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An analysis of welfare costs and distributional impacts for Norway

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Abstract:
We theoretically and numerically analyse the impacts for a small, open country with carbon abatement ambitions of joining a coalition with allowance trading. Besides welfare impacts for both the coalition and the small, open economy joining the coalition, we scrutinise how the studied policy options differ with respect to their distributional impacts across domestic income groups. Our example is the EU 2030 policies and Norway's linking to it. In spite of theoretical ambiguity, the findings suggest that the tighter the links with the EU, the lower the abatement costs for Norway. The distributional profile of the welfare costs tends to be progressive, i.e., the relative (and absolute) incidence of the carbon policy falls more heavily on wealthy households than poor households, regardless of the choice of linking options. However, the less progressive, the lower the overall welfare cost. This indicates a trade-off between efficiency and distribution concerns. A national cap-and-trade system without linking to the EU is the least cost-effective option for Norway but also the most progressive as the higher income deciles face lower capital return and wages.

Keywords: Carbon policies, Distributional impact, Emission Trading System, Effort Sharing Regulation, Computable General Equilibrium model

JEL classification: 68, Q43, Q48, Q54, Q58

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Sammendrag

Vi undersøker ulike muligheter for en liten, åpen økonomi med klimapolitiske ambisjoner for å knytte seg til klimapolitikken i en større koalisjon. Analysen ser på landenes samfunnsøkonomiske gevinster samt på sektorvise endringer og de innenlandske inntektsfordelingseffektene.

Den teoretiske delen av analysen bygger inn stiliserte fakta for Norges samarbeid med EU både i det europeiske kvotemarkedet og i EUs innsatsfordelingsforordning som gjelder for ikke-kvotepliktige utslipp. Tre ulike reformer blir belyst: (1) Landet går fra et rent nasjonalt marked for utslippsrettigheter til å knytte deler av sine utslipp til kvotemarkedet i en større koalisjon, (2) landet knytter også sine resterende utslipp til et parallelt marked for utslippsrettigheter i koalisjonen, og (3) koalisjonen det lille landet inngår i slår sammen sine to parallelle markeder. Den teoretiske analysen viser at selv om reform (1) vil være gunstig for noen av utslippssektorene, kan økonomien som helhet få økte kostnader ved å nå sitt klimapolitiske mål. Grunnen er at økt fleksibilitet på tvers av land for hvor utslippskuttene kan tas, går på bekostning av fleksibilitet innad i landet. Også reform (3) gir tvetydig resultat for landet, fordi kvoteprisen vil øke for noen utslippskilder og falle for andre.

For å bestemme den samfunnsøkonomiske totalvirkningen samt utslaget på inntektsfordelingen og for enkeltsektorer i Norge, gjør vi en numerisk analyse av det norsk-europeiske klimasamarbeidet ved hjelp av den globale versjonen av den generelle likevektsmodellen SNOW. I tillegg til å beregne de direkte kostnadene ved å nå klimamålene gjennom å innføre en uniform karbonpris, får SNOW også tatt hensyn til indirekte samfunnsøkonomiske effekter klimapolitikken vil i samspillet med annen politikk og import- og eksportprisene.

Simuleringene viser at norsk økonomi stort sett tjener og aldri taper på å styrke koplingen til EUs klimapolitikk. Dette gjelder også i de også i de tilfellene der de teoretiske resultatene ikke var entydige og på tross av enkelte negative samspillsvirkninger. Når det gjelder inntektsfordelingen vil innføring av karbonpris virke progressivt i alle tilknytningsalternativene. Det vil si at det er de relativt mest velstående som blir mest belastet, målt både absolutt og som prosentvis reduksjon i inntekten. På tvers av tilknytningsalternativene vil imidlertid progressiviteten falle jo lavere de samfunnsøkonomiske kostnadene er. Det er altså en avveiing mellom å spare totalkostnader og å bedre fordelingsprofilen.

1 Introduction

The EU countries have among the worlds' most ambitious policies aimed at combatting greenhouse gas emissions. The EU 2030 climate and energy framework includes targets for greenhouse gas emissions for sources covered by the EU emission trading system (EU ETS) as well as for those outside of the EU ETS.[1] The 2030 climate and energy framework does, in practice, also allow for non-EU associates. Non-member Norway has decided to link its climate policy to the EU framework.

This paper looks into costs and benefits of such a strategy for a small, open economy. Why does a small country without right to participate in EU decisions lay its fate in the hands of a larger coalition? Are the decisions of the coalition the best options for the small associate? This study compares alternative, unilateral climate policy options for a small, ambitious country. In addition to economy-wide impacts, the analysis examines how the studied policy options differ with respect to their distributional impacts across production sectors and across domestic income groups. Overall costs as well as distributional consequences are important concerns with respect to public acceptance and political feasibility (Bretschger and Pittel, 2020). In many cases, there are potential trade-offs between them: Policy instruments chosen for overall cost-effectiveness can have distributional disadvantages and vice versa. Such potential trade-offs in policy design are important to identify.

The analysis addresses the nexus between the two subjects in the present Energy Modeling Forum (EMF36) study (Böhringer et al., 2021, this issue). It combines the study of linking ETS systems with the study of how the linking choices affect different income groups. We examine four options for a small, open economy for meeting its Nationally Determined Contribution (NDC) in the Paris Agreement:

The national regime (NAT): The country sets an economy-wide target equal to the NDC that is met by a domestic, fully flexible, cap-and-trade system and a subsequent uniform carbon price. The NAT regime is justified by typically ensuring a given national emission target in a cost-effective manner.

The partial emission-trading regime (ETS): The country participates in an international emission-trading system that partly covers the emission sources of the country and meets the residual NDC commitment by a national target for the remaining sources. The country's citizens will face two

[1] See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015PC0337 and https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32018R0842, respectively (accessed May 9. 2021).

carbon prices, one given internationally for the domestic emission sources covered by the ETS and one determined domestically in a cap-and-trade system for the remaining sources.

The regime with two, independent international markets (SILO): The small country also joins an international trading system for the remaining emissions, so that two siloed, i.e. disparate, systems with one international price each, co-exist.

The one-price regime (ALL): The international community establishes one overall allowance market for all emission sources with one uniform allowance price, and the small, open economy links to it. Even if the full coalition is likely to benefit from equalising the marginal abatement cost among all its emission sources, this is not necessarily true for each of the partners, for instance the small, open economy.

We have three main research questions:

1. What are the cost-effectiveness and distributional impacts of obtaining partly access to international flexibility mechanisms at the expense of less national sectoral flexibility, i.e. moving from regime NAT to ETS?
2. What does the country gain in effectiveness terms from involving in further regional flexibility, i.e., moving from regime ETS to SILO, and what are the distributional implications?
3. How will a fully flexible international regime impact effectiveness and distribution in the small country, i.e. moving to regime ALL?

Our case study assesses different strategies for meeting Norway's NDC in the Paris Agreement with respect to overall cost-effectiveness, household distribution and sectoral impacts. Norway is not member of the EU but part of the European Economic Association and has an extensive cooperation with the EU within energy and climate issues. First, the EU ETS constitutes an international system that Norway can involve in, and actually has been part of, since the Norwegian allowance system was linked to the EU's in 2008. Second, recently Norway and the EU have also agreed to include Norway in the European effort-sharing regulation (ESR) of emissions outside EU ETS from 2021 to 2030.[2] Part of its intention is to establish flexibility mechanisms across borders. The latter would imply some type of allowance trading within Europe also for the non-EU ETS emission sources.

[2] https://www.regjeringen.no/contentassets/4e0b25a4c30140cfb14a40f54e7622c8/national-plan-2030_version19_desember.pdf, accessed May 9. 2021.

Many previous articles have studied EU's ETS and non-ETS targets and flexibility (e.g., Tol, 2009; Böhringer, 2014; Aune and Golombek, 2020; Veille, 2020), and a literature strand has looked into linking regional allowance trading systems (e.g., Anger, 2008; Carbone et al., 2009; Flachsland et al., 2011, Mehling et al., 2018, Doda et al., 2019; Holtsmark and Weitzman, 2020). This paper assumes the perspective of the small, open Norwegian economy and asks whether it is worthwhile and feasible to join the larger EU coalition.

A main contribution is that we investigate the national distributional impacts in the small, open economy under alternate coalition options and scrutinise whether there is a trade-off between efficiency and distribution concerns. How does, for instance, the regional flexibility of being part of the EU ETS compare, in terms of welfare and equity, to a fully flexible cap-and-trade system nationally? Is the regional flexibility gained of joining the EU ETS more welfare-improving than enjoying sectoral flexibility within Norway? And while overall gains for Norway are plausible from also linking non-ETS to EU's effort-sharing, would there be any distributional concerns? We will also study the case where a coalition encompassing both the EU and Norway regulates all emissions by one, merged allowance market. While this is expectedly the least costly solution for the coalition as a whole, distributional concerns might appear both across national borders and internally.

We start by theoretically illustrating the main abatement cost implications for a small open economy, including its sectoral distribution. To obtain a detailed picture of distributional impacts not only across sectors but also for household income groups, we use the global, computable general equilibrium (CGE) model SNOW (Statistics Norway's World model). Its main virtue is a detailed household module which constitutes a microsimulation model splitting households into ten income groups (deciles) based on household data hard-linked to SNOW. Thus, we are able to address the impacts among various types of households differentiated with respect to income levels, income sources and expenditure patterns. The realistic, economy-wide context provided by the SNOW model is important, since it captures market interplays that generate indirect spillover effects across countries, sectors and households. Moreover, the climate policy strategies interact with existing tax structures and other market interventions. Such CGE mechanisms incorporated in the SNOW model can significantly affect the effectiveness and distributional results.

