour and capital are mostly mobile across domestic sectors in SNOW-NO. Some capitals are more sector-specific and, thus, not mobile. The latter is particularly relevant for the resource-reliant production sectors, such as Agriculture or Crude oil and gas production (see Rosnes and Yonezawa, 2024). Capital inflow is given in the base year and then endogenized in line with domestic investment, which in turn is determined by household savings in each period. Total labour supply is endogenous and depends on the real wages received by employees – see the description of households below.

Figure 2.1 Nested CES structure of production sectors in SNOW-NO.



[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.

Source: Rosnes and Yonezawa (2024)

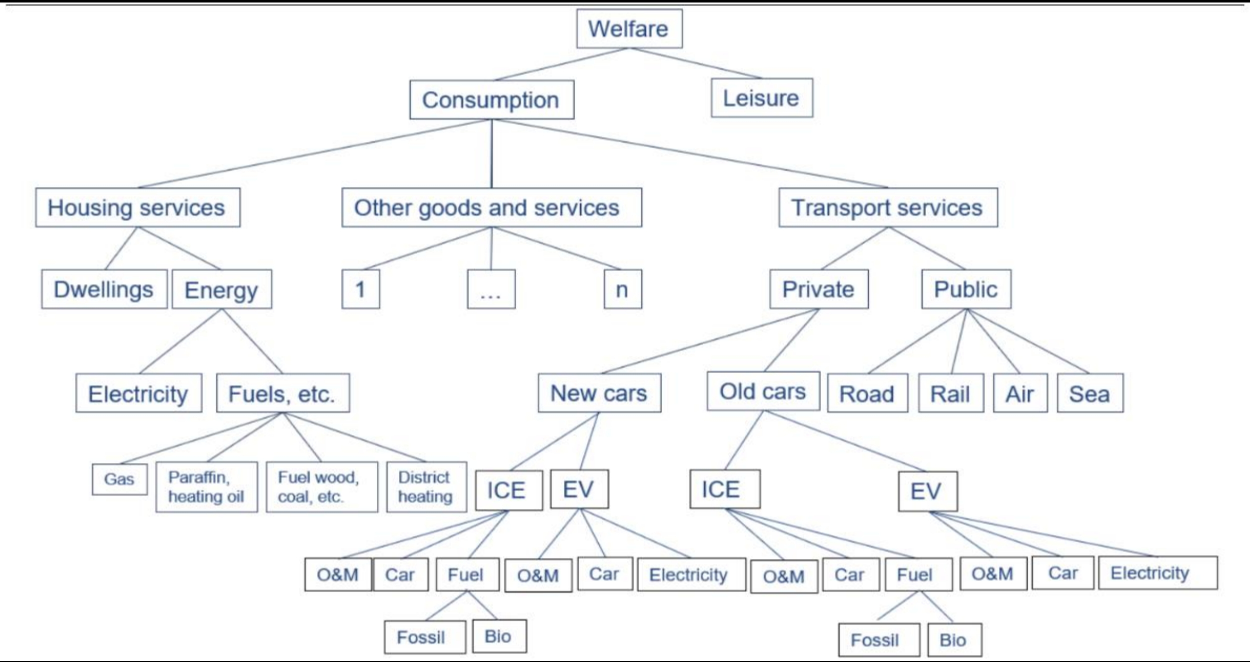
Trade

Norway is specified as a small open economy in the SNOW-NO model, taking world prices as given. All goods in the domestic market, both intermediate and final, have their composition determined by a CES composite of imported and domestically produced varieties. The elasticity of substitution in these CES composites are based on the Armington (1969) type, where their degree of substitutability is higher the larger the parameter value of the elasticity between imported and domestic varieties in the preferences of households and use of inputs in firms. Exports are determined by a Constant Elasticity of Transformation (CET) function between domestic and export market deliveries. The CET specification comes with the implicit assumption that there is an adjustment cost of reallocating deliveries between the domestic and export market, determined by the elasticity of transformation. A higher parameter value implies more flexibility in switching from domestic to export deliveries when the relative price changes, and vice versa. Factor prices and the price of domestic deliveries are both determined by the domestic market equilibrium.

Households

The household demand side of the SNOW-NO model is inhabited by a representative household that owns and receives net-of-tax income from labour, capital and natural resources and transfers from the government. Labour supply adjusts endogenously to changes in overall income, savings, and prices, including the net-of-tax wage rate, which reflects the cost of choosing an additional hour of leisure over work. Once the household has determined its labour supply, the household makes a consumption-savings decision according to a Cobb-Douglas utility function, i.e., a CES function with elasticity of substitution equal to one. The optimal distribution of consumption across goods and services is governed by a nested CES function, as shown in Figure 2.2. At every stage there is an elasticity of substitution determining how optimal expenditure allocation changes in response to changes in relative prices. Abatement behaviour in response to a GHG price and the resulting price rise in emission intensive products or services, will take place as substitution by the household towards the relatively cheaper, less polluting alternatives.

Figure 2.2 Nested CES structure for the representative household in SNOW-NO



Source: Rosnes and Yonezawa (2024)

Government

The government sector in SNOW-NO collect and distribute taxes, and purchase goods and services from the domestic sectors and abroad to provide public services. These are supplied through either the state or municipality sector. Government expenditure is determined exogenously and is assumed to grow in line with the overall economy. In implementing climate policy, it is assumed that both the nominal government deficit and real government spending follow the same trajectories as in the reference scenario, ensuring revenue neutrality. Under this assumption, all revenue changes are recycled to the representative household. The default setting assumes lump-sum transfers (as in scenario 2A). However, the model user can choose other channels, e.g., reducing other taxes like the labour income tax (as assumed in scenario 2B).[2]

The existing public interventions in SNOW-NO include product and business taxes, subsidies, and labour costs such as employer taxes. All taxes and fees are represented as percentage (ad valorem) rates in the model, and all taxes are recorded net of subsidies (taxes minus subsidies). The government distribute tax income, through public goods and services, deposit it in the Government Pension Fund Global, or transfers to the household.

[2] See section 3.1 for more details related to the scenarios in this study.

Emissions, abatement policies and abatement behaviour

The greenhouse gasses modelled in SNOW-NO include carbon dioxide (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 $PM_{2.5}$). Emissions result from energy production and industrial processes. We distinguish between emissions covered by the EU ETS and the non-ETS emissions covered by the ESR. Energy-related emissions arise from burning fossil fuels, with the amount of emissions determined by the share of fossil fuel-based energy production and the carbon content of the fuels used. Industry-related emissions are determined by a per-unit emissions coefficient, multiplied by the production volume. The emission coefficients are determined by a base year calibration and adjustments over time to reflect emission efficiency improvements. Abatement of energy-related emissions can be achieved by fuel switching or by scaling down production and/or final consumption.

The menu of climate policy instruments available to the government is relatively detailed in SNOW-NO and is reflected in the reference path. These include sector- and commodity-specific CO_2 taxes and subsides, the EU ETS allowances and the CO_2 compensation scheme for producers. Further, there are bans on emitting methane from landfills and on using fossil fuels for heating. In transportation, bio blending and blending mandates are represented, and non-fiscal interventions and incentives to promote the purchase of electric vehicles are modelled.

We use changes in three instruments in the policy scenario simulations. First, we let uniform GHG emission prices adjust to meet emissions targets. The tax revenue gained from the emission prices is then reallocated into the economy via two different transfer mechanism. One is lump sum transfers to the household, which does not distort behaviour and, thus, has no efficiency impact. The other is via cutting the income tax on labour, a policy intervention that directly affects the trade-off between spending time on labour versus leisure and normally has efficiency impacts.

Normally, firms facing changes in climate policies will respond by finding new input compositions and output levels, and households, likewise, by choosing new consumption patterns and labour supply levels. How behaviour will change depends on the type and dimensioning of the policies. In the SNOW-NO model simulations, the endogenous emission price per tonne of emitted GHG will spur domestic responses that reduces GHG emissions, until the cost of abating another tonne equals the GHG emissions price. The recent years' model development has focussed on including more details, particularly when it comes to transport (road, water, air) and other use of capital and mobile machines (tractors, excavators, etc.). Besides fossil fuel-driven vehicles, vessels and machines, the options of electricity-driven and biofuel-driven types are explicitly modelled and calibrated by means of relevant data. More on this is found in the documentation of the SNOW-NO model (Rosnes and Yonezawa, 2024).

In addition to these endogenous responses, we extend the range of actions to include some externally specified technological solutions, either because they cannot be regarded as covered by the current model mechanisms or because some industries have fixed input structures and outputs. The externally collected abatement information on these options is added ex post to the simulated results and integrated in the analysis through an iteration procedure. These abatement options are:

(a) Abatement (and removal) options involving CCS.

(b) Technological measures in the exogenously modelled Crude oil and gas.

(c) Technological measures in the exogenously modelled Agriculture.

We come back to the treatment of these options in Section 2.2.

Cost of climate policy

Private abatement cost

The abated GHG emissions and the emissions price/MAC form the basis for computing costs of private, domestic, abatement. We use the MAC, curve(s) simulated in Phase 1 to calculate the total private abatement cost, *AC*, which is the area under a MAC curve. It can be approximated by the triangle area with the two legs represented by the total abatement, *A*, and the GHG price, *MAC*:

(1) $$\mathrm{AC} = \frac{A * \mathrm{MAC}}{2}$$

In scenarios with an economy-wide target for 2035 (Policy i)), we have one abatement target and a common MAC for the ETS *and* the ESR sector. In Policy ii)-scenarios, where the ETS and ESR-covered emissions have one target each, the two sectors will typically face different GHG prices and associated abatement. For the ETS sector the cost of possible trading of ETS allowances come on top.[3]

When the abatement relies on external information, the cost of the external abatement needs to be added to the cost derived in equation (1) to arrive at the total abatement cost. We include these measures as exogenous GHG reductions, A_x, *if* the externally available estimates of their private abatement costs are lower or equal to the computed *MAC*. The *MAC* is the result of the abatement options in SNOW-NO, given that the abatement targets are set at (A-A_x) in both sectors. A_x depends on the MAC for abating ((A-A_x), so that A_x and MAC have to be iterated.

The total private abatement cost (*AC*), is then

(2)
$$AC = AC^{ESR} + AC^{ETS} + g^{ETS} * p^{ETS} + AC_x$$
$$= \frac{A^{ESR} * MAC^{ESR} + A^{ETS} * MAC^{ETS}}{2} + g^{ETS} * p^{ETS} + \sum_i A_{xi}^{ESR} * p_{xi}^{ESR} + \sum_j A_{xj}^{ETS} * p_{xj}^{ETS}$$

where the external abatement A_x consist of *i* abatement options in the ESR sector with different costs P_{xj}^{ESR} and of *j* abatement potentials in the ETS sector at costs P_{xj}^{ETS}.

Note that $MAC^{ETS} = p^{ETS}$, i.e., the MAC in the ETS sector is given by the price of allowances in the EU ETS. This price is determined in the EU ETS market, set exogenous in our simulations, and present in both the reference path and the policy scenarios.

