Marginal Abatement Costs under EU's Effort Sharing Regulation

A CGE analysis

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Abstract

Norway intends to join the EU's proposed Effort-Sharing Regulation (ESR) that regulates the emission sources outside the EU Emission Trading System (ETS) – henceforth the *NETS* sectors. The NETS sectors include domestic transport, agriculture and households, among others, and account for almost 60% of total EU greenhouse gas (GHG) emissions. This analysis estimates the projected 2030 marginal abatement costs (MACs) for reducing CO_2 emissions in EU.

The proposed ESR provides several flexibility mechanisms. The analysis assumes full, efficient buying and selling opportunities across borders. Flexibilities proposed vis-á-vis the ETS and vis-á-vis the Land Use, Land-Use Change and Forestry (LULUCF) sector are varied. This analysis quantifies the MACs under different assumptions about these flexibility mechanisms, about the reference emissions and about the abatement of other greenhouse gases (non-CO_2 GHGs). The *basic scenario* assumes proportional abatement of all GHGs, disregards flexibilities proposed vis-á-vis the ETS and LULUCF sectors and results in a 9% CO_2 cut in the NETS sectors from the 2030 reference scenario in EC (2016). 11 other different combinations of assumptions leave us with cuts between 4% and 18%.

Based on the scenarios, we have estimated the MACs for the NETS sectors by means of the global Computable General Equilibrium model SNOW. It can be used to assess the marginal costs for meeting different levels of an emission reduction target in the EU. The resulting MAC estimates are in the range of 25–158 €/t CO_2. These moderately low costs partly reflect the relatively low remaining abatement commitments on top of reference projections provided by the European Commission (EC, 2016) and the member states (EU, 2017b). The estimated MAC curve is convex, implying that increasing the abatement ambition in NETS increases the MAC relatively more. To address uncertainty, sensitivity analyses of alternative assumptions and comparisons with related scenarios in other analyses are performed. The SNOW scenarios are within the range of previous findings, and sensitivity analysis indicates relatively small impacts of alternative parameter choices when emission reductions are relatively small, as in the basic scenario.

We have analysed two scenarios in detail: the basic 9% scenario and the scenario representing the largest abatement of CO_2, the 18% scenario. The MACs of abating 9% and 18% in NETS amount to 64 €/t CO_2 and 158 €/t CO_2, respectively. In both these scenarios we see that the *Transport* sector and *Household* sector reduce their emissions less than the average for NETS, while the *Primary* and the *Other* industries cut correspondingly more. Comparing the two scenarios reveals that the composition of the abatement across sectors is insensitive to the level of the abatement ambition. We also find that more than 90% of the abatement is due to increased energy efficiency and fuel switching within the sectors; the remaining mitigation is attained by downscaling production in the sectors.

Sammendrag

Norge har en intensjon om å bli med i EUs foreslåtte innsatsfordelingsforordning som regulerer utslippskildene utenfor EUs kvotesystem, heretter kalt NETS-sektorene (Non-Emission-Trading-System). NETS-sektorene inkluderer blant annet innenriks transport, landbruk og husholdninger og står for nesten 60% av utslippene av klimagasser fra EU. Denne analysen anslår marginale rensekostnader (marginal abatement costs - MACs) for å redusere CO_2-utslipp i EUs NETS-sektorer.

Den foreslåtte innsatsfordelingsforordningen åpner for fleksibilitet på flere måter. For det første vil det være adgang til å kjøpe og selge NETS-utslippsrettigheter over landegrensene. På dette punktet forutsetter vår analyse full fleksibilitet. Forordningen foreslår videre fleksibilitet både vis-a-vis kvotepliktig sektor (ETS) og vis-a-vis endringer i bruk av skog og andre landarealer (LULUCF). Vi kvantifiserer MAC-ene under ulike forutsetninger om disse to fleksibilitetsmekanismene. Vi varierer også forutsetningene om nivået på utslipp i referansebanene og om reduksjonen av andre klimagasser enn CO_2. I et basisscenario er det lagt til grunn proporsjonal reduksjon av alle drivhusgassene, samt ingen fleksibilitet overfor ETS- og LULUCF-sektorene. Dette resulterer i en 9% reduksjon i CO_2-utslipp i NETS sektorene fra 2030-referansescenarioet i EU (2016). 11 andre forskjellige kombinasjoner av antakelser gir oss kutt i utslippene på mellom 4% og 18%.

Basert på scenarioene har vi estimert en MAC-kurve for NETS-sektorene ved hjelp av den globale numeriske generelle likevektsmodellen SNOW. MAC-kurven kan brukes til å vurdere marginalkostnadene ved ulike mål for utslippsreduksjon i EUs NETS-sektorer. De beregnede MAC-estimatene ligger i området 25-158 € /t CO_2. De moderate kostnadene reflekterer at de to referanseframskrivningene som ligger til grunn fra EU-kommisjonen (EC, 2016) og fra medlemslandene (EU, 2017b), allerede viser relativt lave utslipp. Den estimerte MAC-kurven er konveks, noe som innebærer at økte ambisjoner om utslippsreduksjoner i NETS øker de marginale rensekostnadene relativt mer. Usikkerheten er belyst med sensitivitetsanalyser av alternative forutsetninger og sammenligninger med tilsvarende scenarioer i andre analyser. SNOW-scenarioene ligger innenfor referanseområdet for tidligere analyser, og følsomhetsanalysene indikerer relativt liten effekt av alternative parametervalg når utslippsreduksjonene er nokså små.

Vi har analysert to scenarioer i detalj: basisscenarioet på 9% utslippsreduksjon og scenarioet som representerer den største reduksjonen av CO_2 på 18% utslippsreduksjon. MAC-ene med en reduksjon på 9% og 18% i NETS utgjør henholdsvis 64 € /t CO_2 og 158 € /t CO_2. I begge scenarioene ser vi at transportsektoren og husholdningssektoren reduserer sine utslipp mindre enn gjennomsnittet for NETS, mens primærnæringene og andre næringer kutter tilsvarende mer. Sammenligning av de to scenarioene viser at sammensetningen av utslippsreduksjonen på tvers av sektorer er lite følsom for nivået på utslippsreduksjonen. Vi finner også at mer enn 90% av reduksjonen skyldes økt energieffektivitet og substitusjon til mindre utslippsintensive energivarer innad i sektorene; Den resterende reduksjonen oppnås ved nedskalering av produksjonen i sektorene.

Contents

1. Introduction

1.1. Background and motivation

When assessing the costs for Norway of fulfilling its 2030 targets, estimates of the marginal abatement costs (MACs) of reducing emissions not covered by the EU's Emissions Trading System (ETS) – henceforth the NETS emissions – are pivotal. Norway aims for joint action with the EU for the NETS sectors. If full flexibility across national borders is obtained, Norway anticipates saving costs of fulfilling her Paris commitments. This will depend on the MAC in the EU as compared with the MAC of meeting the targets domestically.

The European Commission (EC) proposed the Effort Sharing Regulation (ESR) of the NETS emissions in July 2016. Norway is negotiating to be part of this. The ESR has the purpose of regulating the emission sectors not covered by the ETS for the period 2021-2030. On 13th of October 2017, the Environment Council declared that the ESR is ready for starting negotiations with the European Parliament (EU, 2017a). The ESR proposes binding annual, state-specific greenhouse gas emission targets for emission sources that fall outside the scope of the Emissions Trading System (ETS) – the NETS sectors. These sectors account for almost 60% of total EU greenhouse gas (GHG) emissions.