The theoretical exposition leaves many of the research questions unsettled. The abatement cost impact is in general ambiguous of moving from a national cap-and-trade as in the national regime (NAT) to a regime where the emissions from sectors covered by EU ETS become part of the EU ETS (regime ETS). Also, moving from two to one regional allowance market (from SILO to ALL) can either increase or decrease the abatement costs for the small country. The numerical analysis indicates that moving from regime NAT to regime ETS by linking the Norwegian *ets*-sector, i.e., the emission sources that can choose to be part of the existing, international emission trading system, EU ETS, saves costs, made possible by cheaper abatement options within the EU's *ets*-sector. The simulations further suggest that adding regional flexibility mechanisms for emissions outside the EU ETS slightly raises the welfare costs for the small, open economy. The theoretical exposition rules out increased abatement costs of this move from the ETS to the SILO regime. However, the model captures more detailed general equilibrium effects and reveals that the emission pricing also generates additional inefficiencies of the resource allocation when interacting with the rest of the economy. Finally, the simulations clearly settle the outcome of moving from the SILO to the ALL regime with one merged regional allowance market. It will cut costs of Norway substantially. This gain is not so much a matter of national abatement costs. The major explanation is found in what goes on in the EU. Specifically, marginal abatement costs increase in EU's *ets*-sector, allowing Norway to exploit higher export prices in the European markets for crude oil, natural gas and electricity.

When we consider the distributional impacts among households, carbon pricing has two main channels through which equity across households is affected: First, the costs decrease macroeconomic activity, implying a downward pressure on factor income. Distribution will change to the extent that income groups rely differently on income sources (transfers, wages and capital earnings). Second, households spend different shares on goods and services. A recent meta-analysis by Ohlendorf et al. (2020) shows that the current empirical literature arrives at ambiguous net results. In particular, the conclusions are mixed for high-income economies. The results rely on which sectors are most heavily regulated. The policy regimes analysed in this paper vary with respect to overall costs and sectoral impacts.

Our findings suggest that while the magnitude differs among the scenarios, the general characteristics are the same for all the scenarios. The income share channel has a progressive incidence, i.e. the relatively wealthy pay relatively more as they rely more on labour and capital income and less on transfers than do the lower income deciles. On the other hand, the spending share channel has regressive incidence: The low-income households spend higher shares of their income on gasoline/diesel. In total, the incidence is progressive for all the regimes, as previously also found in studies of other high-income countries like the US in Rausch et al. (2010) and Canada in Dissou and Siddiqui (2014).

While all the scenarios show progressive incidence, the national regime (NAT) is more progressive than other scenarios. This is because the national regime has much higher carbon price in the *ets*-sectors, which are capital-intensive, and thus capital return is more affected than in the other scenarios. Larger share of capital income for high-income households leads to stronger progressive incidence. While this higher carbon price in *ets*-sectors in the national regime strengthens the regressive incidence of the spending share channel as the price of gasoline and diesel goes up, the income share channel dominates.

Thus, the most expensive option, the national regime, is the most progressive, and the lower the macroeconomic cost, the less progressive the policies. This indicates that there is a trade-off between equity concerns and economic efficiency, assuming that the progressive incidence is positive. That said, we should keep in mind that the public acceptance of the climate policy is also important, and possibly the progressive nature could discourage the acceptance of the wealthy households.

The paper is organised as follows: Section 2 provides a qualitative discussion of the economywide and sectoral gains and losses associated with the carbon policy regimes. Section 3 describes the numerical approach, while the analysis of the results is provided in Section 4. Section 5 concludes.

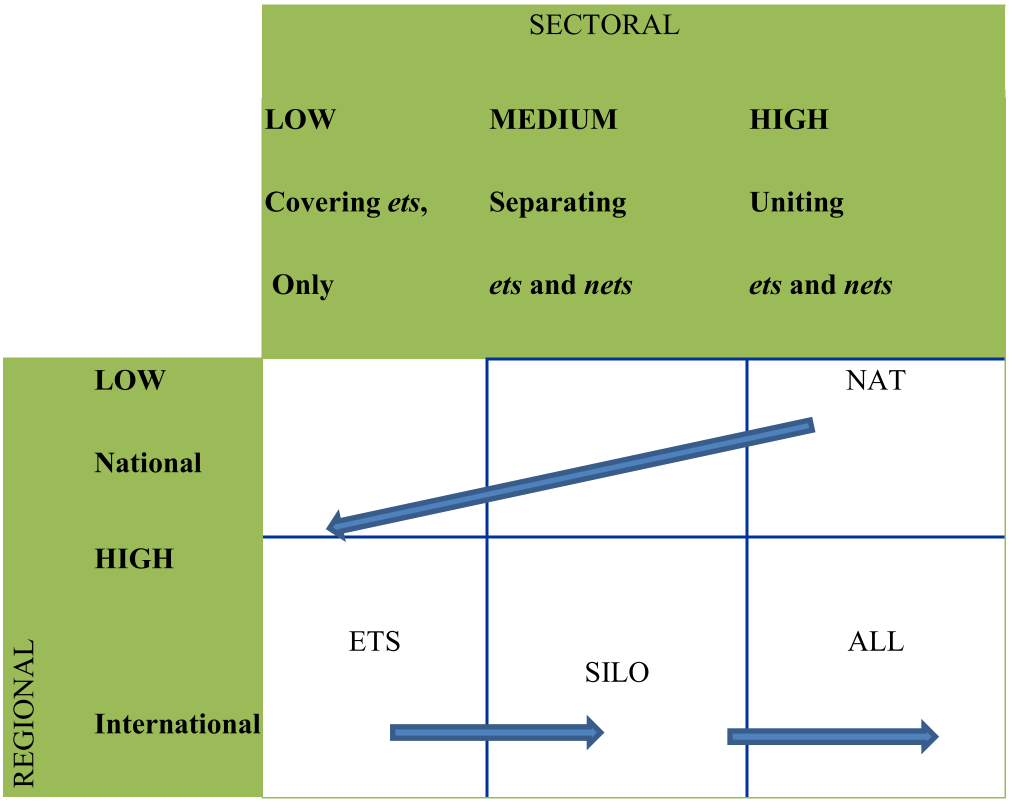
2 Theoretical illustration

Here, we use a stylised equilibrium exposition of the abatement costs to qualitatively compare elements of costs and benefits. The exposition takes an aggregate perspective by analysing economywide gains and losses and also look at distributional impacts by distinguishing between two sectors. The first consist of those emission sources that can choose to be part of an existing, international emission trading system, *ets*. The other covers the rest of the economy (*nets*). More detailed distributional impacts are left for the considerably more detailed numerical analysis in Section 4.

We first show the theoretical result of our research question 1, i.e., the abatement cost effectiveness and sectoral impacts of moving from a national cap-and-trade system, with sectoral flexibility in accordance with strategy NAT depicted above, to an international system for selected emission sources, only, as in regime ETS. We then discuss the qualitative impacts of increasing regional flexibility further, as addressed in research question 2, by moving from ETS to SILO. Finally, we respond to research question 3 by illustrating the foundation of one overall allowance market with full regional as well as sectoral flexibility in regime ALL.

The four scenarios NAT, ETS, SILO and ALL are depicted in Figure 1, where the arrows illustrate the changes of regimes that we analyse:

Figure 1: The flexibility (sectoral and regional) regimes for the small, open economy



While regime NAT reflects full sectoral flexibility, it is restrained to a national allowance system. Let the sets *ets* and *nets* include emission sources that can and cannot be part of the existing, international allowance market, respectively. Figure 2 illustrates research question 1, i.e., how will the movement from the NAT to the ETS regime, where *ets* and *nets* emissions are separated in two systems and where only the former has regional flexibility, perform?

Assume the two sectors *ets* and *nets* have different marginal abatement cost (MAC) curves. Since our numerical analysis addresses the potential cooperation between Norway and the EU, the exposition accounts for stylised facts established about the MAC curves in these regions and at the relevant abatement levels.[3] Both Norway and the EU have fixed their caps for their *ets* and *nets* emissions at the outset unless either of the flexibility regimes NAT, ETS, SILO and ALL apply. ETS represents the EU ETS, SILO represents two separated flexibility mechanisms for EU ETS and ESR-covered

[3] Besides the numerical analysis presented in Section 4, these are based on previous related studies; see Veille (2020), Aune and Golombek (2020) and Fæhn et al. (2020).

emissions, and ALL is the extreme assumption of one overall allowance market. The Norwegian MAC curve for the *ets*-sector lies below the respective *nets* curve in the relevant area:

(a) $MAC_{ets} < MAC_{nets}$

The same applies for the EU:

(b) $MAC_{ets, EU} < MAC_{nets, EU}$

Furthermore, for both sectors the EU levels are below the Norwegian in the relevant areas, i.e.:

(c) $MAC_{ets, EU} < MAC_{ets,}$

(d) $MAC_{nets, EU} < MAC_{nets,}$

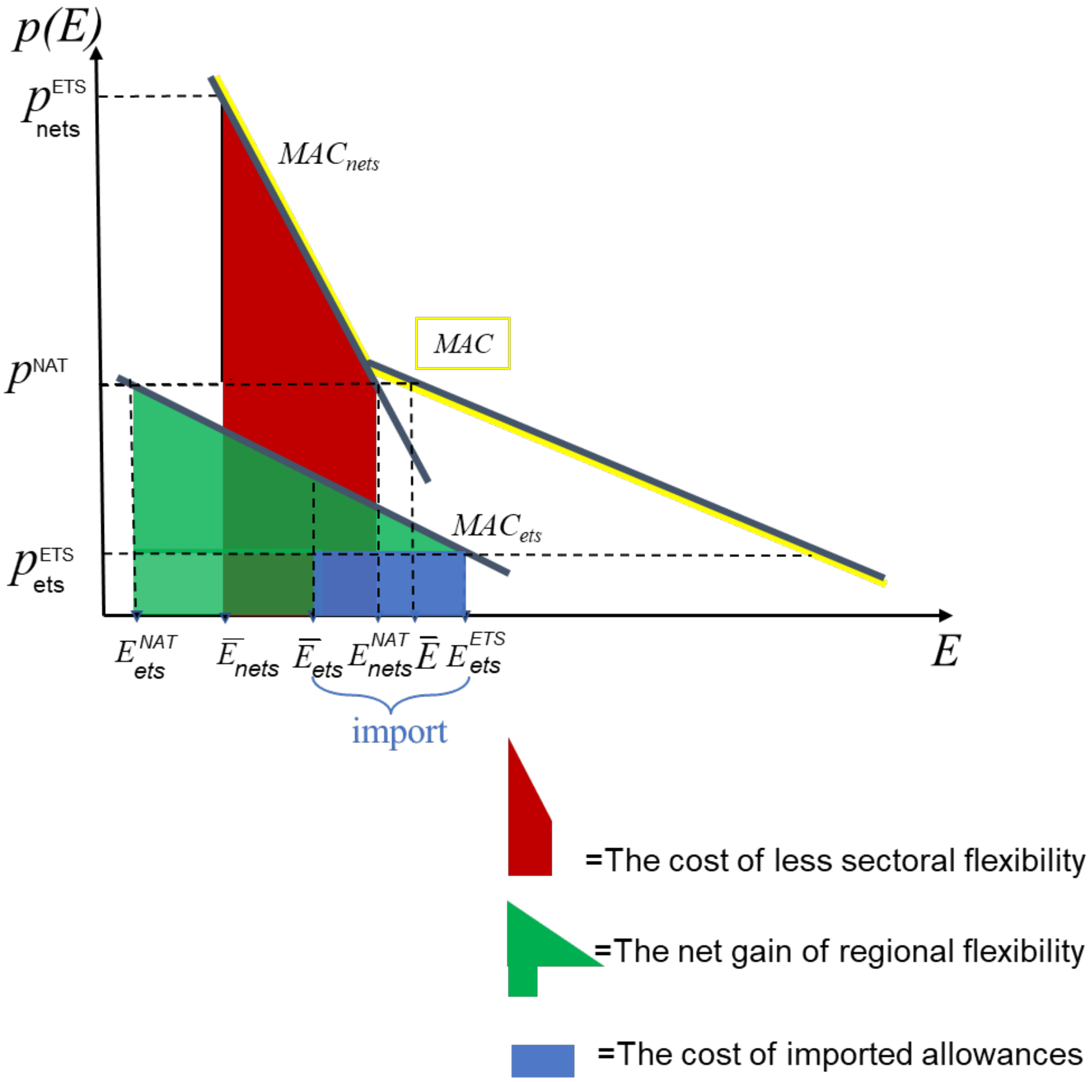
Figure 2 shows the caps for CO_2-emissions set by the small, open economy for its *ets* and *nets* emissions. $\bar{E}_{nets}$ is the target for *nets* emissions, while $\bar{E} - \bar{E}_{nets}$ is the target for *ets* emissions. In a national cap-and-trade system, NAT, only the economy-wide target $\bar{E} = \bar{E}_{ets} + \bar{E}_{nets}$ matters, and the economy-wide MAC curve is represented by the yellow, kinked curve.[4] At the emission level $E = \bar{E}$, the kinked MAC curve will yield the resulting national carbon price, p^{NAT}, which is a weighted average of the domestic MACs in the two sectors, *ets* and *nets*, in absence of a national cap-and-trade system. The emissions in the two sectors will be E_{ets}^{NAT} and E_{nets}^{NAT}, respectively. With the relative MACs chosen as described in the Inequations (a) to (d) above, the *nets*-sector emits more than given by its cap, and vice versa for the *ets*-sector.

Next, we move from NAT to the hybrid regime ETS, in which only the *nets*-sector is subject to a cap-and-trade nationally, while the *ets*-sector joins an international cap-and-trade system. The caps are as in NAT; for *ets* sources it can be met by abating or by importing international allowances. We assume that the country is small and cannot affect the ETS allowance price, p_{ets}^{ETS}, that as stated in Inequation (c) above, is assumed to be lower than the national allowance price in regime NAT. In Figure 2, the emissions in the two sectors will be E_{ets}^{ETS} and E_{nets}^{ETS}, respectively, the latter equal to the target for *nets* emissions $\bar{E}_{nets}$ in Figure 2. The *nets*-sector will have to abate more in ETS than in NAT ($E_{nets}^{ETS} = \bar{E}_{nets} < E_{nets}^{NAT}$) and at a higher marginal cost ($p_{nets}^{ETS} > p^{NAT}$), while *ets* abates less

[4] It appears kinked, since for more ambitious abatement targets than in the kink, additional abatement will only be possible in the *nets* sector – emissions have reached zero in the *ets* sector.

domestically than in NAT ($E_{ets}^{ETS} > E_{ets}^{NAT}$) at a lower marginal cost ($p_{ets}^{ETS} < p^{NAT}$). What will be the overall abatement cost impact of moving from NAT to ETS?

Figure 2: Net abatement cost impact for the small country in the hybrid ETS regime vs. the national cap-and-trade regime, NAT



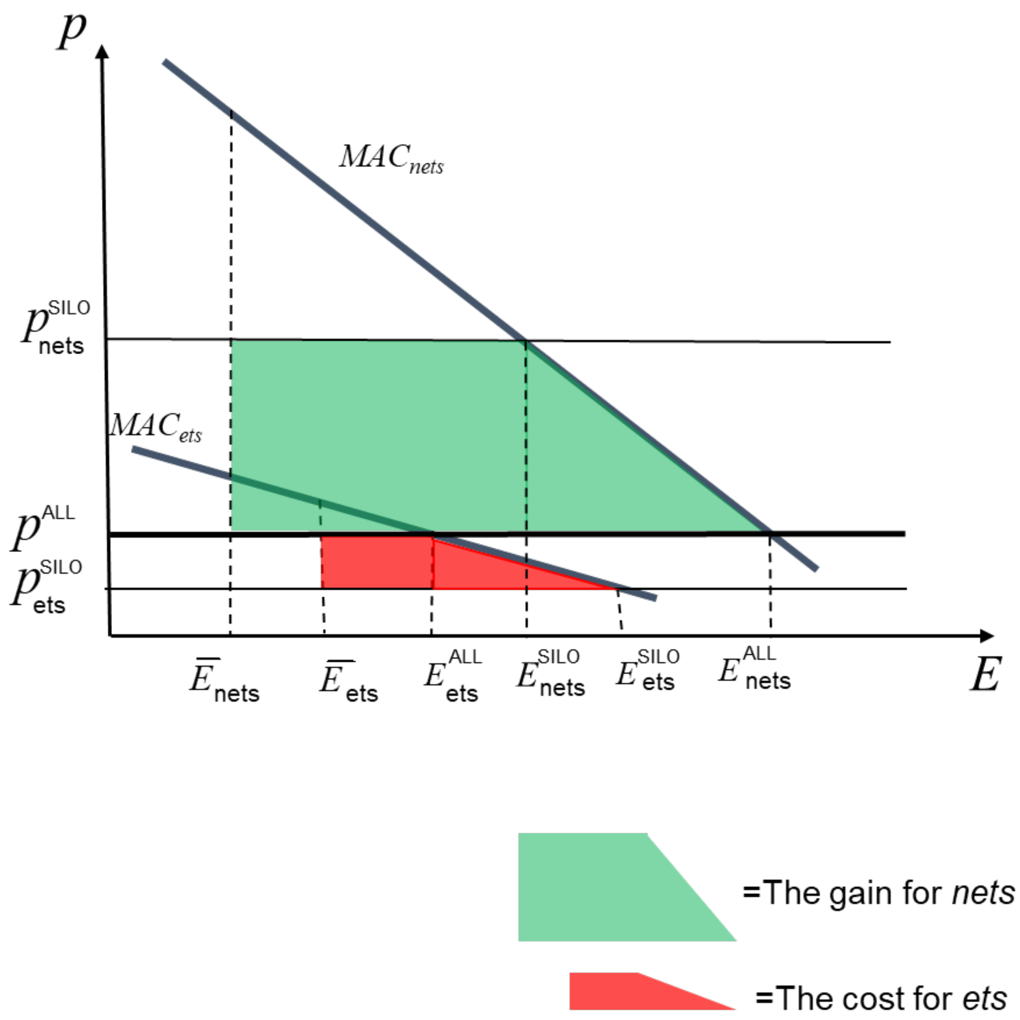
As illustrated in Figure 2, the net abatement cost impact can be decomposed into three: (*i*) the cost of less sectoral flexibility, (*ii*) the gain of regional flexibility, and (*iii*) the cost of importing allowances. The *(i)* component is depicted in red. It is the cost for the *nets*-sector of having less national flexibility and committing to abate more within the sector. The size of this cost component will depend on the marginal abatement cost that unambiguously lies above the common p^{NAT} in regime NAT. How much higher depends on how p^{NAT} weights the two sectors' MACs that, in turn, depends on their relative positions (given Inequation (a) above) and steepnesses as well as the sizes and abatement targets of the sectors. For instance, a steeper MAC_{nets} will, *cet. par.*, increase the cost component, as will a more ambitious abatement target in *nets* relative to *ets*.