The (exogenous) abatement target, *T*, is the sum of the total abatement targets for the two sectors, T^{ESR} and T^{ETS}:

(3) $T = T^{ESR} + T^{ETS,}$

where

(4) $T^{ESR} = \mathrm{A}^{\mathrm{ESR}} + \Sigma_i A_{xi}^{ESR}$, and

(5) $T^{ETS} = A^{ETS} + \Sigma_j A_{xj}^{ETS} + q^{ETS}$.

Equations (3) - (5) imply that the abatement target is met by a combination of the simulated abatement, the sum of the included external abatement potentials in the ESR-sector, and the allowance purchases in the ETS sector.

[3] The ETS price is also present in the reference path.

Recall that the industries Agriculture, Electricity, and Crude oil and gas are assumed to keep their production and input use unchanged, irrespective of the climate policies. These industries will therefore not reduce their energy or process emissions endogenously. Their “simulated” abatement is therefore zero, but their abatement can be implemented as external options. Combining cost information from different sources in this way has serious caveats. While the cost computations from 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. Most seriously, the external abatement and abatement costs will not be able to impact the markets in the model and, vice versa: they will not be affected by general equilibrium effects taking place in the model. The exogenously quantified abatement and costs must be regarded as approximations. They are included, as the alternative is to set them to zero, which is less credible.

Social cost

In a CGE model without market imperfections, and no governmental price distortions, such as taxes, subsidies, or restrictions on quantities, other than the imposed GHG target, the social costs of introducing an emission target are equal to the sum of all agents’ private abatement costs (Paltsev, 2013). However, a major virtue of a CGE model like SNOW-NO is its ability to take relevant market imperfections and public interventions into account. In their presence, productivity differences on the margin between sectors arise, and social resources, like labour and capital, will be used inefficiently, making the model more realistic.

When abatement policies are introduced in an economy with distortions, the interplay with already present inefficiencies can affect utility, depending on where the interactions with the existing policy instruments occur. Some of these distortions will be counteracted by the abatement policies. 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), thus, result in an extra efficiency gain for society not reflected in the private abatement costs. Some pre-existing distortions may also be reinforced. A relevant example is the labour tax, which discourages labour supply. When households face increased consumption costs because of climate policy, it may be tempting to spend their time on even more leisure at the expense of labour supply, which will increase social costs above private abatement costs.

Since the private abatement costs derived from the model are based on equilibrium prices faced by agents, a change in total abatement cost is a function of changes in equilibrium prices in response to climate policy. These are many, since the model computes the general equilibrium for the *entire* formal economy, in contrast to analyses of individual measures project analyses or partial equilibrium model analyses. 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.

As mentioned, we assume throughout the simulations 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 to the household sector. The transfers may also cause distortions, to the extent that they involve changes in taxes and subsidies. Section 4 compares two different recycling alternatives: non-distortionary transfers (lump-sum subsidies) and reduced labour taxation, which affects efficiency and social costs by affecting households’ choice of time devoted to labour vs. leisure.

In order to capture such contributions to the social cost, the model should have a rich representation of public interventions, including funding and recycling options, as well as market imperfections. SNOW-NO takes account of public interventions, funding and revenue recycling options, but not market imperfections like asymmetric information, market power and externalities (e.g., pollution). We discuss this further in section 5.4.

In each period, the total social costs of abatement will be measured in the model by the utility loss of the household. 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.

In addition to these endogenous social costs, we must also account for the social costs of the external abatement measures that are brought into the analysis. Since we have no model-generated indirect impacts of and interactions with the external abatement activities, we assume that the private abatement cost associated with external measures translates directly, 1:1, to the social cost for the consumer. In other words, the difference between social and private costs due to the interactions of external measures with modelled, existing policy interventions, as well as their interactions with the modelled measures that take place endogenously in the simulations are assumed out, as is the impact of the external abatement and their cost on the goods and factor markets in the model.

This analysis focuses on 2035 costs. Cost indicators for a single year do not provide the full cost of phasing in and keeping up abatement measures. The conventional method for capturing the whole-time profile is to discount the annual estimates of all future years, both pre- and post-2035, to a current value. An alternative indicator is annuity, which converts the current value into equal, annual costs. In contrast to our one-year cost concepts, the full social cost of setting abatement targets would include the full current value of post- and pre-2035 utility impacts. This full, discounted welfare impact depends on the relevant discount rate.

2.2. External information on abatement options

Integrating external input on technological measures based on bottom-up data

In two key aspects, we consider the simulation results to become more representative when supplementing the model mechanisms with external data on abatement measures. Firstly, some abatement options cannot be regarded as captured by the input and output changes in the SNOW-NO model. Abatement options develop fast, often faster than the model parameters are updated, which is mainly based on new empirical analysis of historic evidence. In particular, there is a risk of misrepresentation in cases of rapidly developing, large projects like carbon capture and storage (CCS). On the other hand, the breakthrough of still immature technologies during the next decades is uncertain.

Secondly, some sectors are modelled as exogenous and insensitive to the climate policy changes in SNOW-NO. Neither output nor input factors can then be changed, implicitly assuming no sectoral abatement.

To improve the MAC curves, we have thus iterated the model simulations and the external abatement options mapped outside of the SNOW-NO model. This is true for:

(a) Abatement (and removal) options involving CCS.

(b) Technological measures in the exogenously modelled Crude oil and gas extraction.

(c) Technological measures in the exogenously modelled Agriculture.

There are several reasons for choosing to hold these industries exogenous. Traditionally, they have been heavily regulated by the government. Moreover, they rely on natural resources, making their activity dependent on (more or less) fixed resources. For the agriculture sector, it is also the case that the aggregation level in the data is regarded too crude to satisfactorily represent detailed input and output changes. Finally, though the industries in principle can be endogenized, the lack of experience with the sector-specific mechanisms and parameters in the model has led us to keep production and input levels as given in this analysis and look for abatement potentials of technological options from other sources. For more on the quantifications, see the next subsection.

The iteration process is performed in stages as follows:

(i) SNOW-NO is simulated given an exogenous emissions *cap* corresponding to the *abatement ambition level*.
(ii) The resulting MAC (GHG emissions price) indicates which of the externally mapped abatement options will be part of the cost-effective solution, i.e., are profitable if the relevant agents were subject to the simulated emissions price.
(iii) When including the externally mapped abatement options that are profitable given the *abatement ambition level*, the most expensive abatement options simulated at stage (i) will be crowded out. The given *cap* to be simulated is increased accordingly.

These stages are repeated until the abatement potentials of the profitable external measures and the gap between the emissions in the reference path and the emissions *cap* included in the model add up to the *abatement ambition level*.

Note that *non-convergence* can occur. An external abatement measure may become profitable at the GHG price in Stage (ii), however, when the cap is raised accordingly the emissions price falls below the cost of the marginal external abatement measure, which indicates that the measure should not be implemented. Taking it out, increases the emissions price again, etc. A solution is then obtained by including only part of the externally estimated abatement potential. Here, we assume the cost is increasing linearly from the minimum to the maximum potential and find the exact potential and cost that will ensure convergence.

Quantifying the external input

Detailed information about domestic measures available by 2035 and their abatement potential and costs are based on “bottom-up” analyses in the report by The Norwegian Environment Agency (2024). We need to be able to supplement the model simulations with relevant abatement potentials and costs.

Abatement potential

Abatement potentials are taken directly from The Norwegian Environment Agency’s report. If intervals are given, we allow for introducing the measures in two steps with differentiated costs. In other words, they can be regarded as two separate abatement measures. How the costs are differentiated is described below. In some cases, we use abatement potentials that lie in between the lower and upper level in the rapport. This occurs when the iteration process between the model results and the external information does not converge

Abatement costs

The information on costs by The Norwegian Environment Agency (2024) is in many respects difficult to transform into relevant model parameter estimates. They use the following cost definition:

$$\frac{Net\ present\ value\ of\ economic\ effects\ from\ base\ year\ until\ the\ end\ of\ measure}{Sum\ of\ total\ CO_2e\ abatement\ from\ base\ year\ until\ end\ of\ measure} \quad (6)$$

We make several rough approximations and rules of thumb in our transformation. First, the cost definition above can be interpreted as an average cost per abated CO_2e over the lifetime of the investment. This deviates from SNOW-NO's yearly abatement and cost impacts (see Section 2.1). Each measure has individual time profiles of investment and operating costs as well as of abatement impact, to which we do not have access. We interpret the cost per tonne of CO_2e as the annual cost, even if it is not overlapping with the annuity and will be heavily affected by the underlying time profile assumptions.

In the SNOW-NO model, the agents consider abatement by comparing costs of different input and output decisions. Abatement options that appear cheaper than the computed MAC will be realised. Thus, the most relevant concept when supplementing the simulations with external data from The Norwegian Environment Agency is the private costs. In cases where external estimates for private costs are missing from their report, we either use data from Fæhn et al. (2020) and Klimakur 2030 (2020), or use the social cost, but double it as a rule of thumb, since social costs tend to underestimate the private cost faced by the agents. The doubling can be interpreted as an add-on that represents (some of) the barriers to implementation that are discussed by The Norwegian Environment Agency (2024), as well as the uncertainty around the cost and abatement potentials.

Many of the abatement options have no cost estimates, neither social nor private, and no relevant additional information can be found in Klimakur 2030 (2020). These are left out of our analysis or, if the abatement potential is of significance, approximated by other comparable cost estimates.

Recall that some abatement potentials are given as intervals. Here, we treat the minimum potential as cheaper to realise than the maximum potential. As a rule of thumb, we double the cost from minimum to maximum implementation if no interval is given for the cost. In several cases, the iterations between the estimates for the external measures and the model results do not converge, and we need to interpolate (linearly) to find a point in between the min and max solutions. The subsequent subsections quantify the three types **(a)** – **(c)** of external abatement measures.

(a) Abatement (and removal) options involving CCS

The SNOW-NO model lacks the option to simulate carbon capture from stationary combustion and industrial processes. We have implemented the estimates for CCS abatement in the waste and manufacturing industries producing metals, minerals, pulp and paper, refined oils and chemical products. CCS is either used to abate fossil-fuel-originated CO_2 (CCS-FF) or to abate bio-originated CO2 (BECCS). We include both types as measures in the analysis, though BECCS is not internationally approved or regulated yet.

The manufacturing industries with CCS potentials are all part of the ETS sector, whereas the Waste industry is part of the ESR sector. Finally, we have also considered direct air capture and storage (DACCS) as an option. For DACCS it also applies that international approval and regulation are yet not in place. Table 2.1 sums up our input for CCS costs and the related potentials.[4]

[4] Recall that the final numbers might deviate if iterations do not converge with the stepwise data in Table 2.1 and 2.2.