EU's common aim for the sector is an at least 30% reduction from 2005, with country-specific targets varying between 0 and 40% based on GDP/capita. The proposed effort sharing in case Norway joins assigns Norway a 40% reduction target. Each participant must follow an emissions reduction path to ensure that its emissions continuously decrease throughout the period. The starting point of the trajectory calculation is set for 2020, as proposed by the Commission, and will be based on the average emissions from 2016 to 2018.

The EU intends to increase flexibility for NETS emission sources to ensure cost-effectiveness and fairness; see EU (2017a). This analysis looks particularly at the role of flexibility mechanisms for the EU's 2030 target for the NETS sectors. As will be elaborated in Section 1.2., there are some flexibility mechanisms in the proposed ESR that are central for this study:

i) First, there will in principle be full access to buy and sell allocated allowances among all the participating states, which will include Norway if the country becomes integrated in the ESR. If efficient mechanisms for such transfers are established, the cheapest emission cuts can be accessible for buyers and revenue attained for sellers.

ii) Second, as a one-off possibility, the EC proposes that allowances from the ETS can be used to meet NETS commitments from 2021-2030. Eligible states are allowed to meet part of their targets in NETS by not auctioning some of their ETS allowances. EU-wide, this cannot be more than 100 million tonnes (Mt) of CO_2 over the period. The decision on the exact amount an eligible nation will use must be notified before 2020 to the EC; this to ensure predictability and environmental integrity.

iii) Third, the EC proposes to accept a certain amount of credits from the Land Use, Land-Use Change and Forestry (LULUCF) sector. All states will be eligible, but to different extents according to their shares of emissions from agriculture. For the participants as a whole, the credits are limited to 280 Mt over the entire period 2021-2030 and to certain land use categories, only. The motivation for this flexibility is that additional action should be stimulated in the land use sector and that the mitigation potential is relatively small in agriculture.

iv) A fourth flexibility applies across time periods: In years where emissions within a participating state are lower than the annual emission allocation it can bank any surplus for use later. When emissions are higher than the annual emission allocation borrowing from the following year is allowed by a limited amount.

1.2. The task and the present analysis

The task given to Statistics Norway (SSB) by the Norwegian Environment Agency (NEA) is to give an assessment of the marginal abatement costs of reducing ESR emissions of CO_2 in the EU in 2030 under different assumptions. Specifically, we vary the assumptions on

- how some of the flexibility mechanisms in the ESR can be interpreted,
- from what reference situation the 2030 targets are to be met, and
- what is assumed about abatement of non-CO_2 GHGs (since only CO_2 is modelled).

Combinations of these three types of assumptions, as shown in Table 1.1, leave us with 12 different abatement scenarios spanning from 4% to 18% reduction targets of the NETS CO_2 emissions. See also table A.1 in Appendix A for more information of the calculations of the reduction targets.

Table 1.1 Simulated percentage reductions of CO_2 in the study

	a: Reductions as for other GHGs		b: No reduction in other GHGs	
	From R1	From R2	From R1	From R2
Policy scenarios 1: No adjustment for ETS and LULUCF flexibility	9 %[1]	13 %	11 %	18 %[2]
Policy scenarios 2: Adjusted with ETS and LULUCF flexibility linearly	4 %	9 %	6 %	13 %
Policy scenarios 3: Adjusted with ETS and LULUCF equally each year	6 %	11 %	9 %	16 %

[1] Defined as the basic scenario and one of the key scenarios in this analysis.
[2] Used as the other key scenario in the analysis.

When it comes to the flexibility assumptions, i) buying and selling of allowances are assumed to be efficiently and fully implemented (and also be accessible to Norway). The policy scenarios differ in their assumptions on whether flexibility mechanisms ii) vis-á-vis ETS and iii) vis-á-vis LULUCF are used and, if so, how the adjustments are spread across the period 2021 to 2030. In Policy scenarios 1 the flexibilities are not exploited. In Policy scenarios 2 they are fully used, and the use increases linearly over the period 2021-2030. In Policy scenarios 3 they are also fully used and to the same extent in each of the ten years. Also note that the analysis does not account for iv) flexibility across years, i.e., we implicitly assume that the target for 2030 is not adjusted because of behaviour the preceding years.

The percentage reductions are also affected by from which reference situation the target is assumed to be met. NEA specifies two alternatives, R1 and R2 given in EC (2016) and EU (2017b), respectively. R1 is based on the projected 2030 CO_2 emissions in the "official" reference path of EC (2016). R2 is based on the sum of 2030 emissions as projected by each member state, see EU (2017b).

Finally, since the task only includes CO_2 emissions, the targets need to be adjusted for anticipated abatement of other GHGs. NEA has provided calculations of CO_2-reductions based on two stylised assumptions: a). Proportional abatement for all GHGs, including CO_2 and b). no abatement of other GHGs in addition to what is anticipated in the references R1 and R2. We refer to Appendix A for more details on the task. This analysis uses the global Computable General Equilibrium (CGE) model SNOW. From a given reference situation in 2030, the model simulates CO_2-emission reductions in the EU ESR sectors as given in Table 1.1, and calculates uniform marginal carbon prices for the NETS sectors.

Section 2 presents the model, Section 3 the main assumptions underlying the analysis and Section 4 the estimated MAC curve based on the simulations. In Section 5 we dig deeper into the results by focussing on two key scenarios, while Section 6 concludes.

2. An overview of the SNOW model

We use the global version of the multi-sector computable general equilibrium (CGE) model, SNOW[1], that is developed to analyse CO_2 abatement policies. CGE-models combine behavioural assumptions about economic agents, all assumed to behave rationally, with the assumption that all markets are in equilibrium. Hence, it is possible to study economy-wide impacts of policies that are introduced to some or all sectors of the economy. The model enables us to compare outcomes of different policy regimes ex-ante and to study counterfactual scenarios.

The SNOW model assumes optimising agents: producers maximise profits and representative consumers maximise welfare. Labour and capital are mobile across all industries *within* a region, but immobile *across* regions. Each industry produces one good. In addition to production in industries, household consumption, government consumption and investments are modelled separately.

The global version of the SNOW model is based on the *Global Trade Analysis Project* dataset (GTAP 9.0), which includes detailed national accounts data on production and consumption (input-output tables) together with bilateral trade flows and CO_2 emissions for up to 112 regions and 57 industries (Aguiar et al., 2016). The grouping of sectors and regions in the model is optional. See Table 3.1 for the aggregation of regions and Table 3.2 for the aggregation of sectors used in this analysis.

2.1. Production

The production technologies of all industries (see Table 3.2) are described by nested Constant Elasticity of Substitution (CES) functions that capture the combinations of capital, labour, energy and intermediate products in each industry.[2]

For most commodities, the combination of capital, labour, energy and intermediate products that is used in production can change, depending on prices, see Figure 2.1 and 2.2. Substitution possibilities between different inputs are represented by the (constant) substitution elasticities. The elasticity of substitution determines how the relative use of inputs changes as the relative prices change. The larger the value of the elasticity, the easier it is to substitute one good for another.