Turning to the gain component *(ii)*, it arises from the small country being able to enjoy regional flexibility. For the international allowance price, p_{ets}^{ETS}, which in Inequation (c) above is assumed to be lower than the common p^{NAT} in regime NAT, it can import allowances to meet all abatement commitments that have costs higher than the international price. The import has a cost *(iii)*, depicted in blue. However, the savings from lower abatement domestically *(ii)* more than offset this, per definition. The net of *(ii)* and *(iii)* is depicted in green in Figure 2. The size of this component is also case-specific, depending on the p^{NAT} determinants as well as the exogenous p_{ets}^{ETS}. For instance, the higher this price, i.e., the higher the $MAC_{ets,\,EU}$, the smaller the gain. The sum of *(i)*, *(ii)* and *(iii)* is the red area minus the green. In Figure 2, the cost of less sectoral flexibility is larger than the import-cost-netted gain of regional flexibility (the red area exceeds the green area). In general, the net impact is ambiguous, depending on the relative positions (given Inequations (a) to (d) above) and steepnesses of the MACs and how the ambitions are composed of the emissions and targets of the two domestic sectors. Numerical estimations are needed to indicate whether the NAT or the ETS regime represents the lowest abatement cost for the country. When comes to the distribution across emitters, the two sectors will face opposite consequences, one will lose, and one will gain. In the case depicted in Figure 2, the *nets*-sector is the loser, deprived of sectoral flexibility while not offered regional flexibility.

The answer to research question 2 is more straightforward and needs no deeper analysis: Increasing the international flexibility of abatement options also for the remaining emissions, while assuming no change for the already flexible part of the emissions, will unambiguously increase abatement cost-effectiveness for the small country. It will involve no change in the abatement cost of the *ets*-sector, while the *nets*-sector gains from increased flexibility. Its behavioural change will depend on the international price it faces in the international market for *nets* allowances. According to our assumptions in Inequation (d), the price is lower than p_{nets}^{ETS} in Figure 2. The *nets*-sector will, thus, meet some of its required abatement by buying allowances abroad. The higher the price, the more the *nets*-sector will abate domestically.

Research question 3 addresses how the country and its sectors will experience a shift from two parallel international allowance markets in SILO to the case with one common marginal abatement cost (carbon price), only, as in regime ALL. It is illustrated in Figure 3.

Figure 3: **Net abatement cost impact for a small country of moving from two international allowance markets (SILO) to one allowance market with full coverage (ALL)**



We know from economic theory that for the coalition as a whole the abatement cost unambiguously declines as more flexibility is introduced. However, Pareto improvement is not necessarily obtained: some members of the coalition might lose unless redistribution transfers are allowed (Carbone et al., 2009; Doda et al., 2019). In this case the conclusion is, thus, less obvious for the small, open partner. It will, *inter alia*, depend on where the common, uniform price in the fully flexible system in regime ALL renders relative to the former two prices in SILO. All these prices are determined internationally, dependent on the targets, emissions and MAC curves within the EU (see Inequation (b) above). In the particular situation depicted in Figure 3, the small, open partner will gain. Its *nets*-sector, which has the highest MAC according to Inequation (a), will gain when moving from SILO to ALL, illustrated by the green area, while its *ets*-sector will face a loss equal to the red area. The areas include the changes in costs of domestic abatement as well as allowance trading. The gain for the *nets*-sector (green area) turns out to exceed the loss for the *ets*-sector (red area). Figure 3 reflects that the closer the international uniform carbon price, p^{ALL} ends up to the lowest of the two regional prices in SILO, p_{ets}^{SILO}, the larger will the net abatement cost saving (green minus red area) for the economy be. On the contrary, a high p^{ALL} close to p_{nets}^{SILO} could turn the net effect negative for the small country.

Our numerical analysis below will settle the most likely net results in the ambiguous cases presented here, for the case of the small, open Norwegian economy when linking to the EU policies. In addition to direct abatement costs, our analysis will include overall welfare impacts – including terms-of-trade and tax-interaction effects that can reinforce or counteract the welfare impacts of the abatement (Flachsland et al., 2011). In addition, the distributional impacts across household groups will be addressed, most importantly with respect to income groups, but sectoral costs and competitiveness impacts will also be scrutinized in more detail.

3 The numerical approach

We use a global, multi-sector CGE model, focussing particularly on the Norwegian and European economies, their possible climate policy collaboration and energy and trade interactions. Within the CGE framework, a micro-simulation module of Norwegian households is integrated in order to grasp distributional impacts by following the approach by Rutherford and Tarr (2008).

3.1 The micro-simulation module

Micro information on income and consumption by population groups are based on the Norwegian Consumption Survey. The micro-simulation module features households grouped in ten income groups (deciles).[5] Income originates from the factor income as well as from government transfer. Consumption patterns vary across income decile groups. For each income group, the welfare (consumption) function of a representative household is modelled by a constant elasticity of substitution (CES) function of goods defined in the CGE model (Table 2). In this framework, it is possible to include as many households as household data allow. However, in this paper, we use the household data of income and spending for income decile groups, and, thus, consider the distributional impact of income deciles. The percentage change in national as well as decile group welfare are

[5] The data are available at https://www.ssb.no/statbank/table/10444/, https://www.ssb.no/statbank/table/07751/, https://www.ssb.no/statbank/table/12682/, accessed May 9. 2021.

measured by the Hicksian equivalent variation relative to the benchmark income (Rutherford, 1995). Except from different incomes and spending patterns, the ten households are assumed to be similar and each individual's consumption weighted equally in the national welfare measure. We solve the CGE model and micro-simulation module iteratively until the equilibrium is achieved, and thus these welfare measures are consistent with each other.

3.2 The rest of the CGE framework

The micro-simulation module is placed in a CGE framework programmed in GAMS/MPSGE (GAMS, 2020; Rutherford, 1999) and calibrated to global GTAP9 data, which includes detailed national accounts of production and consumption (input–output tables) together with bilateral trade flows and energy-related CO_2 emissions for the year 2011 (Aguiar et al., 2016).[6]

CGE models build on general equilibrium theory that combines behavioural assumptions about rational economic agents with analysis of equilibrium conditions. The main virtue of the CGE approach is its comprehensive micro-consistent representation of price-dependent market interactions in a setting with various, existing public interventions. The simultaneous explanation of the origin and spending of the agents' income makes it possible to address both economy-wide cost-effectiveness and distributional impacts of policy reforms.

The CGE model in this paper is a static model, and while the base year data is 2011, we create the benchmark dataset of 2030 through forward calibration. Specifically, we use the forecasted values of GDP and energy demand for each region and energy prices in IEO (International Energy Outlook) dataset.

[6] The emission data do not account for process emissions of CO_2; see Bednar-Friedl et al. (2012).

The regional specification in the CGE model is described in Table 1.

Table 1: Model regions

Norway
Europe without Norway
China
Japan
South Korea
India
Canada
United States
Brazil
Russia
Australia and New Zealand
Middle East regions
African regions
Other Americas
Other Asia

For the sectoral disaggregation, see Table 2. Note that all major primary and secondary energy carriers are distinguished: coal, crude oil, natural gas, refined oil products and electricity. This disaggregation is essential in order to distinguish energy goods by CO_2-intensity and degree of substitutability.