Table 2.1 Associated emission price minimums and abatement potentials for CCS-related options

	Lower emission price (NOK/tCO_2)	Upper emission price (NOK/tCO_2)	Lower abatement potential (metric tCO_2)	Upper abatement potential (metric tCO_2)
FF-CCS				
NFM and I_S	3,000	6,000	852,500	1,303,000
NMM	3,000	6,000	540,000	690,000
OIL	4,840	5,000	958,320	990,000
Waste*	3,000	-	488,925	-
BECCS				
NFM and I_S	3,000	6,000	772,500	1,007,000
PPP	3,000	-	300,000	-
Waste*	3,000	-	536,075	-
DACCS				
DACCS	6,500	13,000	1,000,000	3,000,000

* ESR sectors

Definitions/abbreviations for interpreting Table 2.1:[5]

- FF-CCS is CCS of CO_2 from fossil fuels.
- BECCS is CCS of CO_2 from biofuels.
- DACCS is direct air capture and storage.
- Industry abbreviations (See also table A.1 in Appendix A):
  - NFM and I_S (Non-Ferrous Metals and Iron and Steel)
  - NMM (Non-Metal Minerals).
  - OIL (Refined oil and chemical products) .
  - PPP = Pulp and Paper Products.
  - Waste= waste handling and incineration.
- Waste = AVK+AVP in the industry list in table A.1 in Appendix A.

Starting from the left of Table 2.1, we go through the data for the industry NFM and I_S (combined): The abatement potential of CCS from fossil fuels will be 852,500 tonnes of CO_2 (tCO_2) if the MAC (emission price) is 3,000 NOK/tCO_2 or higher (in fixed 2022- prices), which is the minimum potential given in The Norwegian Environment Agency (2024). If the MAC increases above 6,000 NOK/tCO_2 the potential is estimated to reach its maximum of 1,303,000 tCO_2. Moving further to the right, we see that NFM also has potential for CCS of CO_2 from biofuels (BECCS), since there is substitution of bio for fossil fuels going on as part of the endogenous responses in SNOW-NO. Capturing and storing this CO_2 costs 3,000 NOK/tCO_2 up to a potential of 772,500 tCO_2. If the MAC reaches 6,000 NOK/tCO_2, the potential increases to 1,007,000 tCO_2.

Similar interpretations can be made for the other industries in Table 2.1, NMM, OIL, PPP, and Waste. Observe that we have not defined DACCS as ETS- nor ESR-related but as a separate category.

(b) Technological abatement solutions in Crude oil and gas (CRU)

Crude oil and gas is categorised as an ETS sector. We treat the industry as exogenous in the current SNOW-NO version, in the sense that the aggregate input and output volume, including the oil and gas resource, are inelastic and kept unchanged from the reference path. With this assumption, the predominant abatement mechanisms for industries in the SNOW-NO model are ruled out. Moreover, no specific abatement technologies are modelled in the industry.

The Norwegian Environment Agency (2024) concludes that there is principally one solution for abating CO_2 emissions in CRU by 2035: electrification of installations that currently are fueled by natural gas. Roughly 2 million tonnes of CO_2 (MtCO_2) can be abated by substituting electricity for current fossil-fueled combustion processes. Two energy options are possible, renewable or natural

[5] See also the SNOW documentation (Rosnes and Yonezawa, 2024).

gas. Renewable power will have to be produced on land and transferred to the offshore installations by grids and cables. Gas-powered plants can be located offshore but require CCS. Both solutions will need similar investments to electrify installations. The Norwegian Environment Agency (2024) assesses the private costs of the renewable solution to lie in the interval 2,000 – 6,000 NOK/tCO_2e. If natural gas is chosen as the energy source instead of renewable energy from land, CCS will have to remove the carbon emissions. This would add substantially to the cost.

In our simulations we assume a minimum potential of 0.5 MtCO_2 will be abated in 2035 with renewable power from land if the emissions price in 2035 reaches 3 000 NOK/tCO_2e with a maximum potential of 2 MtCO_2 if it exceeds 6,000 NOK/tCO_2e. We exclude the CCS option, as it will always be less cost- effective than the renewable option.

A couple of measures for reducing methane is also described by The Norwegian Environment Agency, but a large part of the potential is already included in the Reference path. Partly, this is explained by the Methane Regulation of the EU that came in force as a result of an agreement in the COP26 negotiations in Glasgow and that is expected to bind Norway. Thus, we disregard (further) abatement of methane in CRU as an option.

(c) Technological abatement solutions in Agriculture (AGR)

GHG emissions in Agriculture (AGR) come from fossil energy use and industry processes. The former is linked to the input volumes of oil, gas and coal products, while the latter is linked directly to the output volume. Process emissions dominate in SNOW-NO's AGR sector. They consist mainly of emissions of CH_4 from animal husbandry and N_2O from the use of fertilizers.

We treat the agriculture industry as exogenous in the current analysis by fixing the aggregate input and output volumes. Similar to CRU, holding input and output fixed imply that the abatement mechanisms for industries in the SNOW-NO model are ruled out.

In contrast to the assumption of fixed inputs and outputs, The Norwegian Environment Agency (2024) presents a detailed overview of measures that could potentially reduce GHG emissions in the agriculture sector. To complement the SNOW-NO model results, we make use of their information on private costs, social costs, barriers, uncertainty evaluations and abatement potentials on the relevant measures. Table 2.2 reports the quantifications made to account for abatement in AGR in our analysis. Note that the AGR industry in SNOW-NO does not overlap completely with the definition of Agriculture in The Norwegian Environment Agency (2024), as indicated with *J* in their list of measures. Those relevant for AGR in the model are included in Table 2.2. below.

Table 2.2 External information on measures in Agriculture; abatement and costs; 2035

	Potential abatement (MtCO_2e)		Cost per tCO_2e in SNOW_NO (2022-NOK)		Measure cost (mill. 2022-NOK)	
	Lower	Upper	Lower	Upper	Lower	Upper
Transition from red meat to plant-based diet and fish (J01)	1.366	2.258	1,000	2,000	1,366	4,516
Reduced food waste (J02)	0.213	0.349	1,000	2,000	213	698
Livestock manure for biogas (J03)	0.063	0.063	2,000	2,000	126	126
Fertilizer measure storage and distribution (J04-1)	0.004	0.004	2,000	2,000	8	8
Fertilizer measure timing and storage (J04-2 and 3)	0.042	0.042	6,000	6,000	252	252
Stop in new cultivation of marshes (J05)	0.008	0.008	2,000	2,000	16	16
Agriculture machines and vehicles are electric (T27)	0.043	0.076	5,000	>10,000	215	760
Sum	1.739	2.799			2,196	6,376

The lower and upper estimates of the abatement potentials in Table 2.2 are taken directly from The Norwegian Environment Agency (2024). For J05 there is no information on the abatement interval. For J03 to J04-3 we have excluded the upper potential, since these are conditioned on J01 and/or J02 not being realised (The Norwegian Environment Agency, 2024). We regard this situation as less likely, since J01 and J02 are among the least costly measures.

The cost estimates are based on a combination of information and on rules of thumb, quite similar to the approximations made for CCS. That is, if an interval is given for social cost, we have chosen the upper cost estimate. To arrive at private costs, we multiplied with two. The general reason is that several barriers and uncertainty evaluations are not reflected in the estimates. For the upper potential to be realised, another doubling of cost is assumed. For T27 there is no information on the costs. Hence, we have relied on the social cost information for T28 (Other mobile machines), adjusted to arrive at private cost estimates. Note that we also take into account information that suggests particularly high cost for large abatement of T27, due to relatively low demand (small industry) and need for highly specialised machines in Agriculture (The Norwegian Environment Agency, 2024).

Even if our cost approximations fall well above those indicated in The Norwegian Environment Agency (2024), the costs of relevant measures are mostly much lower than the simulated GHG price (after iterations) in all the scenarios. The main exceptions are J04-2 and -3 that will be excluded in all the scenarios, except Scenario 5 (80 per cent reduction in Policy ii) – see Table 3.2). T27 will only be included in Scenario 3 (65 per cent reduction in Policy i) and Scenario 5, but the upper potential will never be realised.

As explained in Section 2.2, depending on the emissions target and the GHG emissions price it leads to, we include the relevant measures from The Norwegian Environment Agency (2024). If we wish to approximate the total abatement costs, the contribution of the externally collected abatement measures must be added to the simulated abatement cost. For AGR, these are calculated in the two last columns of Table 2.2 and amount to between 2.196 and 5.831 billion NOK in 2035 (and not 6.376 billion NOK since the upper cost of T27 is never realised.)

3. Phase 1: Abatement and marginal abatement costs

3.1. Analytical design

Table 3.1 lists the five scenarios and describes how they are set up. The purpose of Phase 1 is to generate MAC curves for different scenarios that vary in ambition levels and policy structures for a 2035 GHG emission target. To isolate the impact of climate policy on abatement costs, we start by modelling the recycling of emission price revenue as a lump-sum transfer from the government to the household sector.

A MAC curve is obtained by simulating different GHG targets for 2035 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. In the same fashion, MAC curves can be generated for parts of the economy, e.g., for the Norwegian industries covered by the ESR sector, by the ETS sector or for single industries.[6] All measures implemented for a given target have a private cost equal to or below this MAC; only the most expensive implemented ones reach the MAC level.

Policy i) Domestic abatement

In the first phase, five scenarios are simulated that combine ambition levels and target structures according to Table 3.1.

Table 3.1 Target levels and target structures of the five simulated scenarios for 2035[7]

Scenario #	Target structure/ Target level	**Whole economy** % relative to 1990	**ETS sector** % relative to 2005	**ESR sector** % relative to 2005
1	Policy i)	-55%	(endo)	(endo)
2	Policy i)	-60%	(endo)	(endo)
3	Policy i)	-65%	(endo)	(endo)
4	Policy ii)	-65%	-80%	(endo)
5	Policy ii)	-80%	-80%	(endo)

Scenarios 1-3 have a target structure called Policy i). The premise here is that Norway is obliged to meet a 2035 emissions target for the whole economy by domestic abatement, only, removing the option of purchasing emission allowances. It is assumed that Norway pursues a cost-effective abatement policy. We implement this by introducing a uniform emission price for all the covered GHG emission sources, which replaces the current GHG tax system (of 2022). The three Policy i)-scenarios differ in terms of the ambition level of the targets. The first assumes a 55 per cent cut in the domestic emissions from the 1990-level, the second a 60 per cent cut and the third a 65 per cent cut. The uniform GHG emissions price across all sources endogenously determines the resulting emissions pattern. Changes in the ETS and ESR sectors' emissions, as well as the internal allocation within each of the sectors are, thus, endogenous. The results in scenarios 1-3 are measured as changes from the *reference path* – see below. These three scenarios form the basis for constructing a MAC curve for the whole economy pursuing a domestic abatement strategy.