Figure 2.1 illustrates that at the top level, a CES aggregate of intermediates trades off with an aggregate of energy, capital and labour, subject to a constant elasticity of substitution. At the second level, a CES function describes substitution possibilities between demand for an energy aggregate and a value-added aggregate of labour and capital. At the third level, capital and labour substitution possibilities

[1] **SNOW** is **S**tatistics **NO**rway's **W**orld model, see e.g. Böhringer et al. (2017a, 2017b). The model is programmed in GAMS/MPSGE (Rutherford, 1999).

[2] The nested CES function (Varian, 1992) is standard in CGE models. The functions nest inputs and quantify their use according to values for substitution elasticities and share parameters.

within the value-added aggregate are captured by a CES function, whereas different energy inputs (coal, gas, oil and electricity) enter the energy aggregate. Other (non-energy) intermediate inputs are aggregates of domestic and imported goods with substitution possibilities.

Production of resource-based goods as extraction of fossil fuels (coal, oil, gas) are modelled differently in two ways, see Figure 2.2. First, these sectors use fossil fuel *resources*, provided in limited amounts, in addition to other inputs. Second, all inputs other than the fossil fuel resources are used in fixed proportions, i.e., the substitution elasticities among them are assumed to be 0. Fossil fuel resources are sector-specific and country-/region-specific.

Capping or pricing CO_2-emissions in production sectors gives incentives to the producers to adjust production technologies. The nested CES-functions model this without specifying the possible technological or production mode changes. The capital-labour-energy aggregate represents possibilities for substituting labour and capital for energy, i.e., energy efficiency improvement can take place depending on the CES substitution elasticity. Similarly, the energy mix in the lower levels of the nests can be altered for given energy input, according to the substitutability in these nests.

The CES elasticities determine the potentials for abating CO_2 for given policies. The values for the elasticities used in the CES-functions are based on international empirical studies (see Section 2.5). Thus, historical data are used to represent abatement possibilities in 2030, and Section 6 discusses the reliability of the results in light of other forward-looking, comparable studies.

Figure 2.1 Production technology (nested CES structure) of most goods. L denotes nests with Leontief structure, i.e. no substitution possibilities

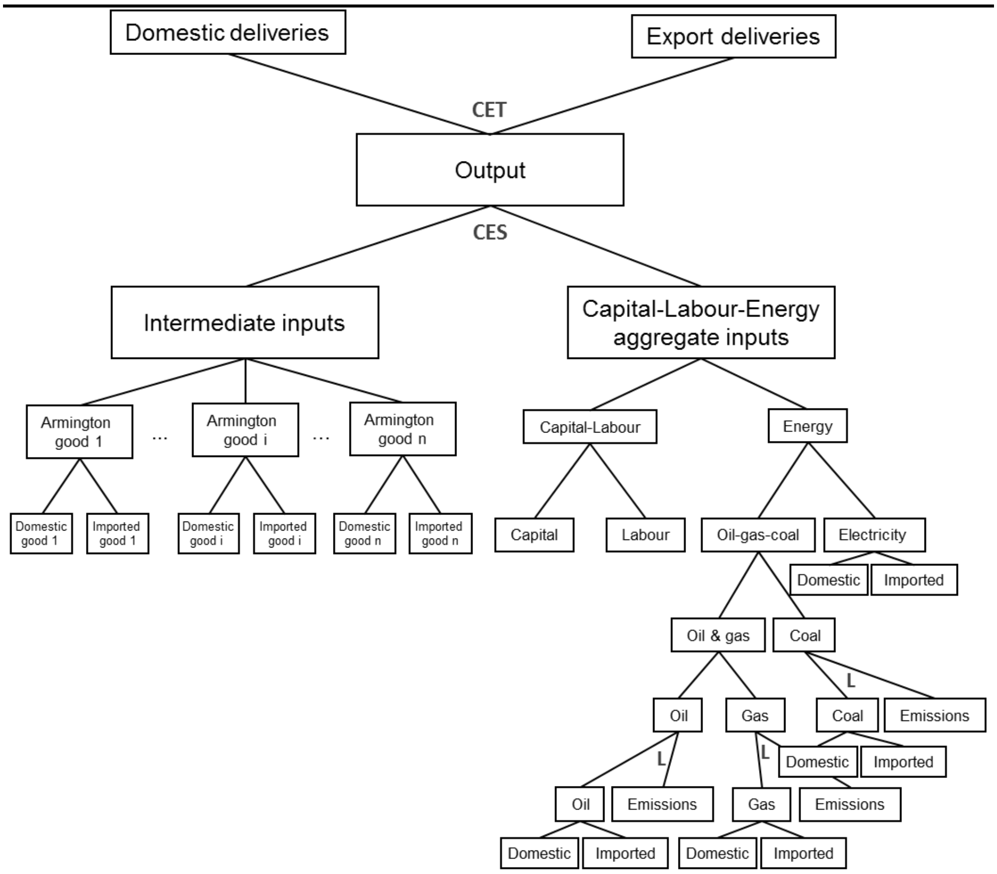
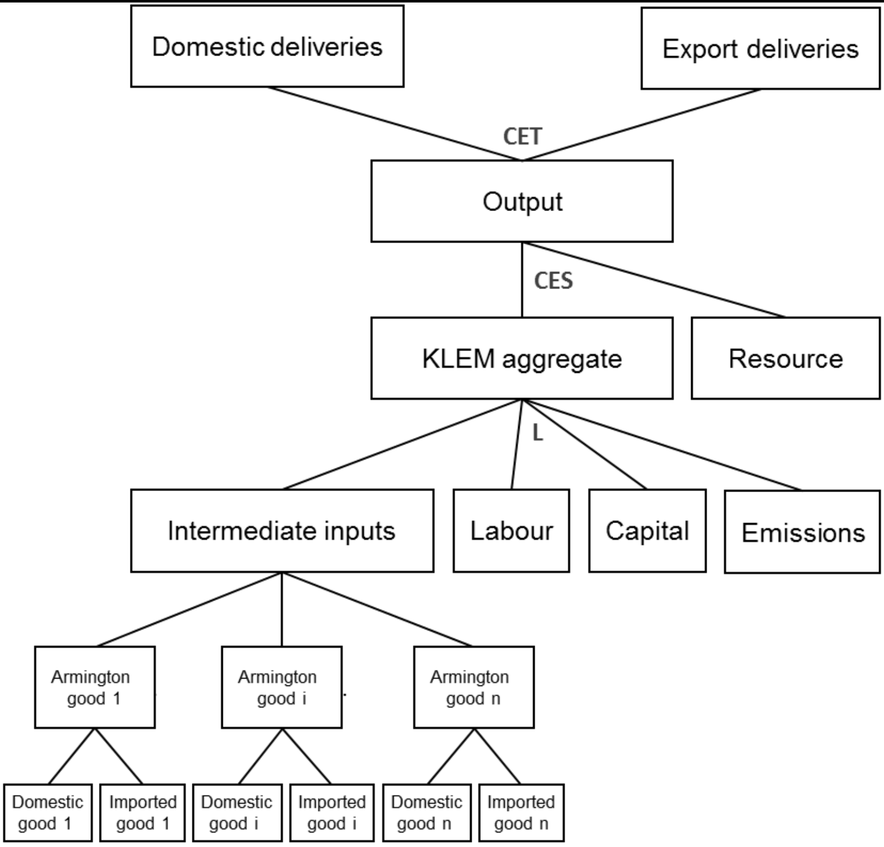