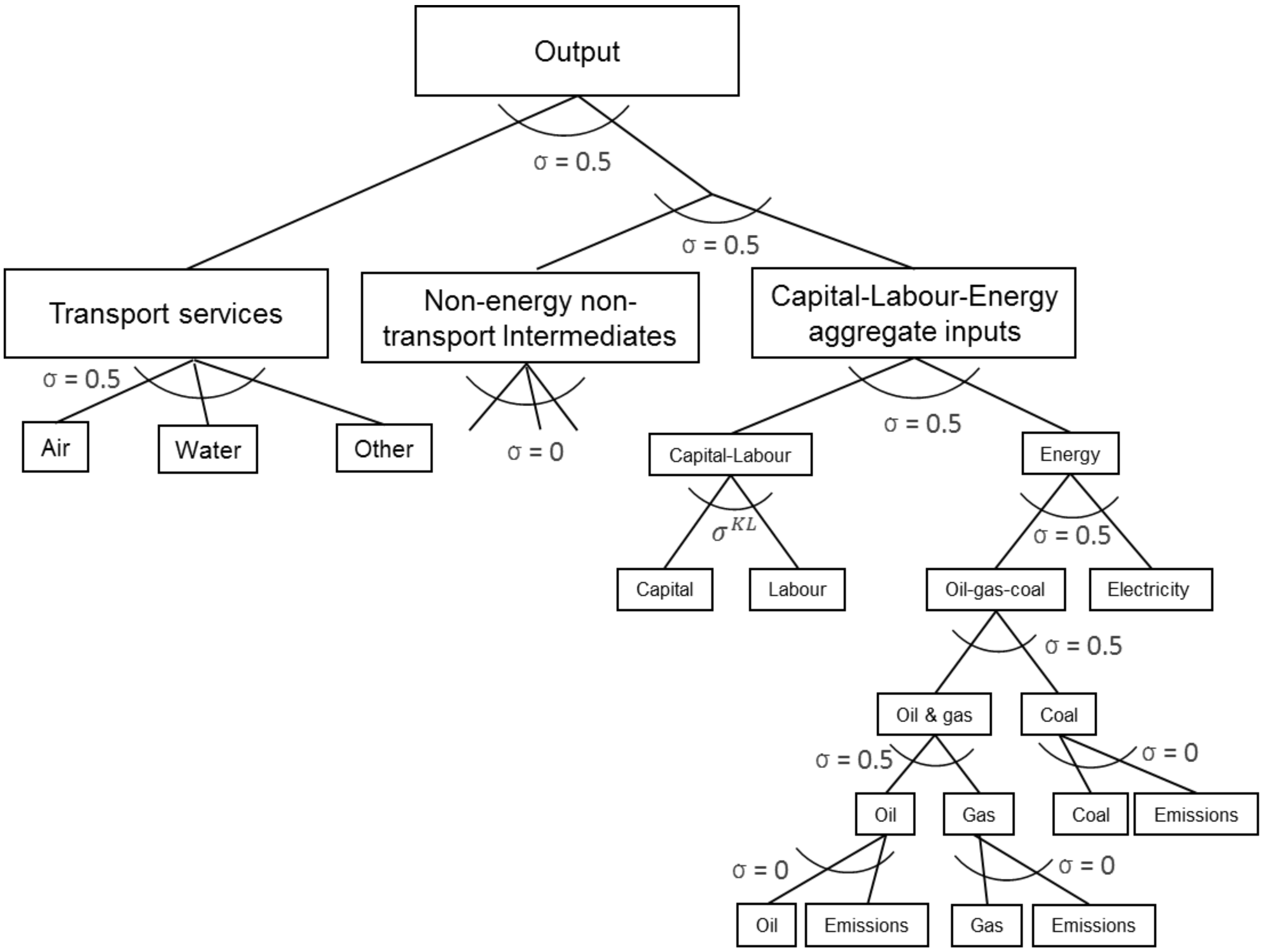
Table 2: Model industries

Industries in the *ets set**
Coal (COL)
Crude oil (CRU)
Natural gas (GAS)
Refined oil products (OIL)
Electricity (ELE)
Emission-intensive trade-exposed (EIT)
Air transport (ATP)**
Industries in the *nets set**
Water transport (WTP) **
Other transport (OTP)
Agriculture (AGR)
All other manufacturing (MFR)
All other services (SER)

* The *ets* set consists of sectors that can be covered by the EU emission trading system, ETS. The *nets* set contains the remaining sectors.
** Only emissions territorially accountable for Norway.

The production of commodities is captured by nested constant elasticity of substitution (CES) functions describing the price-dependent use of capital, labour, energy and intermediate inputs. Figure 4 shows the nesting and substitution elasticities in a typical industry.[7]

Figure 4. Nested CES structure of production technology for non-fossil fuel extraction industries



Labour and capital are intersectorally mobile within a region but immobile across regions. Natural resources are a third type of production factor. These resources are industry and region-specific and used by the fossil fuel extraction industries (crude oil, coal and natural gas). In addition to the nesting

[7] Some exemptions apply: σ^{KL} is differentiated for each sector and taken from GTAP data. For the electricity sector, the substitution elasticities between oil and gas and coal and the composite of oil and gas is 2. This reflects the substitution possibility of fuel switching in electricity generation.

illustrated in Figure 4, these industries have a natural resource factor added at the top of the nesting. We calibrate the elasticity of substitution of this resource factor such that the supply elasticities of the fossil fuel extraction industries obtain values according to the literature (see below). Specifically, the elasticity of substitution of the resource factor (σ) is calculated as follows:

$$\sigma = \eta \frac{\theta}{(1-\theta)}$$

where θ is the cost share of the resource factor.

Household demand is also modelled as CES functions similar to Figure 4. Investment and government spending are modelled as Leontief production functions, and in this static setting they are exogenous in real terms in the counterfactual simulations.

CO_2 emissions are linked in fixed proportions to the use of fossil fuels, with CO_2-coefficients differentiated by the specific carbon content of fuels. Under carbon policies, emission abatement takes place by fuel switching (interfuel substitution), energy efficiency improvements (fuel/non-fuel substitution) or by a scale reduction of production and final consumption activities.

Bilateral trade is specified using the Armington's differentiated goods approach, where domestic and foreign goods are distinguished by origin (Armington, 1969). All goods used domestically in intermediate and final household demand correspond to a CES composite that combines the domestically produced good and the good imported from other regions. A balance of payments constraint incorporates the base-year trade deficit or surplus for each region. Public budgets, and also the composition of the budgets, are kept unchanged from the benchmark, which is ensured by lump-sum transfers. In the sensitivity analysis, we consider different ways to use the revenue from carbon pricing.

The data underlying the elasticity estimates of the model are taken from the pertinent econometric literature. The GTAP database provides substitution possibilities in production between primary factor inputs. The fossil fuel supply elasticities used as basis for the elasticities of substitution in the fossil fuel extraction industries are 4 for coal and 1 for crude oil and natural gas; see Graham et al. (1999) and Krichene (2002). Armington elasticities are also taken from the GTAP database.

3.3 Household data in the model

While we use both the GTAP database and the Norwegian Consumption Survey data, the main data set underlying our model is the GTAP database, which includes both the country-wide information of income and expenditure of households. We use the Norwegian Consumption Survey data to specify the expenditure composition and income source composition of each income decile as Beck et al. (2015) does. In other words, we treat the GTAP database as the reference dataset, and we use the share of the Norwegian Consumption Survey data.

Table 3 shows the income source share for each income decile. As we expect, the share of government transfer is the highest for the households in the lowest-income decile (inc1) and decreases as the income of the households increases. In contrast, capital income is higher for the higher-income households.[8] The share of labour income increases with the income level first, but then it decreases as the high-income households receive larger share of capital income.

Table 3: Income source share by income deciles (percentage)

Income deciles	Labour	Capital	Transfer
inc1	40.6	11.3	48.2
inc2	40.8	28.3	30.9
inc3	47.5	28.2	24.3
inc4	47.1	34.5	18.4
inc5	50.5	34.5	15.1
inc6	52.5	34.4	13.1
inc7	50.5	39.8	9.7
inc8	51.7	39.8	8.5
inc9	42.4	52.2	5.5
inc10	33.8	63.4	2.9

Table 4 shows the expenditure composition of households in each income decile. As we expect, the low-income households have larger expenditure share for electricity (ELE) and refined oil products or mainly gasoline/diesel (OIL). Because of these larger spending share of necessary energy spending,

[8] Note that the scope of the capital income in the Norwegian Consumption Survey (or household survey data in general) is much narrower than the capital income in GTAP data (or national account data in general). This is because household survey data normally reports the capital income that reaches households, such as income from investment, interest and dividends, whereas national account data additionally includes the depreciation and fixed capital investments by corporations as capital income. Also note that, since the Norwegian Consumption Survey does not have the information about the resource income, we split it in the same way as capital income, and resource income and capital income are aggregated as capital income in Table 3.

carbon pricing is often considered as the regressive policy. However, in the case of Norway, we should keep in mind that the electricity in Norway is mainly generated by hydro, and thus the emission pricing does not increase the electricity price.

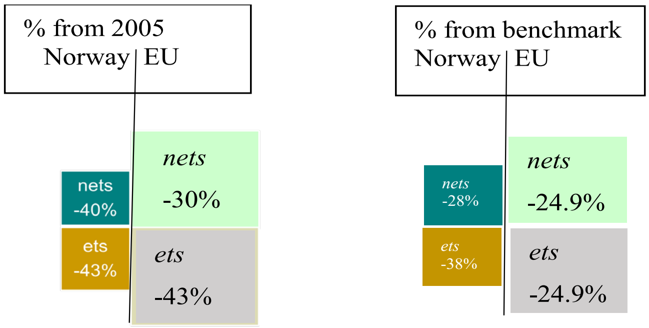
Table 4: Expenditure share by income deciles (percentage)

Income deciles	ELE	OIL	ATP	EIT	AGR	MFR	OTP	SER	WTP
inc1	5.7	3.1	0.8	3.0	11.6	13.7	4.2	56.2	1.6
inc2	4.3	2.4	1.6	2.9	8.0	13.5	8.4	55.6	3.2
inc3	3.8	2.1	1.4	3.1	7.0	14.2	7.4	58.2	2.8
inc4	3.8	2.1	1.3	3.1	7.6	14.3	6.8	58.6	2.5
inc5	3.5	1.9	1.2	3.2	7.0	14.6	6.3	60.0	2.4
inc6	3.3	1.8	1.5	3.0	8.8	13.8	8.0	56.8	3.0
inc7	2.9	1.6	1.3	3.1	7.7	14.4	7.0	59.3	2.6
inc8	2.9	1.6	1.6	3.0	8.2	13.9	8.4	57.2	3.1
inc9	2.2	1.2	1.2	3.3	6.3	15.1	6.5	61.9	2.4
inc10	1.7	0.9	0.9	3.5	4.1	16.1	5.0	66.0	1.8

3.4 Design of the numerical analysis

Our case study assesses different strategies for meeting Norway's NDC in the Paris Agreement with respect to overall cost-effectiveness, household income group impacts and industrial distribution. Our benchmark scenario is a projection of 2030 without climate policies as they are expressed in the NDCs. In the four linking scenarios both Norway and the EU introduce overall emission targets in accordance with their NDCs. Figure 5 shows the respective politically decided targets (as percentage changes from 2005 levels) for abating greenhouse gases for the *nets* and the *ets* sectors. Counted from the projected benchmark, Norway needs to cut emissions by 28.0 and 38.0 per cent in the *nets* and the *ets* sector, respectively, whereas EU needs to cut emissions by 24.9 per cent in both sectors. As the model only includes energy-related CO_2 emissions, we assume the same abatement targets also apply for these emissions. Figure 5 also translates the targets into percentage changes from benchmark, as they are simulated in the analysis. Benchmark economic and emission projections for EU and ROW are based on EIA (2017), European Commission (2016) and Norwegian Ministry of Finance (2019).