Policy ii) Combining domestic abatement with allowance trading

Scenarios 4 and 5 assume Policy ii), which is characterised by accepting international allowance trading as an abatement strategy. In particular, it is assumed that the projected EU ETS allowance price in 2035 forms a MAC for the ETS-covered sources. Domestic abatement options with costs

[6] For the correspondence between ETS and ESR sector and the SNOW industries, see Appendix A. Observe that the analysis does not cover commitments in the agreement with the EU in the Land Use, Land Use Change and Forest (LULUCF) sector.
[7] (endo) indicates that the emissions reductions are endogenous. See Table 3.3 and Table 3.4 for the endogenous emissions reductions (in $MtCO_2e$) resulting from the simulations.

below the EU ETS price will then be implemented. Note that we also expect the current (2022) carbon tax imposed on the Crude oil and gas industry to stay at current level.

The EU policy towards 2035 includes a gradual tightening of the EU ETS emissions cap according to a reduction factor. In 2035 the cap is equivalent to an 80 per cent reduction in ETS emissions from the 2005 level. Including Norway in the ETS market is assumed to increase the total cap correspondingly, i.e., with 80 per cent of Norway's 2005 emissions. In other words, Norwegian ETS-covered firms will need to abate emissions by 80 per cent from the ETS sector's 2005 level either by domestic measures or by purchasing ETS allowances. In these calculations, we disregard the current flexibility in the EU policies. In accordance with current EU rules, it is assumed that buying other international carbon credits is not an option. Moreover, even if purchasing ESR allocations in other European countries is a theoretical option, as is over-fulfilling the ETS commitment in lieu of ESR abatement to some extent, we exclude these options. Consequently, for a given overall target for the economy by 2035, the ESR target will follow residually, as we assume that the targets in the ETS and ESR sectors together corresponds to the NDC.

The ESR target will have to be met by domestic measures. We seek the cost-effective solution in this sector, by applying a uniform ESR emissions price covering the whole ESR sector. We study two different targets for the whole economy, corresponding to a 65 per cent and an 80 per cent reduction target from 2005 for the whole economy. Scenario 5 is simulated to mimic a version of The Norwegian Environment Agency (2023) specified by an 80 per cent cut in emissions from 1990, where 60 of the percentage points result from domestic abatement. Scenario 5 in our analysis meets the 80 per cent total emission reduction from 1990. However, the mix between abatement domestically and abroad, will be endogenous. Based on these two scenarios, we construct a MAC curve for the ESR sector.

The reference path

In addition to the five policy scenarios, we also simulate a reference path for our analysis where climate policies are fixed at the current level. It is taken from the economic and emissions projection in the National Budget for 2023. Thus, the current policy level means the 2022 level. The projection is calibrated using the latest version of the model, with base year 2018. The projection reproduces main economy and emission trends from 2018 to 2022 and a development post-2022 with key building blocks being external estimates on the demographic development of Norway, international market prices, including the EU ETS price, sector- and factor-specific productivity growth rates, and expected emission coefficients. Productivity growth rates and emission coefficients are adjusted to represent the technological developments.

For a more thorough description of the projection and the policy assumptions, cf. Ministry of Finance (2023). Note that the ETS allowance price is determined by markets abroad, not a result of Norwegian policies. Therefore, it is increased along the reference path in line with expected developments in the EU ETS, including a tightening of the reduction factor.

In Policy ii) we keep all the carbon prices in the ETS sector (the GHG taxes and the EU ETS price) unchanged from the reference path. As a consequence, we cannot expect large changes in the ETS-covered emissions from the reference path. However, it is interesting to compare the outcome in the ETS sector to those in the Policy i) scenarios, in particular holding scenario 4 against scenario 3, where the targets for the whole economy are similar, but the role of allowance trading is different.

3.2. Results

Policy i) Domestic solution

Table 3.2 shows which and how much of all the external abatement options will contribute to the simulations results, after iteration. The three first columns represent the Policy i*)* scenarios with 55 per cent, 60 per cent and 65 per cent reductions in GHG emissions from 1990, respectively. The "GHG prices" given in Table 3.2 are the simulated *GHG emissions* prices.

Table 3.2 Final implementation of the external abatement measures ($MtCO_2e$ from the reference path)

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
GHG Price	2018 prices	kr 3,620	kr 4,490	kr 5,100	kr 2,520	kr 10,540
	2022 prices	kr 4,000	kr 5,080	kr 5,950	kr 2,855	kr 12,302
FF-CCS (Mt CO2)	NFM + I_S	0.9	0.9	1.3		
	NMM	0.5	0.5	0.7		
	OIL		1.0	1.0		
	PPP					
	ESR:					
	(AVK og AVP)	0.5	0.5	0.5	0.5	0.5
BECCS (Mt CO2)	NFM + I_S	0.8	0.8	1.0		
	NMM					
	OIL					
	PPP	0.3	0.3	0.3		
	ESR:					
	(AVK og AVP)	0.5	0.5	0.5	0.5	0.5
DACCS						
						2.8
Electrification	CRU					
		0.50	1.00	1.75		
J01		2.26	2.26	2.26	2.26	2.26
J02		0.35	0.35	0.35	0.35	0.35
J03		0.06	0.06	0.06	0.06	0.06
J04-1		0.004	0.004	0.004	0.004	0.004
J04-2						0.02
J04-3						0.02
J05		0.01	0.01	0.01	0.01	0.01
J06	AGR					
J07						
J08						
J09						
J10						
J11						
J12						
T27				0.05		0.07
SUM	**ETS**	3.0	4.5	6.0	0.0	0.0
	ESR	3.7	3.7	3.8	3.7	3.8
	DACCS	0.0	0.0	0.0	0.0	2.8
	Totalt:	6.7	8.2	9.8	3.7	6.6

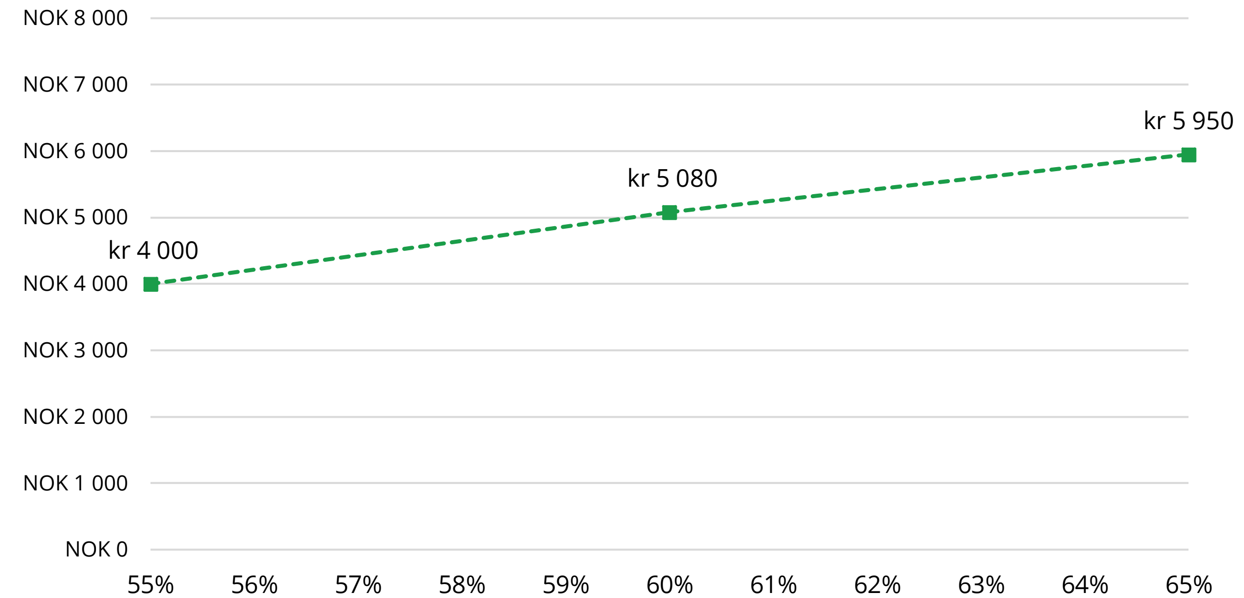
In Policy i*)*, the GHG emissions price is imposed on all emissions in both the ETS and the ESR sector. Measured in 2022-prices, the GHG emissions price increases from NOK 4,000 to NOK 5,950 per tCO_2e along with raising the ambition level of the domestic target from Scenario 1, via Scenario 2, to Scenario 3. The resulting ETS and ESR abatement that the external measures contribute with are given in the SUM rows at the bottom of Table 3.2. In total, between 6.7 and 9.8 $MtCO_2e$ of the necessary reductions originate from the externally collected information. Observe also that DACCS will not be implemented in any of the Policy i) scenarios due to its high cost. The external abatement included in the Policy i) scenarios are allocated on the ETS and ESR sector as reported in Table 3.3. The table shows the deviations from the reference path.

Table 3.3 Abatement contributions in the Policy i)-scenarios (tCO_2e from the reference path)

	Scenario 1 -55% TOTAL	Scenario 2 -60% TOTAL	Scenario 3 -65% TOTAL
External abatement options ESR	- 3,710,000	- 3,710,000	- 3,750,000
External abatement options ETS	- 2,970,000	- 4,470,000	- 6,010,000
External removal DACCS	..	..	..
Endogenous abatement ESR	- 3,540,000	- 4,160,000	- 4,720,000
Endogenous abatement ETS	- 2,220,000	- 2,660,000	- 3,090,000
Total domestic Abatement	**- 12,440,000**	**- 15,000,000**	**- 17,570,000**

The resulting MAC curve for the Policy i) target structure, which assumes a joint target for total domestic emissions, is shown in Figure 3.1. The figure shows the prices in NOK/tCO_2e on the vertical axis and the per cent abatement target in Policy i) on the horizontal axis.