Figure 2.2 Production technology (nested CES structure) for resource-based goods. L denotes nests with Leontief structure, i.e. no substitution possibilities

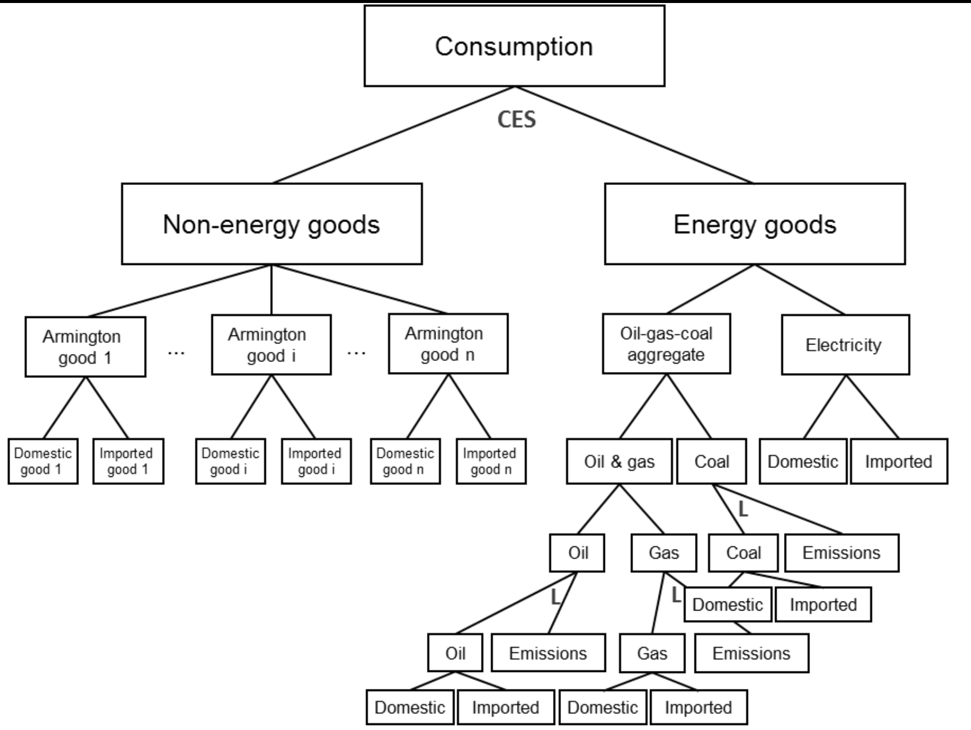


2.2. Household consumption

Final consumption in each region is determined by the representative household who maximises welfare subject to a budget constraint. The representative household in each region receives income from the three modelled primary factors (labour, capital, and fossil-fuel resources) and tax revenues (net of subsidies) and subtracts expenses to fixed investments (i.e., a given demand for savings) and government provision of public goods and services (given exogenously) to determine the budget constraint.

Consumption demand of the representative agent is modelled with a CES function that combines consumption of a composite of energy goods and an aggregate of other (non-energy) consumption goods, see Figure 2.3. Similar to the production functions, the CES substitution elasticities represent the inclination of households to improve energy efficiency, substitute electricity for fossil fuels or change fuel mix. Energy goods are used for both transport and heating.

Figure 2.3 Household consumption (nested CES structure)



2.3. Trade

Bilateral trade is specified following the Armington's differentiated goods approach, where domestic and foreign goods are distinguished by origin (Armington, 1969). This implies that prices of traded goods may develop differently among regions. All goods used in the domestic market in intermediate and final demand correspond to a CES composite that combines the domestically produced good and the imported good from other regions. Similarly, output can be delivered to the domestic market or exported, according to a CET (Constant Elasticity of Transformation) function; see Figure 2.1 and 2.2. A balance of payment constraint incorporates the base-year trade deficit or surplus for each region.

2.4. Emissions

The model includes CO_2 emissions that stem from energy use; see Figures 2.1 to 2.3. The CO_2 emissions are linked in fixed proportions to the use of fossil fuels in production and consumption, with CO_2-coefficients differentiated by the specific carbon content of fuels. Abatement of CO_2 emissions takes place by fuel switching or energy savings (either by reduction of production or consumption activities or by substitution from fuel to non-fuel inputs). No new climate technologies are explicitly modelled, but represented by substitution possibilities as described above.

2.5. Calibration of the model

We follow the standard calibration procedure for applied general equilibrium analysis: the base-year input-output data determine the share parameters of the cost and expenditure functions, so that the economic flows represented in the data are consistent with the optimizing behaviour of the model agents. The SNOW model is calibrated to GTAP data for 2011, and the calibrated solution determines the technologies, input-output structures and consumption pattern.

Substitution elasticities are taken from pertinent econometric literature. The GTAP database provides substitution elasticities in production (between primary factor inputs), with substitution elasticities in the range of 0–1 (Aguiar et al., 2016; Okagawa and Ban, 2008). Emissions are linked to energy goods in fixed proportions, according to base year data. Substitution elasticities in resource-based fossil fuel extraction industries are calibrated to match exogenous estimates of fossil fuel supply elasticities (Graham, Thorpe and Hogan 1999; Krichene 2002). Elasticities in international trade are based on the GTAP database and McDaniel and Balistreri (2002). We present sensitivity analysis of the international trade elasticities; see Section 6.1. The econometric literature is scarce on CES estimates in household consumption, and substitution elasticities are set in the same range, 0-1.

3. Assumptions in the analysis

Projecting future emissions and MACs involves large amount of information, including anticipations of developments in technologies, preferences, economic conditions, etc. The model tool and the approach we use for projecting the 2030 marginal abatement costs of different NETS climate policy ambitions are based on a number of assumptions, simplifications and standardised procedures. This section outlines the main assumptions made.

Both because of the complex economic system and because future projections are the task, the conclusions must be interpreted with caution. To assess the robustness of the results of the present analysis, we use two main approaches:
- sensitivity analysis,
- comparisons with other, related studies.

The sensitivity analysis of trade-related elasticities is presented in Section 6.1. Several sections involve comparisons with other studies: We compare the reference scenario simulated with the SNOW model with the reference scenario in EC (2016) in Section 3.3 below. The responses of capping CO_2 emissions in SNOW is compared with those in Aune and Fæhn (2016) and IEA (2012) in Section 6.2, while the relative magnitudes of technological vs. downscaling responses are assessed compared to existing results for Norway in Section 5.1. See also conclusions in Section 7.

3.1. Model assumptions

The model we use is calibrated to 2011 as mentioned above. This implies that benchmark data, technologies and policies are as in 2011. Abatement policies are implemented in the model as exogenous emission caps. We assume that the emission caps are met by uniform carbon pricing faced by the agents in the covered sectors. These can for example be regarded as cap-and-trade systems; cf. Section 4. The uniform carbon prices represent the marginal abatement costs corresponding to each target and will be computed by the model.