Figure 5: Abatement targets of Norway (small boxes) and the EU (large boxes), percentage change from 2005 and from benchmark



For the analysis of Norway's three strategic options (NAT, ETS and SILO), we let the EU meet its NDC by means of two allowance markets, one for its *ets* emissions (the EU ETS) and one for its remaining *nets* emissions that are regulated by ESR. As indicated in Figure 5, Norway's relative cuts from benchmark are higher the EU's for both sectors. In the NAT scenario, the caps of the two sectors result in an overall cut of 33.4%. It can be met by means of one national, uniform carbon price. In the ETS scenario, Norway links its *ets* emissions to the EU ETS, while meeting its *nets* target (28 per cent reduction from benchmark) through a national allowance market covering the *nets* sector. In the SILO scenario, Norway also enters the EU's market for ESR allowances. Still there is no flexibility across the *ets* and *nets*-sectors. The result is a siloed carbon policy with two, separate allowance markets (*ets* and *nets*). The ALL scenario features a fourth regime where the Norwegian-European coalition merges the two markets into one, ensuring a uniform carbon price for all emissions in Norway and EU.

4 Numerical results and analysis

4.1 Macroeconomic results and cost-effectiveness

Table 5 shows main economic results for Norway.[9] Our first finding is that while theoretically the welfare impact of abatement is ambiguous of moving from a national cap-and-trade as in NAT, to a regime like ETS, where some industries become part of a regional allowance market, the numerical analysis talks in favour of linking the Norwegian emissions to the EU ETS. Welfare increases by 0.4 per cent (to a level 4.1 per cent lower than benchmark in ETS compared with a level 4.4 per cent lower

[9] Prices and values are in real terms, deflated by the price of Norwegian aggregate consumption.

in NAT – see Table 5). The main reason is a large marginal abatement cost wedge between Norwegian and EU emission reductions within the EU ETS-covered emission sources. Abatement cost in a sector (*ets* or *nets*) is measured as the integration under the MAC curves and approximated by the *carbon price*abatement/2* of the sector (Paltsev and Capros, 2013). In addition, the value of allowance trading is taken into account. The *ets*-sectors have very different emission compositions in Norway and the EU. While the EU has relatively cheap abatement options within electricity generation, Norway's is already based on clean hydropower. Abatement in the industry with its largest emissions, oil and gas extraction, is relatively expensive. Being able to exploit this cost difference in the ETS regime is more beneficial for Norway than using the national flexibility in NAT.

Changes in the industrial pattern reflects the abatement cost distribution. As discussed above, moving from sectoral to regional flexibility will be beneficial for one part of the economy at the expense of the other. The Norwegian *ets*-sector will benefit significantly from lower abatement costs and its output will increase, see Table 5. The main expansion takes place in energy-intensive manufacturing and natural gas extraction, both important export industries.[10]

The findings also suggest, somewhat surprisingly, that adding flexible mechanisms also for emissions outside the EU ETS, when moving from ETS to SILO, raises the costs for the small, open economy in spite of a modest abatement cost saving for its ESR-covered sector (as predicted in the theoretical exposition). The cost saving is small (0.1 percentage of the benchmark income), reflecting that energy-related carbon emissions in *nets* are largely concentrated within transportation, where activities and abatement options are rather similar in Norway and the EU. EU's marginal abatement costs are nevertheless lower than Norway's. Some abatement options that are relatively cheap in the EU are substituting electricity for natural gas in households and substituting public transport for private driving in areas with high population density. The small abatement cost saving in the ESR-covered sector is counteracted by a slightly larger cost increase, leaving a minor net welfare loss of 0.1 per cent. Two cost components are identified in the simulations: First, SILO leads to lower abatement in the *nets*-sector and, thus, smaller output cutbacks in the primary industries. These activities are heavily subsidised and/or trade protected, rendering their activities inefficiently high. Cutbacks will, therefore, increase efficiency of resource allocation within the Norwegian economy. The other reason for this loss is through the government expenditure. Along with increasing carbon prices, the real cost of providing the exogenous level of government services becomes lower because of its low emission

[10] Industry-specific results are available upon request.

intensity.[11] Since moving from ETS to SILO implies a lower carbon price, the real cost of government service increases.

Table 5. Economic results for Norway, % change from benchmark unless stated otherwise

Economic indicators:	NAT	ETS	SILO	ALL
Welfare	-4.4	-4.1	-4.1	-2.2
Abatement cost*	2.4	1.6	1.3	0.9
Real factor prices				
Labour	-2.1	-2.2	-1.4	-0.6
Capital	-3.3	-3.0	-2.3	-1.1
Natural resources	-18.0	-14.3	-13.7	-9.0
ets-sector carbon price**	371	32	32	86
ets-sector emissions	-43.2	-10.5	-10.4	-19.0
ets-sector abatement cost*	1.3	0.2	0.2	0.5
ets output	-6.4	-4.5	-1.2	-0.5
nets-sector carbon price**	371	551	324	86
nets-sector emissions	-22.0	-28.0	-19.5	-6.9
nets-sector abatement cost*	1.1	1.4	1.1	0.4
nets output	-1.4	-1.7	-1.2	-0.5

* Measured in billion $.
** Measured in $/t$CO_2$.

It is less obvious what the welfare impact will be of increasing flexibility further by moving to one allowance market for all Norwegian and EU emissions. Even if uniform pricing is expected to minimise abatement costs for the coalition as a whole, the impact on both partners need not be positive. As seen from the theoretical exposition above, the result for the small, open economy is ambiguous. Table 5 shows that moving from SILO to ALL cuts the welfare costs of Norway substantially, by 1.9 per cent. Part of this is explained by lower abatement costs for Norway, enjoyed by the *nets*-sector. However, even more significant for Norway is what goes on in the EU. As can be seen from Table 6, the merging of the two allowance markets into one induces much lower marginal abatement costs in the ESR-covered sector and much higher in the EU ETS-covered sector of the EU. For Norway this means better terms of trade, first of all because the export prices of natural gas, crude oil and electricity increase. The export stimulus counteracts the abatement cost increase in the *ets*-sector, but the total effect leads to the expansion of the *ets* output (relative to SILO). The welfare cost of the EU is also approximately halved. That said, this welfare gain of the EU comes from the linking

[11] "All other services" is the main input for the government spending.

of *ets* and *nets* markets within EU instead of linking to Norway, which is not a surprise with a given size of Norway relative to EU.[12]

Table 6. Economic results for the EU, % change from benchmark unless stated otherwise

Economic indicators:	**NAT**	**ETS**	**SILO**	**ALL**
Welfare	-0.5	-0.5	-0.5	-0.2
ets-sector emissions	-24.9	-25.2	-25.2	-40.7
nets-sector emissions	-24.9	-24.9	-25.0	-9.6
ets-sector carbon price*	31	32	32	86
nets-sector carbon price*	322	323	324	86

* Measured in $\$/tCO_2$

4.2 Household distribution results

The different welfare impacts among households in each income decile is created because of the heterogeneity of income source share and expenditure composition. Carbon pricing affects the relative prices of goods in the economy (spending side) and changes the relative returns on household income sources (income side). Carbon pricing leads to relative price increase of goods with high emission-intensities (such as, refined oil products). Depending on the relative spending share of the goods with high emission-intensities, the welfare impact of each income decile varies. Also, climate policy will affect factor prices in different ways because of the difference in factor intensities of each industry and how the climate policy affects their production. Depending on the relative contribution of the different income sources on households' income, factor price changes will affect households differently. In addition to factor endowments, government transfers form the income basis of households. Transfers tend to be indexed to inflation in the Norwegian economy and stay constant in real terms, and thus in our simulation model, we assume fixed transfer amounts in real terms.

If the households were completely homogenous, the welfare loss would be identical for all households. In the NAT scenario this is equal to a reduction from benchmark of 4.4 per cent ("No heterogeneity" in Figure 6). We split the heterogeneity impacts into two effects: expenditure-share heterogeneity impacts and income-source heterogeneity impacts. The former component reflects how income groups differ in their expenditure patterns and, thus, face different challenges with the carbon pricing. The second component reflects how income groups differ in their main income generating source. As

[12] While we do not include in the paper, we simulate a scenario where a uniform price is implemented in each country/region (Norway and the EU, respectively). In that scenario, while the welfare impact of EU is similar to that in ALL, the Norwegian welfare impact is improved from SILO (i.e., from 4.1 to -2.7 per cent).