Figure 3.1 Marginal Abatement Cost (MAC) curve in Policy i), in 2022-prices, per tCO_2e



Policy ii) Mixing domestic abatement with EU ETS allowance trading

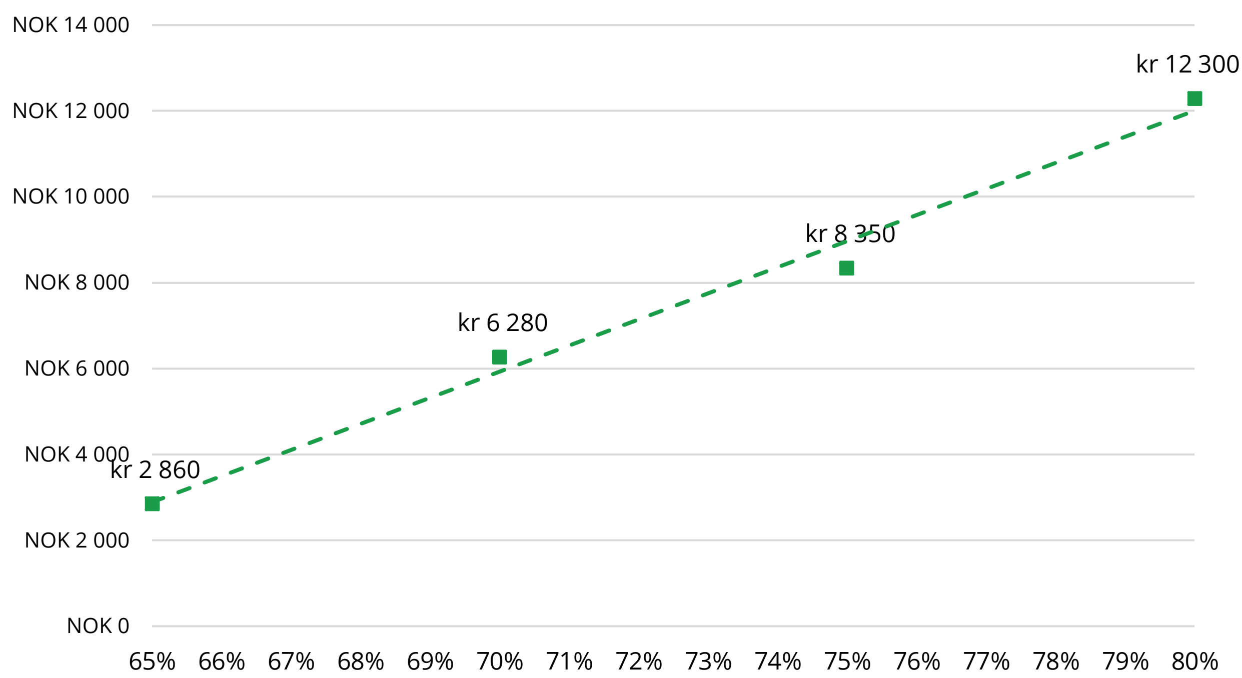
In Table 3.2, the last two columns present Scenarios 4 and 5, i.e., the two Policy ii)-scenarios. In these scenarios, the ETS sector is assumed to face exogenous emissions prices, including the EU ETS price as well as the 2022 tax level on emissions in the CRU industry. These policies also apply in the reference path. Thus, little beyond the reference path takes place in the ETS sector in these scenarios. We see from Table 3.4, however, some indirect impacts on the ETS sector resulting from the changes in the ESR sector. The ESR abatement taking place is due to responses to the endogenous GHG emissions price, which is imposed on all emissions in the ESR sector. Note that DACCS removal is priced at this level, too, implying that DACCS will be implemented if the emissions price rises to or above the cost of the DACCS measures. The emissions price in the ESR sector reaches NOK 2,860 and NOK 12,300 per tCO_2e in the 65 per cent and 80 per cent abatement cases, respectively. In the latter, the cost level of DACCS removal per tonne is substantially exceeded, and almost the full potential of DACCS is assumed to be incentivised. This increases the contribution of the external abatement options from 3.7 Mt to 6.6 Mt; see Table 3.2.

Table 3.4 Abatement contributions in *the Policy ii)*-scenarios (tCO_2e from the reference path)

	Scenario 4 -65% TOTAL	Scenario 5 -80% TOTAL
External abatement options ESR	- 3,710,000	- 3,820,000
External abatement options ETS	..	..
External removal DACCS	..	- 2,790,000
Endogenous abatement ESR	- 2,200,000	- 7,060,000
Endogenous abatement ETS	- 140,000	- 580,000
Total domestic Abatement	**- 6,050,000**	**- 14,250,000**

The total endogenous and external contributions in the Policy ii)-scenarios in 2035 are shown in table 3.4, measured in terms of deviations from the reference path emissions. The resulting MAC curve for the ESR sector in Policy ii) is shown in Figure 3.2 below, in the case that linearity is assumed.[8]

Figure 3.2 Marginal Abatement Cost (MAC) curve in Policy ii) in 2022-prices, per tCO_2e



With the Policy ii)-structure, the fulfilment is made with a mixture of EU ETS allowance purchases and domestic abatement in the ETS sector, while the ESR target is fulfilled domestically only. As mentioned above, it is allowed for DACCS removal as an option, too.

The purchases of allowances amount to 11.6 Mt in 2035 in Scenario 4. In Scenario 5, the allowance purchases necessary to fulfil the ETS target will be lower than in Scenario 4, amounting to 8.2 Mt. The main explanation for this reduction is that DACCS becomes a cost-effective option given the simulated emissions price. Also, domestic ETS abatement increases somewhat.

Recall from Section 3.1 that a motivation for simulating Scenario 5 is that an 80 per cent reduction from Norway's emissions level in 1990 by 2035 is suggested by The Norwegian Environment Agency as a new NDC. The mix of domestic abatement and allowance purchases in our Scenario 5-simulations is endogenously determined. It turns out that 1/3 of the 80 per cent target, or 26 percentage points, are met by allowance purchases while 2/3, or 54 percentage points, are met by

[8] We can learn more about the slope by simulating more of the targets between Scenario 4 and 5.

domestic measures. The Norwegian Environment Agency 's suggestion is to abate 60 percentage points domestically. Our results show that even if DACCS is allowed for, and implemented, 60 percentage points of the abatement domestically are not obtained. If we exclude the DACCS option and rather choose to buy more allowances, the domestic share of the abatement would be even smaller and constitute but 35 percentage points, while allowance purchases would make up the residual 45 percentage points. This solution would turn out much cheaper.

A more detailed comparison of exploiting ETS purchases or not.

Since Scenarios 3 and 4 have the same ambition level for abatement but are distinguished by their target structure, it can be interesting to compare them more thoroughly. In Scenario 3, the abatement will be cost-effectively allocated between domestic ESR and ETS measures. In Scenario 4, ETS and ESR sectors have separate abatement targets. Still, ESR abatement is assumed to take place domestically. The ETS target will be met by a cost-effective allocation between domestic abatement and allowance purchases in the EU ETS.

From Tables 3.3 and 3.4 it follows that the abatement allocations are as in Table 3.5:

Table 3.5 65% cut in 2035 emissions from 1990 in the Policy i) and Policy ii) cases, tCO_2e

	Policy i): 65% cut (Scenario 3)	Policy ii): 65% cut (Scenario 4)
ESR abatement	- 8,470,000	- 5,910,000
ETS abatement	- 9,100,000	- 140,000
Allowance purchases	..	- 11,390,000
Total domestic Abatement	**- 17,570,000**	**- 17,570,000**

Interestingly, the two scenarios, 3 and 4, have resemblances with the two alternative strategies the Norwegian government can choose for its 2030 climate policies: Scenario 3 can illustrate a solution corresponding to the so-called *Transformation ambition* of the government.[9] This ambition is to fulfil the total domestic abatement commitment domestically. Scenario 3 is an illustration of how a similar transformation ambition for 2035 can be implemented in the most cost-effective way.

The second strategy the government can choose is to fulfil its commitments in the collaboration with the EU in the most cost-effective way. In the current agreement with the EU Norway will have to meet separate, given targets for the ESR and the ETS sector towards 2030. The lion's share of the ESR commitment will most probably have to be fulfilled domestically since, in practice, not much flexibility is available.[10] The ETS target is, however, subject to the flexibility represented by the EU ETS market. A mixed solution, like the one modelled in Scenario 4, will be the cost-effective solution.

One question that has come up in the 2030 case is that the cost-effective transformation solution can turn out to under-fulfil the ESR commitment. We can observe from Table 3.5 that this does not seem to be the case, if we assume that Scenario 4 represents the ESR and ETS commitments in a future continuation of the EU collaboration. The commitment in ESR calls for an abatement, primarily domestically, of at least 5.91 $MtCO_2e$ from the Reference path. Fulfilling the 65 per cent reduction commitment completely by domestic measures would reduce ESR emissions significantly more, by 8.47 $MtCO_2e$, and the ESR commitment would be more than fulfilled.

It is interesting to observe that the abatement is quite similarly allocated between the ESR and ETS sector in Scenario 3 – 8.47 $MtCO_2e$ and 9.10 $MtCO_2e$ as compared to the reference path in 2035, respectively. We can delve deeper into the composition by studying Figures 3.3. and 3.4, which present the two scenarios' volume change (_*vol*) and the technology change (_*tech*) for each

[9] https://www.hurdalsplattformen
[10] For an overview of existing flexibility mechanisms, confer the Fit-for-55 regulations.

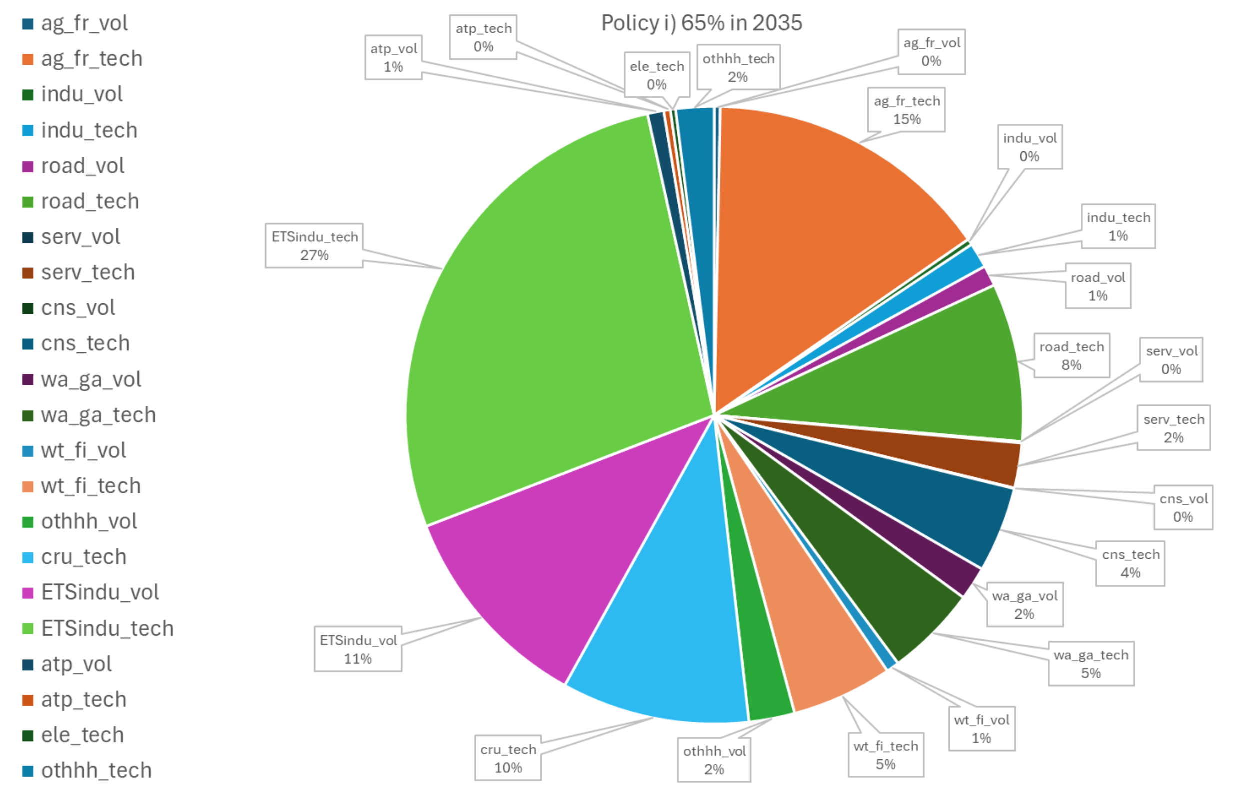
industry.[11] The split between volume change and technology change is done in order to identify the industries' abatement responses of two principally different types. Volume changes are driven by downscaling of output volumes *for a given technology* (_*vol*), while technology changes reflect changes in production technologies that reduce emissions *per unit of output* from the corresponding sector (_*tech*). We do this by the following decomposition:

(7) $$GHG\ emissions\ =\ Output\ \times\ \frac{GHG\ emissions}{Output}.$$

Here, the changes in the first term ($Output$) reflect GHG emission change in each industry caused by changes in its output volume, while changes in the second term ($\frac{GHG\ emissions}{Output}$) explains the residual emission changes. Thus, 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 emissions-emitting input factors such as fossil energy. The industries' emissions abatement mainly consists of a combination of both these types of responses. However, significantly more of the abatement takes the form of technological adaptations, though this inclination is less pronounced in the ETS sector. This is associated with more exposed positions of the ETS-covered industries to international competition and only minor power to affect prices.