The emission constraints can be specified for each sector and each region separately or for groups of regions and sectors. We have aggregated the data to 8 regions and 15 production sectors; see Table 3.1and 3.2. Important to note here is that EUR is one aggregate region, comprising the EU and EFTA except Norway. Norway is a separate region.

Table 3.1 Regions in the current SNOW version

Code	Explanation
NOR	Norway
EUR	European Union (and EFTA without Norway)
USA	United States
CHN	China and Hong Kong
OOE	Other OECD
G20	Other G20
OEX	Oil exporters
LIC	Other low income countries
MIC	Other Middle income countries

The 15 production sectors include five energy sectors: *Coal*, *Crude oil*, *Natural gas*, *Refined oil* and *Electricity*. This disaggregation of energy goods enables us to differentiate energy goods by CO_2 intensity and degree of substitutability. Commercial air, water and land transportation are distinguished. *Primary* industries include agriculture, forestry and fishery. All remaining industries are aggregated into one sector (*Other*).

Table 3.2 also shows how the sectors are distributed between NETS and ETS. Given the aggregation, we are not able to place sectors partly in NETS and partly in ETS, so we chose the category where most of the sectors' emissions belong. Note that we have not modelled a third category for sectors covered by neither ETS nor NETS. This is not realistic; large parts of the transport activities are international and not covered by national commitments. This particularly applies to transport by air and water. Since this study focuses on NETS, we have placed these two sectors as part of ETS. This will of course affect the results for the ETS emissions and MACs, but the indirect effects on NETS results (MACs) turn out to be insignificant.[3]

The NETS emission sectors in the study include transportation on land (labelled *Transport* in Table 3.2), *Primary* industries, *Other* industries and *Households*. It is important to bear in mind that this implies that no domestic air and water transport forms part of NETS, while international commercial land transport is included. This misrepresents the NETS sector somewhat. It is also important to note that besides commercial transportation represented by the three transport production sectors, transport also takes the form of own transportation by production sectors and households. We cannot distinguish emissions from these activities from other emissions from the production sectors and households. We will come back to some of these classification issues in the analysis below.

[3]See Section 6, where we have investigated the magnitude of such indirect effects in a sensitivity analysis.

Table 3.2 Production and consumption sectors in the current SNOW version

Group	Code	Explanation	ETS/NETS
PRODUCTION			
Energy goods	COL	Coal (extraction and transformation)	ETS
	CRU	Crude oil (extraction)	ETS
	OIL	Refined oil (, coal etc.)	ETS
	GAS	Natural gas (works)	ETS
	ELE	Electricity (and heat)	ETS
EITE	I_S	Iron and steel	ETS
	CRP	Chemicals	ETS
	NFM	Non-ferrous metals	ETS
	NMM	Non-metallic minerals	ETS
	PPP	Pulp, paper and printing	ETS
Transport	OTP	Transport (by land)	NETS
	WTP	Transport by water	ETS
	ATP	Transport by air	ETS
Other	AGR	Primary (industries)	NETS
	AOG	Other (goods and service industries)	NETS
CONSUMPTION			
	C	Households	NETS
	G	Government	NETS[1]
	I	Investment	NETS[1]

[1] These have no or insignificant emissions. Moreover, these sectors are treated as exogenous in the model and will not be included as NETS sectors in the analysis.

3.2. Policy assumptions

The sectors comprising EU ETS and those comprising NETS have separate constraints, and so have the ETS and NETS sectors in Norway. As for the ETS sectors, we allow emission trading within the NETS-sectors – also across the EU and Norwegian borders. In other words, we model the NETS sectors as a hypothetical market for emission allowances, similar to the ETS. Such a market can be regarded as a cost-effective way of meeting the target.

We assume that also some other regions (USA, OOE, G20, see Table 3.1) implement abatement policies. In the reference case, we assume that these regions apply emission reduction targets that are half of those implemented in the EU and Norway.

Since one reasonable interpretation of the policy scenarios is that only the NETS reduction targets vary as in Table 1.1, we have performed a sensitivity analysis of what simultaneously varying the other targets implies. This is found to have virtually no effect. We have therefore chosen to vary all targets equally (except in the other abating regions than EUR and NOR, where targets are always the half).

The ESR for 2021-2030 sets annual emission reduction targets for each country and allows for flexibility across years. This implies that the remaining emission cuts necessary in 2030 will depend on the cuts in all previous years. In this study we assume that each year's target is exactly met, including the 2030 target.

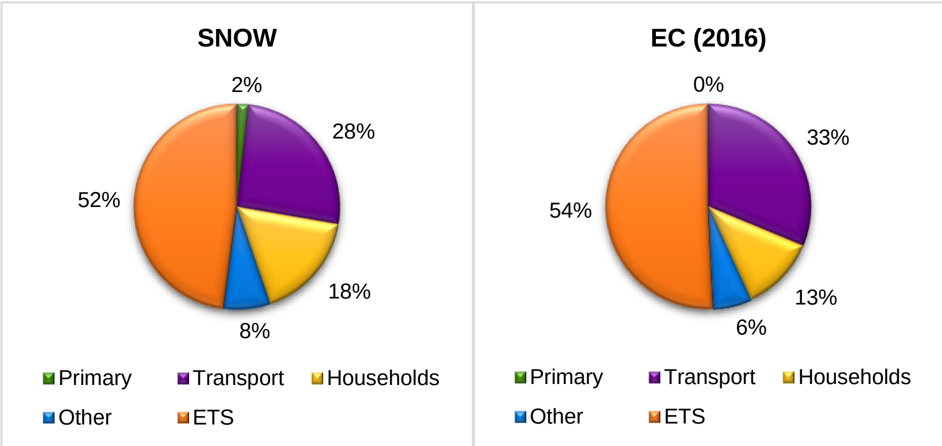
3.3. Comparing reference scenarios

This section compares two reference scenarios: the reference scenario in SNOW and the reference scenario R1 for 2030 in EC (2016), of which detailed information is available. The main purpose of this comparison is to assess whether the SNOW-model (that is based on 2011-data) gives a proper picture of the economy also in 2030. It is particularly important to reveal possible differences between the levels and compositions of energy-related CO_2 emissions in the two reference scenarios.

The first observation is that the *level* of energy-related CO_2 emissions in the NETS sectors is 25% lower in the 2030 scenario R1 (2844 Mt CO_2) than the 2011 base level in SNOW (3801 Mt CO_2). CGE-models like the SNOW model tend to produce equal relative changes as response to relative shifts, irrespective of the reference level. Therefore, if this difference reflects fairly proportional deviations in all sectors, i.e. the *compositions* of emissions are quite similar, the analysis will be representative for 2030 if the constraints in the policy scenarios are formulated in terms of percentage abatement targets and impacts on quantities and welfare are reported in relative terms. This is taken care of by the use of CES functions, constant elasticities of scale and no imposed quantitative restrictions on economic responses, see also Bye et al. (2016). Therefore, the MACs are reported in terms of CO_2 prices for different *percentage* abatement targets.