Table 3 shows, for the low-income households, government transfers are a prominent income source. The higher the income, the more important are wage and capital incomes.

Figure 6: Decomposed household distributional impact of NAT scenario, % change from benchmark

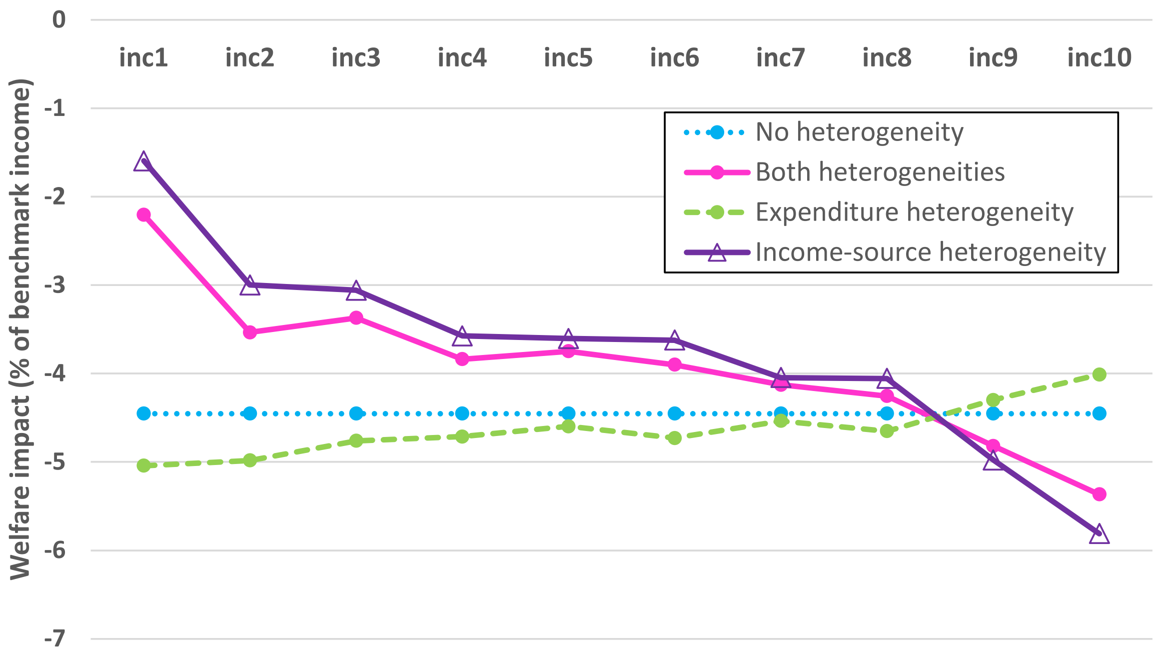


Figure 6 shows the welfare impact of the representative household in each income decile in the NAT scenario as an illustrative example. The line labelled "Expenditure heterogeneity" considers only spending-side heterogeneity. The upward slope of the line, which indicates smaller welfare losses at higher levels of income, suggests that the carbon pricing is a regressive policy. The larger share of refined oil products (OIL) for the lower-income households leads to the progressive incidence, as Table 3 shows. While this is consistent with the previous literature, such as, Rausch et al. (2010) and Dissou and Siddiqui (2014), the regressiveness is modest. This is because in Norway the electricity is mainly generated by hydro, and in spite of the larger spending share of electricity for lower-income households, it does not contribute to regressive incidence, which is the same story as for the carbon tax in British Columbia (Beck et al., 2015 and Beck et al., 2016).

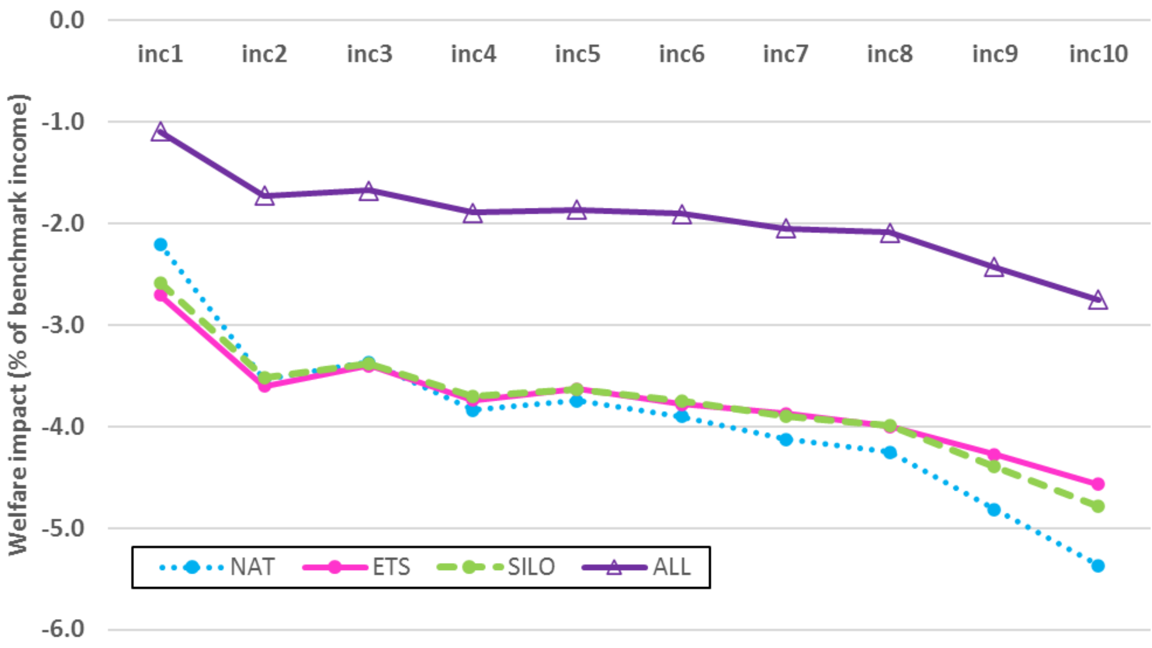
The line labelled "Income-source heterogeneity" considers only income-source heterogeneity. The distributional impact of the income-side effect is progressive. First, low-income households have larger share of government transfer income, which is not damaged by the emission pricing. Thus, the welfare loss of low-income households, especially the first income decile, is more limited. Second, the impact on labour and capital income is different. As emission-intensive industries tend to be rather capital-intensive than labour-intensive, the negative impact on capital return is larger than the negative impact on wage as shown in Table 5. Since the higher-income households obtain the larger share of their income from capital endowments, their welfare loss is larger than that of middle-income households who have larger shares of labour income.

The line “both heterogeneities” considers both types of heterogeneity, and it shows that the carbon prices in the NAT scenario is progressive, i.e. the relative (and absolute) incidence of the tax falls more heavily on wealthy households than poor households. The regressive incidence of the spending heterogeneity is dominated by the progressive income-source impact.

Moving on to the remaining regimes, we find that they are all less progressive than NAT, as the lines are less steep than that of NAT (See Figure 7). Table 5 shows that NAT has the largest negative impact on capital/resource income (which leads to the gap between the government transfer income and capital/resource income) and the largest gap between the impact on capital/resource income and labour income. Thus, the negative impact on high-income households is larger. This is because the *ets*-sector (especially crude oil and natural gas extraction and electricity generation) are more capital/resource-intensive, and in NAT, the carbon price in the *ets*-sector is significantly higher than in the remaining scenarios. On the expenditure side, as the *ets* carbon price is lower in other scenarios than in NAT, the price increase of refined oil products is smaller, and thus the regressive incidence becomes weaker than in NAT. Nevertheless, the difference in the income-side heterogeneity impact dominates.

Lastly, one important assumption here is that we return the carbon revenue (net of the change in other taxes) to the households in proportion to their benchmark income. This way of recycling the extra tax revenue is not meant to be consistent with the current policy context. Instead, this way minimises the distortion on the distributional impact of the carbon pricing itself. For example, if we use the extra tax revenue in a way that is beneficial for low-income households (such as flat-rate lump-sum return per capita), the distributional impact becomes much more progressive. However, the important point in this analysis is that even without such a flat-rate carbon rebate, carbon pricing policies are already progressive because of the income-source pattern.