As can be seen from Figure 3.3, the four sectors that account for over 70 per cent of the total abatement measures in Scenario 3 are: Crude oil and gas (*cru*), private and commercial road transport (*road*), Agriculture and Forestry (*ag_fr*) and ETS manufacturing industries (*ets_indu*).

Figure 3.3 GHG emissions reduction contribution by each sector in Scenario 3, split between volume(_*vol*) and technology (_*tech*) changes in policy i), in 2035

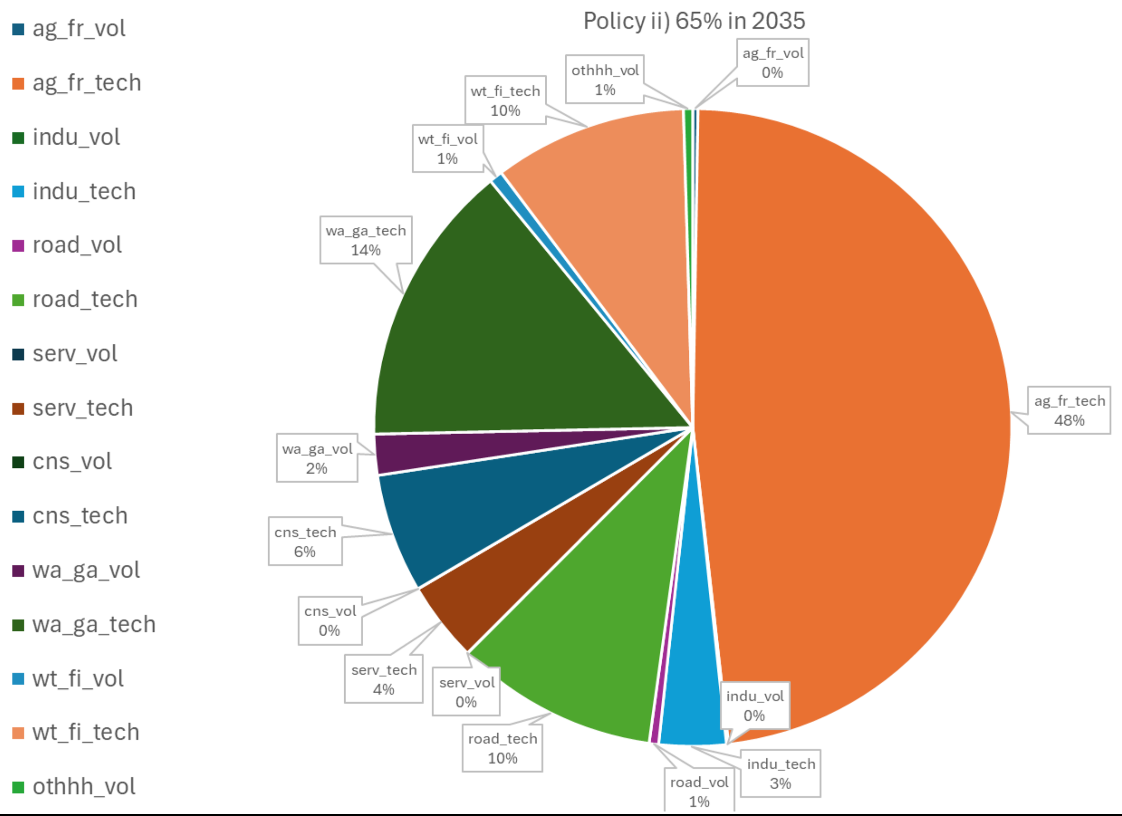


See Table A.1 in Appendix A for overview of aggregated sectors and abbreviations.

[11] For the list of industries, see table A.1 in Appendix A.

In scenario 4, the emissions price is only imposed in the ESR sector and almost the entire impact naturally occurs in this sector. Specifically, as can be seen from Figure 3.4, the industries Waste and District heating (*wa_ga*), Private and Commercial road transport (*road*), Agriculture and Forestry (*ag_fr*) and Water transport and Fishery (wt_*fi*) account for over 85 per cent of the ESR abatement measures.

Figure 3.4 GHG emissions reduction contribution by each sector in Scenario 4. Split between volume(*_vol*) and technology (*_tech*) changes in Policy ii), in 2035



* See Table A.1 in Appendix A for overview of aggregated sectors and abbreviations.

Almost no impact on emissions is observed in the ETS sector compared to the reference path, because the EU ETS price, as well as the CO_2 tax in CRU, are unchanged. The total abatement contribution by ESR of 5.91 $MtCO_2e$ in 2035, compared with the reference path, is 2.56 $MtCO_2e$ less than in Scenario 3. This indicates that not only the ETS sector, but also the ESR sector, benefits when the flexibility offered by the EU ETS market is exploited. Note that the total “pie chart” in Figure 3.4. does not include the allowance purchases, which dominate the abatement in Scenario 4; see Table 3.6.

4. Phase 2: Analysis of a selected scenario

4.1. Analytical design

In the second phase, the task has been to investigate sectoral and macroeconomic implications of *one* of the scenarios simulated in Phase 1, selected by The Ministry of Climate and Environment. The selected scenario is Scenario 2, i.e., the case of having a 60 per cent lower target for the whole economy compared to 1990 that is to be met by domestic abatement. This means that the EU Emissions Trading System (EU ETS) is not fully exploited. We look at two different recycling alternatives for Scenario 2: Scenario 2A treats revenue as a lump-sum transfer as in Phase 1, while in Scenario 2B the revenue is used to simultaneously reduce labour taxation. Section 4.2 reports from these two versions (A and B) of Scenario 2.

4.2. Results

Macroeconomic impacts

Table 4.1 lists changes in selected macroeconomic indicators in 2035. If not given otherwise, the numbers reflect changes from the reference scenario.

Table 4.1 Macroeconomic impact, changes from the reference path, 2035

	Unit	Scenario 2A	Scenario 2B
Private abatement cost*	NOK bn.	45	45
Social cost**	per cent	2.0	0.9
Simulated part	per cent	1.3	0.1
External part	per cent	0.7	0.7
Private consumption**	per cent	-2.9	0,0
Simulated part	per cent	-1.9	1.0
External part	per cent	-0.9	-0.9
Leisure	per cent	0.3	-2.7
GDP	Per cent	-0.9	0.7
Employment/ labour supply	per cent	-0.2	1.9
Ad val. labour income tax	per cent	0.0	-22.7
(Pre-tax) Real wage rate	per cent	-2.2	-3.7
Transfers to household	per cent	5.1	-8.7
Marginal abatement cost, in 2022 (NOK)*	NOK/tCO_2e	5,080	5,300
ESR emissions	MtCO_2e	-7.9	-7.9
ETS emissions	MtCO_2e	-7.1	-7.1

* Level, not change.
**Adjusted by the cost of external abatement.

In Scenario 2A, where GHG emissions are capped at 60 per cent of the 1990 level and the revenue from obtaining this by uniform emissions pricing is transferred to the households as a lump-sum, the emission price – or MAC – renders 5,080 NOK/tCO_2e. The resulting private abatement cost is estimated to be 45 billion NOK. This abatement cost is, as explained in Sections 2.1, a mixture of the cost of simulated abatement and of external abatement based on information from The Norwegian Environment Agency (2023; 2024) and Klimakur 2030 (2020); see Equation 2. The social abatement cost normally deviates from the private abatement cost, as it captures several indirect impacts of introducing abatement policies. The social cost is defined as the simulated drop in the representative household's utility added by the cost of the external private abatement cost; see Section 2.1. The former amounts to a utility loss of 1.3 per cent relative to the reference path, while the latter corresponds to a utility loss of 0.7 per cent, resulting in a 2.0 per cent utility drop all together. The private abatement cost explains 70 per cent of the social abatement cost, indicating that there are other reallocations taking place that all in all reduce utility and can explain the remaining 40 per cent loss. We will come back to the driving forces behind the drop in utility below.

The simulated utility of the representative household consists of contributions from consumption, showing a simulated drop of 1.9 per cent, and leisure, which increases slightly, by 0.3 per cent. These changes mirror the drop in the real wage rate that makes working relatively less attractive. Note that these activity changes of the household miss the impact of the external abatement costs. If we assume that the external abatement cost influences private consumption only, not leisure, its drop would have amounted to 2.9 per cent. This adjusted private consumption decrease can also be seen in Table 4.1. Recall that the *ex- post*-adjusted utility loss and private consumption that account for the external abatement cost, are approximations that do not allow for market interactions. This represents an inconsistency with the model framework that is difficult to assess quantitatively.

As labour supply is discouraged, GDP falls by 0.9 per cent from the reference path in 2035, which is roughly equivalent to one year of economic growth in the reference scenario.

In Scenario 2B, where revenue recycling is achieved by reducing the labour income tax, the macroeconomic outcomes are influenced significantly. The ad valorem labour income tax decreases by 22.7 per cent. This reduction initially leads to a decrease in pre-tax real wages, though smaller than in the lump-sum scenario. The post-tax real wage increases due to the tax decrease. This incentivises labour supply, which in turn stimulates the economy by enabling a more efficient allocation of resources. Consequently, the previously observed reduction in GDP in Scenario 2A relative to the reference path shifts to an increase of 0.7 percent in Scenario 2B.

Along with GDP, the simulated consumption also increases, though when adjusting for the external abatement cost, the increase is virtually eliminated. The social cost is nearly bisected as compared to Scenario 2A, which is explained by significant offsetting of the social abatement cost by social gains from a stimulated labour supply. The emissions cap becomes more challenging to fulfil when the economic activity is higher, and this is reflected in a modest increase of the marginal abatement cost. However, as reflected in Table 4.1, the impact on the private abatement cost is insignificant as compared to Scenario 2A. A more detailed decomposition of the social cost is scrutinized below.