Second, we observe that the *composition* of emissions in the SNOW model reference scenario and in the EC (2016) reference scenario for 2030, are quite comparable, as reflected in Figure 3.1. This eliminates much of the danger that the compositions of the emission sources produce MAC differences due to different sectoral patterns. Figure 3.1 aggregates the data on emissions from SNOW and the reference scenario R1 in order to make the NETS sectors as comparable as possible. Note, however, the sector categories are not completely overlapping. One difference is that emissions from *Households* and *Primary industries* in SNOW comprise some emissions from private transportation, while these emissions are included in *Transport* in the reference scenario R1. The sum of their shares is therefore most relevant to compare: both constitute 46%. The rest of the NETS' emissions are related to buildings, as well as some stationary combustion for machinery in construction, motor vehicles and repairs, etc. The ETS sectors constitute 52% and 54% respectively in SNOW and EC (2016).

Figure 3.1 The composition of emissions in the reference scenarios, SNOW and R1 (EC, 2016)

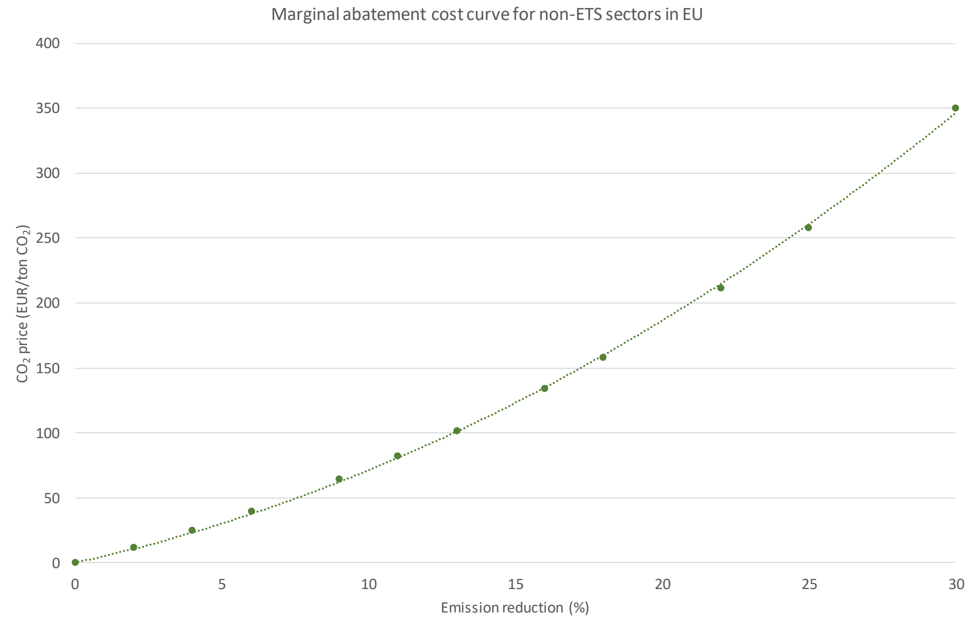


4. Constructing a MAC curve for the NETS sector

Figure 4.1 shows the marginal abatement cost (MAC) curve for the NETS sector. The MAC curve is generated by solving the SNOW model for different emission reduction targets and reading out the marginal abatement costs (MACs) for the different targets. These cost estimates are found by assuming that the economy as a whole minimises the abatement costs in the NETS sectors under a number of modelled restrictions, including the present policy interventions (taxes and subsidies), the market conditions, the resources in the economy and the external international surroundings. This solution will be realised in a competitive market for NETS emission allowances. We, thus, simulate such a hypothetical EU-Norwegian market for emission allowances in the NETS-sector. The allowance price (CO_2 price) that evolves in this market for each given target, represents the MAC corresponding to that target.

The MAC curve plots each pair of *target* and corresponding *MAC* for all the reduction targets in the range estimated by the NEA, 4% to 18% (marked in Figure 4.1), see Appendix A. In addition, we have extended the range of reduction targets in each direction, so that the area from 0 to 30% on the x-axis is covered. This is done in order to explore the curvature of the MAC curve. The CO_2 price[4] – or MAC – in the NETS sector can be read from the y-axis.

Figure 4.1 Marginal abatement cost (MAC) curve for the NETS sector



The dots on Figure 4.1 are the results from the model simulations. We have estimated the MAC-curve (2nd degree polynomial) from these 12 data points, shown by the dotted line. The estimated equation is:

$$y = 0.2211x^2 + 4.9131x$$

where *y* is the CO_2-price in NETS (€/t CO_2) and *x* is the emission reduction (measured in percent from the reference). The MAC curve is convex, implying that a doubling of the reduction target more than doubles the MAC. This also means that the total abatement cost, represented by the area below the MAC curve, more than quadruples.

Appendix B presents the data underlying the estimation.

5. Analysing two key policy scenarios: 9% and 18% reduction targets

We compare the two reduction targets to investigate how the scale of the ambition affects the abatement composition and costs. The 9% reduction target can be regarded as a base policy scenario, as it represents the change from the "official" reference scenario of EC (2016) to Policy scenario 1 (before any adjustments for ETS and LULUCF flexibility). The 18% reduction target is the largest given from the NEA, see Appendix A.

[4] The data in SNOW is measured in $. We use an exchange rate of €/$ of 1.3 that corresponds to the 10 years' average between 2007 and 2017 according to The Norwegian Central Bank. This is chosen instead of the base year (2011) rate, because it represented a peak, while the base year data ideally should reflect a steady state.

5.1. Abatement compositions

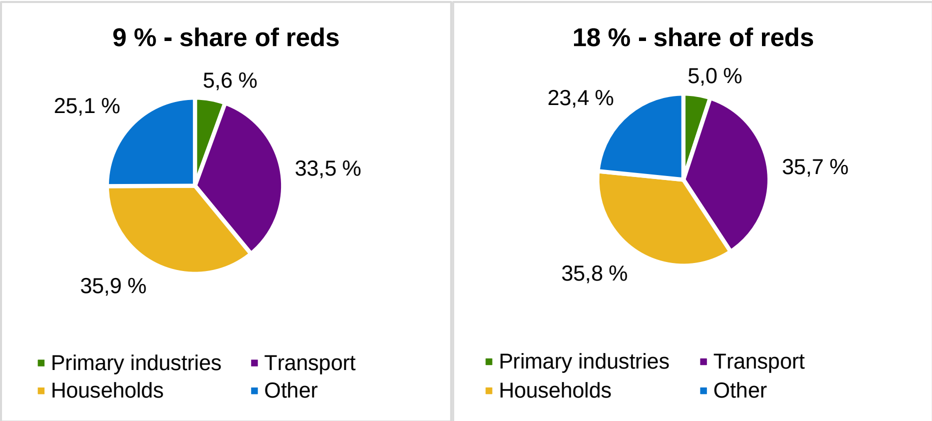
The 9% and 18% reduction targets take place disproportionally across the sectors: While the *Transport* sector and *Household* sector (where most of the emissions are due to private transport) reduce their emissions less than the average, the *Primary* and the *Other* industries cut correspondingly more; see Table 5.1. This reflects the variation in marginal abatement costs in the sectors.

Table 5.1 Emission reductions in NETS sectors, %

NETS reduction targets:	9%	18%
Transport	8%	16%
Household	8%	16%
Primary	12%	22%
Other	13%	25%

The resulting abatement under the two reduction targets (9% and 18%) is distributed across the four NETS sectors as shown in Figure 5.1. Though we can observe that somewhat more of the reductions take place in *Transport* as the ambition is rising, the composition is fairly insensitive to the scale of the ambition. This indicates quite equal steepness of the MAC curves across the NETS sectors.