Figure 7: Progressivity of the carbon pricing regimes, % change from benchmark



4.3 Sensitivity analysis

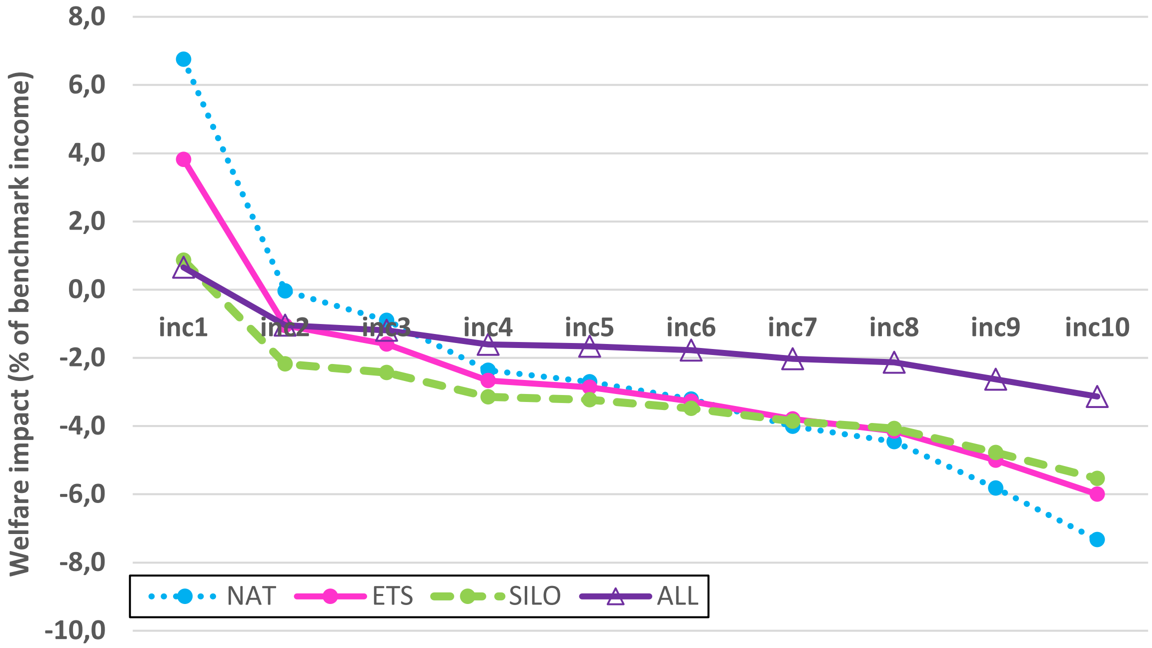
While it is important to examine the distributional impact of carbon pricing itself (separately from the way of using carbon revenue), the way of using carbon revenue is of course important as it may dominate the distributional impact of carbon pricing itself. Although our simulation results show progressive incidence of the carbon pricing in Norway, the concern of the regressive incidence, or negative impact on low-income households, has encouraged the idea of recycling the revenue lump-sum as a flat rate.[13] As one simple way to mitigate it, flat-rate lump-sum return can be an option because the same amount of cash return is more valuable to low-income households than high-income households. With this background, in this sensitivity analysis, we consider the flat-rate lump-sum return instead of lump-sum return proportional to the benchmark income, which has been assumed in the scenarios above.

Figure 8 is basically the same graph as Figure 7 except that the carbon revenue (net of the reduction of other tax revenues) is returned as flat-rate lump-sum payment to each household group. As we expect, in all the scenarios the extent of progressive incidence is increased relative to the case with the lump-sum return proportional to the benchmark income in Figure 7. For example, the lowest income group

[13] This proposal is inspired by the so-called *carbon-fee-and-dividend* policy advocated by Hanson (2015).

is better off in all the scenarios, so the negative impact of carbon pricing is dominated by the positive impact of the lump-sum return. Among four scenarios, especially in the scenarios of NAT and ETS, the progressive incidence becomes stronger because carbon revenue in these two scenarios are larger than other two scenarios, and thus the amount of the flat-rate lump-sum return is larger. Under our simple assumption of using all the extra revenue for the lump-sum return, the change in tax revenue of linking options directly affects the distributional impact.

Figure 8: Progressivity of the carbon pricing regimes with flat-rate lump-sum return, % change from benchmark



5 Conclusions

This analysis addresses the nexus between the two subjects in the present energy modelling forum (EMF) study. It combines the study of linking ETS systems with the study of how the linking choices affect different income groups. It looks into costs and benefits of different strategies for meeting the international abatement commitments for a small, open economy. The case is Norway and different options the country has for linking its policies to that of the EU, both for emission sources covered by the EU ETS and for those outside. How will Norwegian abatement costs and distribution across income groups be affected by different linking options? Are there trade-offs between the two goals of overall cost-effectiveness, on the one hand and equity concerns, on the other?

We examine three changes in linking strategies:

1. Norway obtains partly access to international flexibility mechanisms by linking to the existing EU ETS. This comes at the expense of national sectoral flexibility in a national cap-and-trade system.
2. Norway links further to the EU policies by also joining the cross-border flexibility for non-ETS sources.
3. EU decides to merge the two allowance markets for sources inside and outside of the EU ETS, and Norway links to it.

Theoretically, the abatement cost implications of the shifts in 1. and 3. are ambiguous, and numerical estimations are needed to indicate what option represents the lowest abatement cost for the small country. Moreover, welfare impacts depend not only on these direct abatement costs, but can be significantly affected by interactions across markets, policy interventions and country borders that can only be grasped by numerical macroeconomic analysis. CGE simulations show that welfare improves for Norway when pursuing option 1, i.e., moving from the national cap-and-trade system to collaborating with the EU as part of the EU ETS. These are encouraging findings, as the Norwegian *ets*-sector has been part of EU ETS since 2008. One caveat is worth noting: when limiting the analysis to energy-related carbon emissions only, a significant part of the Norwegian *ets* emissions and abatement options are left out that are likely to decrease the marginal costs of *ets* abatement. The superiority of EU ETS over a national system is, thus, less obvious.

The linking to the EU ETS has removed the option of a national trading and, thus, increased the abatement challenge for the remaining part of the Norwegian economy. The insignificant mitigation that has taken place within Norwegian borders since 2005 can be interpreted in this light. In option 2, flexibility is increased further by establishing a separate international market for the remaining emission sources. This unambiguously decreases the costs of abatement. The simulated welfare impact is, nevertheless, negative due to interaction between the carbon policies and existing policy interventions and real cost of government service.

Increasing flexibility further, as in option 3, involves ambiguous abatement cost changes for the small coalition partner. Numerical analysis is necessary and clearly reveals a gain for Norway of merging all allowances into one, regional European-Norwegian market. The uniform carbon price generated is much lower than the prices that would emerge in the other regimes. However, this is only part of the story. Norway also experiences substantial terms-of-trade gains from increased prices in its European export markets. The abatement within Norway’s own borders is at its smallest in this regime; only

40% of the commitments are abated domestically. A potential consequence that our model is not designed for throwing light on, is the risk of not investing sufficiently and timely in the transformation to a carbon-free economy.

In the study of distributional impacts, we have split the heterogeneity impacts into two effects: expenditure-share heterogeneity impacts and income-source heterogeneity impacts. The former component reflects how income groups differ in their expenditure patterns and, thus, face different burdens due to the carbon pricing. The second component reflects how income groups differ in their main income-generating resource. For the lower parts of the income scale, transfers are a prominent income source. The higher the income, the more important are wage incomes and capital income.

In the Norwegian economy, the expenditure-share heterogeneity contributes to regressive incidence; however, the impact is low in an international context. Energy (e.g., electricity and gasoline/diesel) constitutes a relatively high expenditure share in low-income households. The low regressive incidence is explained by clean electricity generation based on hydropower in Norway. Income-source heterogeneity, on the other hand, tends to contribute to progressive incidence. It is driven by reduced wages, which more seriously hit middle-income deciles, and by reduced capital income, which more seriously hit high-income deciles. Low-income groups are more dependent on transfers. All in all, thus, carbon pricing in all the regimes in this paper is progressive, i.e. the wealthy households bear more of the costs than poor households. Moreover, a sensitivity analysis shows that progressivity can be substantially reinforced by recycling the revenue in a flat-rate lump-sum manner. In this case, the households in the lowest income decile obtain positive welfare impact in all the regimes.

While all the regimes show progressive incidence, the national regime (NAT) is more progressive than others because the national regime has much higher carbon price in the *ets*-sector. The main mechanism is that production technologies in the *ets*-sector tend to be relatively capital-intensive, and thus capital return is more affected than in the other scenarios. While this higher carbon price in the *ets*-sector in NAT strengthens the regressive incidence of the spending share channel as the price of gasoline and diesel goes up, the income share channel dominates.

Thus, the most expensive option, the national regime, is the most progressive, and we find a trade-off between cost effectiveness and distributional profile, assuming that the progressive incidence is positive. With the link to EU ETS (in the ETS regime), the progressive nature is softened, and the macroeconomic cost goes down too. Further linking of the remaining economy (SILO) does not reduce the welfare loss, and the distributional impact is not affected much, either. The ALL regime shows the lowest welfare cost and similar but slightly less progressive profile.

The results are case-dependent and simplified in many respects. For instance, though heterogenized, the description of the household sector is still crude; characteristics likely to affect distribution are omitted, including residency, income sector and household composition. The model takes existing public interventions into account, and we have identified that some interplay significantly with the climate policies and affect welfare outcomes. However, numerous price wedges arising from policy regulations and market imperfections are not part of the data basis and will not be reflected in the analysis. The fact that our analysis is static also leaves out many aspects of decarbonization, which is a long-term and dynamic process. The analysis does not bring in negotiation dynamics nor endogeneity of the ambition levels, which can be critical for successfully linking systems (Carbone et al., 2009; Flachsland et al., 2011; Holtsmark and Weitzman, 2020). Furthermore, transitional costs are not reflected, nor are administrative hurdles (Doda and Taschini, 2017). One challenge is implementing feasible flexibility mechanisms for non-ETS emission sources.[14]

Nevertheless, our numerical example can offer relevant lessons for several states considering joining existing allowance systems like the EU ETS. While Norway has long experience as part of the EU ETS, it has only recently taken on binding mitigation commitments under the EU ESR legislation. Cooperation with the EU like the Norwegian can, for instance, be topical for the UK after Brexit. Our study particularly brings new insight into the domestic distributional impacts of linking policies.

[14] Non-ETS entities are typically small and difficult to engage in allowance trading; thus, regulating fuel providers upstream seems the most feasible (Achtnicht et al., 2015; Pollitt and Dolphin, 2020).

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