Industry-specific impacts

The macroeconomic effects presented in Table 4.1 can be further analysed through the sector-specific results in Tables 4.2.

Table 4.2 Industry specific impacts, GHG emissions and Activity volume per sector, 2035, percentage change relative to REF*

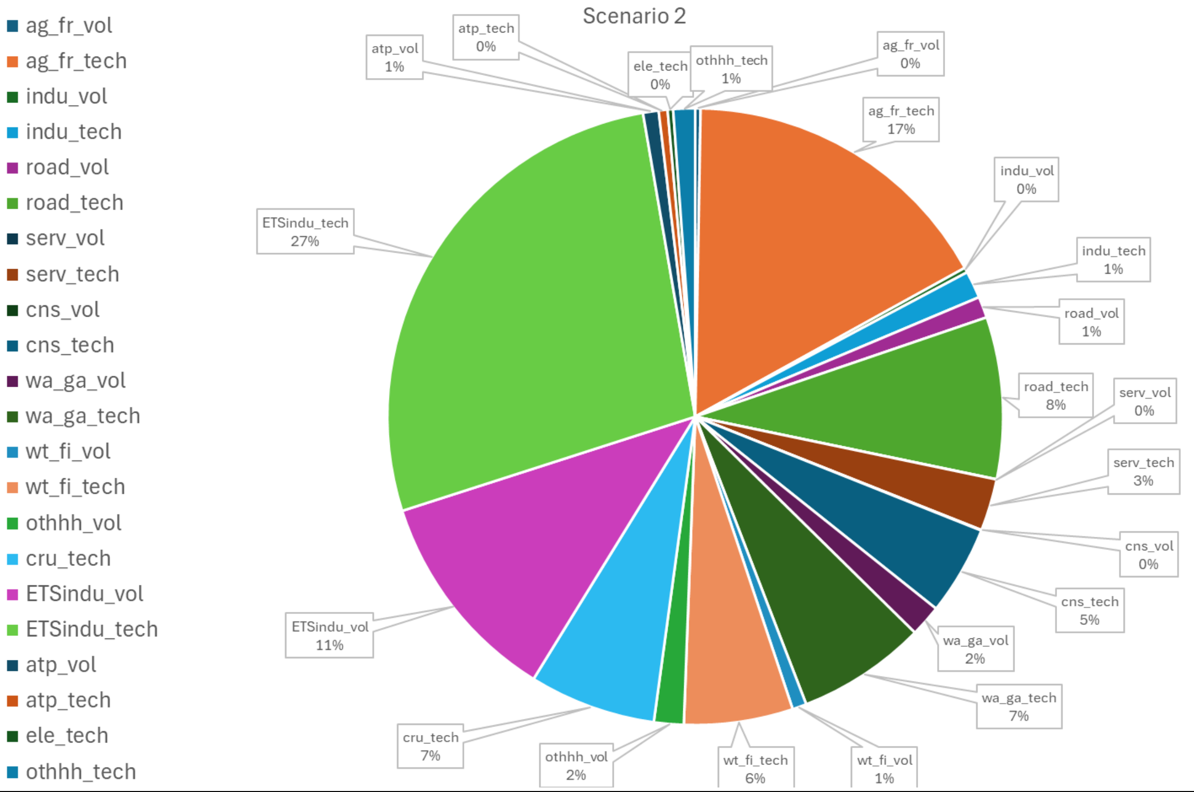
	GHG emissions		Activity volume	
	Scenario 2A	Scenario 2A	Scenario 2A	Scenario 2A
Agriculture and Forestry	-50.6	-50.6	-0.8	-0.7
Construction	-35.6	-37.0	-0.2	-0.1
Industry (non-ETS)	-16.1	-15.5	-4.2	-3.1
Other household consumption	-37.1	-35.4	-4.3	-1.5
Road transport	-29.7	-30.7	-4,9	-3.1
Services	-26.6	-25.7	-0.4	1.2
Waste and district heating	-75.0	-74.2	-8.1	-6.6
Water transport and fishing	-52.8	-53.0	-6,1	-4,2
ETS sectors	**-40.9**	**-41.0**	**-6.8**	**-6.6**
Manufacturing ETS	-66.7	-67.0	-19.7	-19.4
Crude oil and gas	-13.7	-13.7	0.0	0.0
Air transport	-19.2	-18.6	-12.7	-10.7
Electricity	-12.0	-13.1	0.0	0.0

* See overview of the aggregated sectors in Appendix A, Table A.1.

While there is a significant reduction in production activity across all sectors, except for the Services industry in scenario 2B, this change is less pronounced when the labour income tax is reduced. The unchanged activity level in Electricity, Crude oil and gas, and Agriculture is due to these resource specific sectors being exogeneous (see Section 2). Thus, the 0.8 and 0.7 per cent activity reduction in Agriculture and Forestry is caused by the activity changed in Forestry. Moreover, in these sectors (except for electricity) the external technology measures is the driver for the GHG emission reduction.

In Figure 4.1, we disentangle the reduction contribution by technology and volume (see Section 3.2 for further explanation). Also here, it is visible that the while volume is unchanged for Crude oil and gas (*cru*) and Agriculture, the GHG emissions reduction is significant. Crude oil and gas, Agriculture and Forestry *(ag_fr)* contributes with 7 per cent and 17 per cent respectively in 2035, with *ag_fr*, *road* and Waste and District heating (*wa_ga*) being the main GHG emission reduction contributors in ESR sectors. Overall, the major driver for the GHG emissions reduction is still the ETS manufacturing industry (*ETSindu*) with a contribution of 38 per cent with 11 per cent of these being due to reduced activity. The technology contribution in *ETSindu* is mainly due to the external measures that represents the future technology possibility for the ETS sector. Whether we assume scenario 2A or 2B, the Figure in 4.3 remains the same.

Figure 4.1 GHG emissions reduction contribution by each sector in Scenario 2A and 2B, split between volume(*_vol*) and technology (*_tech*) changes in policy i), in 2035[12]



* See Table A.1 in Appendix A for overview of aggregated sectors and abbreviations.

[12] See sector abbreviation in Appendix A.

A decomposition of the utility impacts

In Scenario 2A, the only introduced policy interaction compared to the reference path is the national cap on emissions leading to an emission price level of 5,080 NOK/tCO_2e. As explained above, the social cost of this introduction exceeds the private abatement cost. By a utility decomposition procedure, some of the major indirect utility elements can be identified and quantitatively approximated. While the private abatement cost explains 70 per cent of the total social cost, it remains to explain another 30 per cent by other reallocations taking place in the economy. The reasons for generated losses and benefits of such reallocations are that there exist several price distortions already in the reference path, and the introduced emissions pricing interacts with these.[13] If there are distortive taxes and regulations that encourage any activity in the model, rise in this activity caused by the abatement policies will contribute to reinforce the distortion and the social cost; see Section 2.1.

By going through the Reference path, we have identified two price wedges of some size in 2035: in the labour market and in the choice of private cars, respectively. The first originates from a considerable taxation of labour, both payroll and other taxation at the firm level and income taxation and consumption taxes (primarily the VAT tax) at the household level. These taxes affect the equilibrium in the labour market in several ways. In total we see a discouragement of labour supply and employment. When the abatement policies are introduced, the labour supply is further discouraged, resulting in a reinforced social cost. This interplay between existing labour taxation and introduced abatement policies explains 20 per cent of the social cost in Scenario 2A relative to the reference path in 2035. Another 10 per cent of the social cost is due to various electric vehicle incentives, both fiscal and non-fiscal. Since some of the fiscal treatment of electric and fossil-fuel-driven cars has been harmonised during the recent years, non-fiscal distortions dominate. Besides local advantages and priorities lent to electric vehicles, part of the background is that a price wedge is calibrated in the reference path to obtain policy-decisions on shares of zero-emission vehicles and machines in the years to come. These instruments are not specified; they can represent support, investments, rights or regulations. They are assumed to remain in the abatement policy scenarios.

The three calculated contributions to social costs in Scenario 2A above approximately explain the total, suggesting that the remaining indirect gains and losses generated by the climate policies more or less offset each other.

In Scenario 2B, the social cost is nearly bisected as compared to Scenario 2A. The reason is a considerable social gain from cutting the wage income tax that stimulates labour supply. In addition to the direct, rather small, gain due to the lower income tax rate, this reallocation of labour supply for leisure reduces the efficiency distortions of the other, tax rates on labour, which are still in place. In addition, the socially costly transport market distortions still prevail

[13] In practice, the price distortions consist of already existing economic policies and regulations, theoretically also of market imperfections, but there are no major market imperfections modelled in the current SNOW-NO model.

5. Discussion

5.1. Forward-looking analysis with backward-looking method

CGE models in general, and SNOW-NO in particular, have equilibrium as a main premise. At no point in time can actual economies be said to rest in a state of equilibrium. The equilibrium concept is nevertheless useful in studies of policy changes as market mechanisms tend to drive markets into balance over time. The real-world tempo of the transition is crucial for the time perspective chosen for the analysis. The outcome of CGE model simulations should be understood as reflecting results once the transitional costs have been absorbed. The present analysis focuses on 2035, and we regard this as sufficiently distant into the future to meaningfully use CGE model simulations.

The main characteristics of the SNOW-NO model are described briefly in Section 2. In particular, the smooth reallocation of labour and capital across the Norwegian economy are symptomatic of a long-term perspective. The model describes the labour market as perfect, with no gap between labour supply and demand. A less strict interpretation is that the unemployment remains unchanged. Note that employment can nevertheless change as a response to endogenous real wage adjustments. Perfect labour mobility also implies that the education system is flexible, providing sufficiently rapid, low-cost (re)training programs as the economy is restructuring. In the capital markets, agents can invest and disinvest seamlessly. An interpretation is that there exist efficient rental and second-hand markets for capital and durable goods. The assumptions of fixed current account and public budget balances also call for a long-term perspective. Focusing on the long-run equilibrium disregards the real costs of transition. Since the analysis spans more than ten years, a portion of that time will likely see underutilised resources, such as unemployment, idle capacity, and the premature retirement of capital goods. Downsizing or closing businesses can have significant consequences not only for individuals but also for entire economic and social communities, with some resource losses potentially becoming permanent.

The uncertainty introduced by using backward-looking data to analyse forward-looking scenarios adds to the intrinsic uncertainty of any forward-looking scenario analysis. The further into the future the focus is, the more crucial it is to critically examine the quantified mechanisms of the model. SNOW-NO is calibrated to 2018 input-output data from the National Accounts, and the emission coefficients is a result of combining the input-output data with the 2018 Emissions Inventory of Statistics Norway. A key advantage of these data is consistency, as activities and components are aligned from both supply and demand perspectives and adhere to macroeconomic conditions. However, for abatement studies the finest aggregation level of the data is in many respects not sufficient. Relevant examples include a lack of differentiation in the data between agricultural products (e.g., red meat vs. vegetables), or between high and low-emission technologies in various industries.