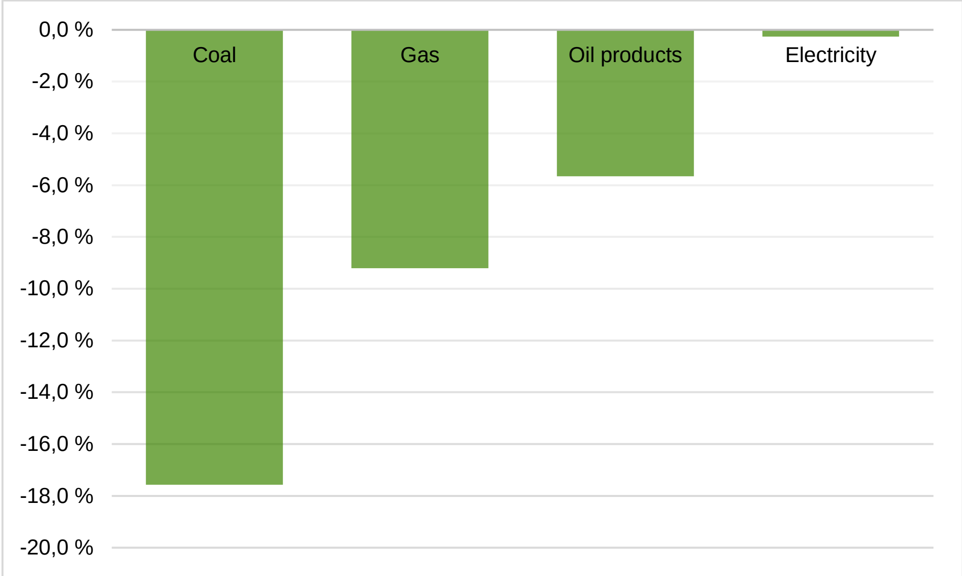
Figure 5.1 Composition of abatement across NETS sectors, 9% reduction target (left), 18% reduction target (right)



It turns out that more than 90% of the abatement is a result of increased energy efficiency and change of energy mix within the NETS sectors. The remaining mitigation is achieved by reducing the activity level of the NETS sectors. (See Figure 6.3 for sectoral information.) The share that takes place as technological adaptations (energy efficiency and energy mix changes) is high relative to studies of Norwegian abatement responses for 2030 in Fæhn et al. (2013) and Fæhn and Aune (2016).

As can be seen from Figure 5.2, it is first of all the use of coal that falls, but also gas and refined oil products face reduced domestic demand in EU. There is a marked substitution towards electricity in the energy mix.

Figure 5.2 EU demand for energy goods with 9% reduction of CO_2 emissions (change from the reference scenario)



5.2. Abatement costs

As explained in Section 4, the CO_2 price in NETS reflects the marginal abatement cost of a particular reduction target.[5] In the 9% case, it amounts to 64 €/t, while the 18% case (doubling) implies a rise to 158€/t (more than doubling). The relative increase is larger than for the abatement because of the convex MAC curve.

The total abatement costs in the two cases can be computed as the area (integral) below the MAC curve between zero and the respective reduction target. The interpretation is that the smooth MAC curve can be regarded as numerous small abatement measures ranked according to their costs per abatement of CO_2 emissions. The larger the abatement ambition, the more measures will be necessary, and the higher will be the cost of the last measure (i.e., the marginal cost). To find the total costs, we need to sum the costs of all these small measures.

In terms of welfare, the computed total abatement costs in the 9% and 18% cases amount to losses of 0,05% and 0,26% of welfare[6], respectively. Again, the convexity of the MAC implies a large extra cost of doubling the reduction target from 9% to 18%.[7] These minor estimated welfare impacts do not include the abatement costs in other sectors than the NETS sectors, the gains of reduced climate effects or other environmental externalities.

6. Assessing uncertainty

To assess the robustness of the results of the present analysis, we present sensitivity analyses in Section 6.1 and comparisons with other, related studies in Section 6.2. Section 6.3. concludes on the uncertainty assessments.

[5] The reference scenario includes base year energy taxes, but no explicit CO_2-price.

[6] Welfare is measured as the Hicksian equivalent variation, i.e, the household income change from the reference scenario that is necessary to restore the utility level (based on ex-ante relative prices).

[7] A linear MAC would result in four times the total abatement cost when doubling the ambition; here it is about five times due to the convexity.

6.1. Sensitivity analysis

Obviously, the results of introducing a cap on NETS emissions in the EU will differ across model studies depending on the qualitative and quantitative modelling of responses to the policy change. Besides the initial composition of emission sources, which is addressed in Section 3.3, the responses of policies will depend highly on the substitution elasticities in the model, i.e. how easy it is to replace activities/goods with each other in response to relative price changes.

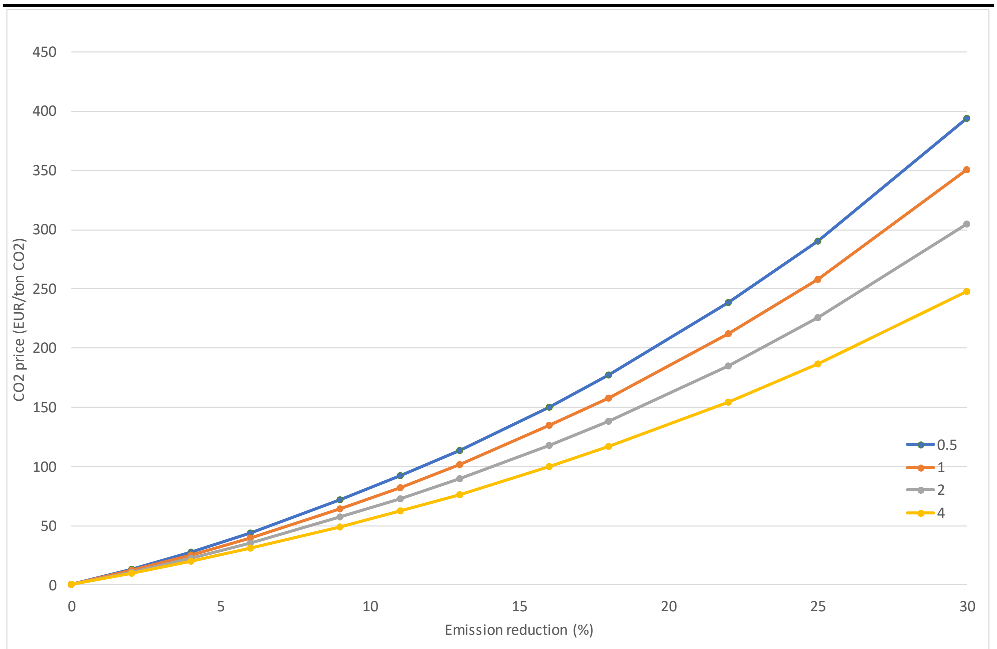
Model simulations tend to be sensitive to trade (Armington) elasticities, and the empirical estimates in the literature vary. Therefore, the first subsection below addresses the sensitivity of the results to the trade elasticities. They determine how well domestic and foreign varieties of the same good can substitute each other in consumption and as intermediate inputs. Other elasticities could have been chosen, as well. In general, increasing (decreasing) elasticities increases (decreases) the flexibility of the model, implying that, for instance, emission caps become less (more) difficult/costly to meet. Since trade elasticities apply to more or less all goods and services in the model, they have a rather generic impact across the whole economy. This has also motivated our choice.