When it comes to the behavioural and technological parameters of SNOW-NO, they are typically based on econometric studies. Thus, they reflect historic relations. It is common to regard such parameters as stable over time. However, in a rapidly changing world with growing focus on climate change and environmental policies, individual preferences and technological options can shift. Other sources of empirical uncertainty are that available econometric studies are rarely tailored to our model structure and that studies using Norwegian data are limited. As a result, many parameter-estimates in the SNOW-NO model are based on international studies.

To overcome limitations of the empirical basis of the model, several approaches are used and combined. First, in the yearly National Budget processes, the SNOW-NO model is involved when making projections of economic and emissions development; see Ministry of Finance (2022) for the projections used as the reference path in the present analysis. In order to improve the empirical basis of the model, empirical observations from the model's base year (2018) to present (2022), as well as expected future developments according to experts' views, were collected and tracked. Emissions, industry production and tax rates are key examples of variables that are harmonised with evidence and future expectations. As part of this, the outputs, inputs and emissions of the exogenous industries Crude oil and gas, Electricity, Agriculture and industries providing public services, are quantified. A challenge is how to account for new or more stringent policies that have been decided but not yet implemented, e.g., specified future shares of zero-emission transportation means. If policy variables are absent, other variables and parameters that influence emissions must be modified instead of relying on the model's mechanisms.

Second, the SNOW-NO model has been developed recently to distinguish between transport using electric vs. integrated combustion engines, between new and old models, and between fossil fuels and biofuels; see Rosnes and Yonezawa (2024). To quantify these new modules, recent data and experts' expectations on forthcoming trends form the basis. Third, we have supplemented the abatement options in the model with information on CCS, electrification in the Crude oil and gas industry and several abatement options in Agriculture; see Section 2.2.

5.2. Interpretation of existing policies and the introduced emission price

In the policy scenarios, we introduce a uniform GHG price instead of the CO_2-taxes in the reference scenario. In the scenarios relying on targets for both ETS and ESR-covered emissions (Policy ii)), this applies only to the ESR-covered emissions, while in the scenarios presuming domestic abatement (Policy i)), we also replace the EU ETS price, and the CO_2 tax rates in the ETS-covered sector with the uniform GHG price. These replacements have two impacts relevant for the social abatement costs. First, the emission price level rises and, second, it makes the pricing system more homogenous. The former will increase the costs, while the latter will make the pricing system more efficient, reducing costs. Our analysis has not quantified the latter, but we expect its impact to be minor, as the reference path system of 2022 is already fairly homogenous.

Homogeneous emissions pricing in the policy scenarios is meant to bring about a cost-effective fulfilment of the abatement targets. However, as the utility decompositions in Section 4.2 indicate, the sustained presence of numerous existing policy interventions implies that there is a theoretical potential for improving the economic efficiency by tailoring emission prices to each individual emissions source. If market imperfections were modelled, these would interact in similar ways with the emission prices. However, we do not allow for such non-uniform emission price solutions. The conventional recommendation by economists is keep the emission price uniform and rather direct the emissions pricing revenue to reduce existing distortions. The observation that utility results occur from policy interactions has inspired the analysis of using the revenue in a distortive manner to counteract the inefficiencies; see the analysis of recycling revenue via lower labour taxation in Scenario 2B (Section 4.2).

The homogenous emission tax can be interpreted as a technical tool for identifying the most cost-effective abatement options according to the model. The results of the analysis can guide policymakers to emission sources and abatement behaviour that likely belong to optimal solutions, even if using other instruments than pricing should be preferred by the government for political or practical reasons. E.g., distributional concerns, industrial priorities, security considerations or administrative burdens can be rationales for selecting other instruments than emissions pricing in practical politics. One should be aware, however, that other policy instruments can increase the implementation costs and decrease the public revenue.

5.3. The treatment of abatement in Agriculture

The analysis also includes cost-effective abatement in Agriculture. This industry is assumed to have exogenous output and input compositions and is, therefore, technically insensitive to emissions pricing. Our approach to abatement in Agriculture is to integrate external information on abatement options and costs by means of iterations; see Section 2.2. As there are no endogenous emissions reductions in Agriculture, introducing an emission price would not generate any responses. The only impact would be to transfer revenue from Agriculture to the state, which would be undesirable and unrealistic. Technically, we choose to refrain from imposing the emission price in Agriculture, as it would merely inflate the recycled emission price revenue. Moreover, emissions pricing has only had a minor role in Agriculture in practical politics until now. Rather, an agreement between the state and the industry, yearly negotiations and a complex support and regulation system are key parts of the abatement strategy for the industry.

There is also a limitation that the input-output data in the National Accounts are aggregate and, therefore, the SNOW-NO model are unfit for simulating alternative output compositions in Agriculture. By treating abatement in Agriculture outside of the model, we are able to include measures that change the output composition for given aggregate output and given fiscal tax and subsidy rates. One of the identified measures is to substitute other outputs for decreased production of red meat. Our analysis indicates a large abatement potential for reducing production of red meat at relatively low cost. Note that policies that upscale support levels or downscale agricultural output will not be easy to represent in this framework, unless reasonable exogenous estimates for quantities and costs of these actions are available.

5.4. Market imperfections

The current version of SNOW-NO does not account for externalities or other market imperfections. While the Norwegian economy generally functions well and markets tend to produce efficient outcomes, certain activities, such as road transportation and industrial processes, generate externalities. These can be related to pollutants. In case of transportation, other externalities like noise, congestion, and accidents are also topical. Moreover, market power may exist in industries or niches with few players. The reason for excluding market failures from the model is primarily that impacts on health, eco-systems and infrastructures are difficult to quantify. Note, however, that emissions of SO_2, NO_X, CO (carbon monoxide), PM, NMVOC, and NH_3 are estimated in model simulations and could be used as basis for estimating environmental damage.

In many cases, policymakers recognise these market failures and implement regulatory measures to counteract them. For instance, the road tax and NOx tax systems are designed to address issues like congestion, infrastructure wear, and pollution. The paradox in the model is that while these instruments are included as part of the input-output system, the underlying market failures they aim to address are not accounted for. As a result, these policies can appear as efficiency distortions in the model. When a GHG price is introduced in an economy with such distortions, it can either reduce or exacerbate inefficiencies, depending on how it interacts with existing policy measures (see Sections 2.2, 4.2, and 5.2).

6. Concluding remarks

This analysis assesses economic costs, macroeconomic impacts and sectoral consequences of various climate policy targets and policy structures that Norway can choose for the year 2035. The targets are to be reached by means of uniform emission prices in all our policy scenarios. This ensures cost-effective abatement across the target-covered emissions. The policy scenarios are compared to a reference path where the economic development is projected for climate policies fixed at the 2022 level. Other economic policies as well as the development abroad reflect assumptions made in the projections of the National Budget 2023 (Ministry of Finance, 2023).

The analysis is performed in two phases. Phase 1 compares different 2035 policy scenarios with a focus on their MACs. Based on these, we construct MAC curves for two different policy structures: The first, Policy i), assumes economy-wide targets for 2035 to be fulfilled by domestic abatement measures, only, while the other, Policy ii), splits the abatement targets into two sub-targets: one for emissions presently covered by the EU ETS (*The ETS emissions sector*) and one for those covered by the Effort-sharing regulation (*The ESR emissions sector*), respectively.

All the simulated policy scenarios in Phase 1 will require significant rises of emission prices relative to the emission prices in the reference path, where the carbon taxes in 2022 and an EU ETS price projected to 2035 of 1,150 NOK/tCO_2e are present. The emission prices of the policy scenarios span from 2,900 to 12,300 NOK/tCO2e, depending on the policy design and ambition levels. The simulations also reveal that choosing Policy i) instead of Policy ii) matters substantially. The MAC will be more than doubled when all abatement of ETS-covered emissions is forced to take place domestically even if buying allowances in EU ETS renders less costly. It is worth mentioning that other flexibility mechanisms than EU ETS trading is also allowed according to current EU policies and the collaboration agreement with Norway, but these are not considered in our analysis. It is neither allowed for exploiting cross-border funding of abatement in countries outside of the EU, e.g., under the auspices of the United Nations. Such trading is illegal under the current EU agreement but can be topical in a future agreement for 2035.

In Phase 2, we disentangle sectoral and macroeconomic implications of one of the scenarios. It is characterised by an abatement target of 60 per cent from the 1990 level and by Policy i), i.e., domestic abatement, only. We consider two revenue recycling alternatives: lump-sum transfer back to the household (scenario 2A) or simultaneous reduction of labour taxation (scenario 2B). We find that the macroeconomic impact is less negative in scenario 2B than in scenario 2A. Specifically, the social cost is halved. This reflects that there are significant interaction effects between emissions pricing and other economic policies, including a significant tax wedge between labour supply and leisure that contributes to increase the costs of abating. Reducing this tax wedge is, therefore, beneficial for the economy at large.

The analysis discusses pros and cons with the chosen method for assessing future climate policy targets. It relies mainly on simulations on the SNOW-NO model, a detailed macro-economic model for Norway. Despite several improvements of the model framework recently aimed at adapting the model to studies of the next decades' climate policy, we have supplemented the simulations in this analysis with additional abatement options. By consulting expert knowledge, we have been able to include rapidly advancing abatement technologies like CCS as well as quantify abatement options for industries that, for various reasons, are kept exogenous in the model. Bottom-up information from The Norwegian Environment Agency (2024) is our main external source.

Uncertainty of the results in this analysis must, nevertheless, be stressed. First and foremost, it is important to have in mind that models are simplifications of the real world. Specifically, SNOW-NO relies on market equilibria. This implies that transitional costs are disregarded and that the relevant perspective is long-term, at least 7-10 years ahead. Even if our focus on 2035 fulfils this criterion, future scenarios are, by definition, based on guesswork of what the future might bring, and the more distant the forward-looking perspective, the more uncertainty will be involved.

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Appendix A: The ETS and ESR sector in the reporting and in SNOW-NO

Table A.1 List of aggregated sectors

Reported industries	Code	SNOW industries (see Rosnes and Yonezawa, 2024)
ESR-covered		
Agriculture and Forestry	ag_fr	Agriculture (AGR); Forestry (FRS)
Manufacturing ESR	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) (AVK); waste (private)(AVP)
Water transport and fishing	wt_fi	Domestic water transport; fishing
Other household consumption	othhh	Paraffin and heating oil; furnishings & household equipment and routine household maintenance; gas; fuel wood & coal etc.
ETS-covered		
Manufacturing ETS	ets_indu	Refined oil products & chemicals industry (OIL); non-metal minerals (NMM); iron and steel (I_S); non-ferrous metals (NFM); paper products, publishing (PPP)
Crude oil and gas	cru	Crude oil and gas
Air transport	atp	Air transport
Electricity	ele	Electricity

Source: Statistics Norway

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