The other sensitivity test we have performed concerns the interaction between the NETS and the ETS sectors. We investigate how sensitive the marginal abatement costs for NETS in the EU are to the assumptions about emissions in the rest of the economy.

6.1.1. Varying the trade elasticities (international competitiveness)

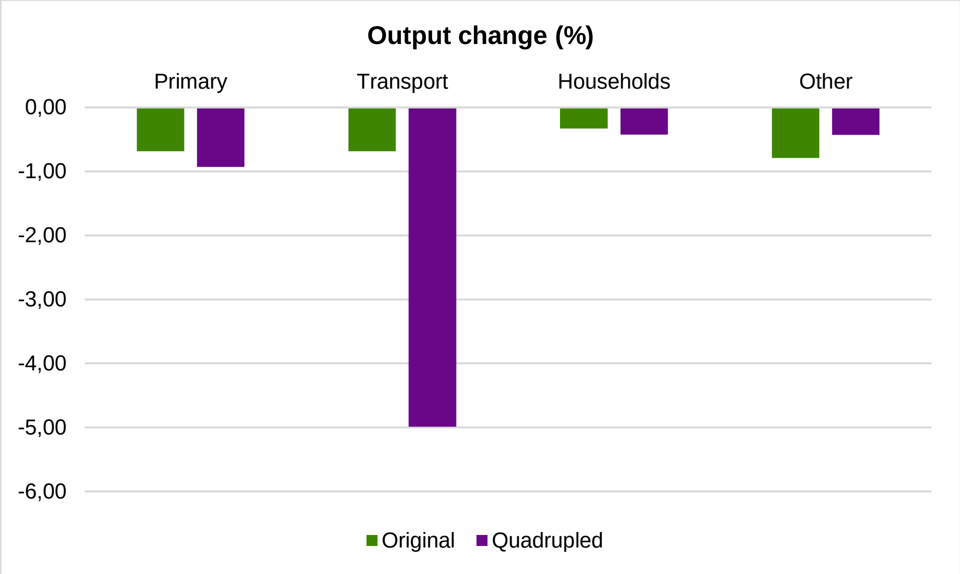
The marginal abatement costs for the NETS sector depends on to what extent European and foreign goods can substitute each other. This sensitivity is found by varying the trade elasticities (Armington elasticities; cf. Section 2). Figure 6.1 presents the MAC curves for NETS for four different sets of trade elasticities. Compared to the original case (multiplier = 1), the NETS MAC falls with a quadrupling of the trade elasticities. In case of the base scenario, the reduction is 23%, and with increasing abatement, the relative distant increases.

Figure 6.1 MAC curves NETS sector for different trade elasticities (1 = original elasticities; 0.5,2,4 = multipliers of the original elasticities)



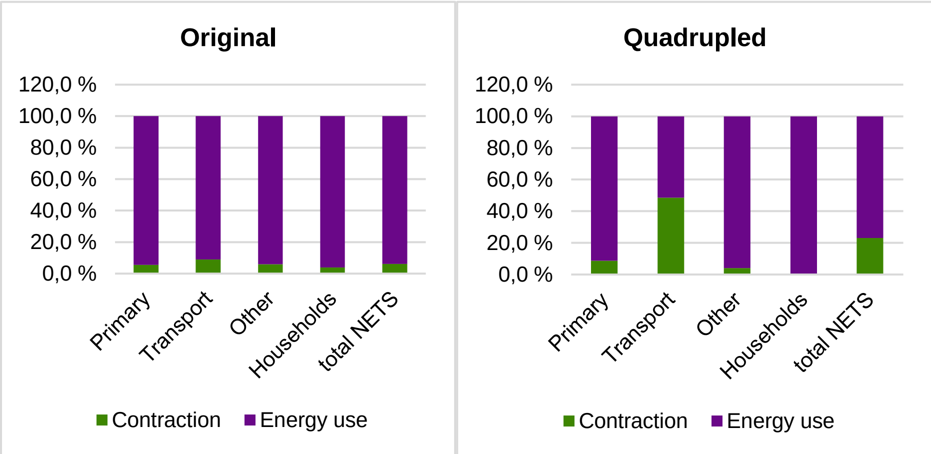
One reason for lower MACs with higher trade elasticities is that reducing domestic production and substitute it with imports will be less of a sacrifice for Europeans, since the goods are perceived as more homogenous. The result is larger European output reductions. Because of the higher exposure to foreign competition, prices of European goods cannot be raised as much as with the original elasticities without large domestic output reductions. European *Transport* activity does, for instance fall by 5% compared with 0,7 % with the original trade elasticities when the NETS reduction target is 9%; see Figure 6.2.

Figure 6.2 Output changes in NETS sectors with emission reduction target of 9%, reference and quadrupled trade elasticities



When output of the most emission-intensive, trade-exposed NETS goods in Europe falls, this facilitates the necessary cuts in emissions at lower marginal abatement costs. Compared with the original Armington elasticities case, less of the abatement taking place will now be energy efficiency and energy mix changes and more will result from output contractions in emission-intensive sectors. Figure 6.3 illustrates the compositions for the 9% shift. It reflects the larger output contractions taking place in Transport when Armington elasticites are quadrupled. The flip side of the coin is that loss of European competitiveness gives rise to carbon leakage to less regulating regions and a loss in European welfare.

Figure 6.3 Output changes in NETS sectors, reference and quadrupled Armington elasticities



6.1.2. Impacts of caps in ETS and Norway

In all scenarios, we concentrate on the effects within the EU of varying the NETS reduction targets. To investigate how sensitive the marginal abatement costs for NETS in the EU is to the assumptions about emissions in the rest of the economy, we compare two cases: One with an 18% reduction target in NETS in EU, while ETS in EU has a 9% cap (as has the ETS and NETS in Norway) and one with an 18% reduction target for both ETS and NETS in EU (and Norway); see also section 5.2. We find that the CO_2 price in NETS in this sensitivity scenario is approximately the same as in the 18% reduction target scenario, 159 €/t CO_2 vs. 158 €/t CO_2. Hence, we conclude that the marginal abatement costs in NETS are virtually independent of the targets in ETS (and in Norway). We can therefore simulate the same percentage reduction targets in the ETS and NETS sectors when the NETS sectors' marginal abatement costs are calculated.

6.2. Relating results to other studies

Another approach for shedding light on the reliability of the analysis is to compare the outcomes with other, related studies with other model tools. We compare with a study using a partial energy market model for Europe with detailed technology specifications projected to 2030, LIBEMOD.[8] We also relate the results to IEA (2012) that uses an energy system model. None of these analyses explore identical policy shifts with our analysis. We discuss the main sources of discrepancies.

The LIBEMOD study in Aune and Fæhn (2016) analyses the 2030 climate targets of the EU and Norway and how the degree of flexibility across countries and emission sources within and outside the EU ETS may affect the Norwegian economy. We have access to detailed output data from this study. One of the scenarios assume, as in this report, that there is full flexibility in the NETS sector across European countries, including Norway.

The reduction target from the reference situation in Aune and Fæhn (2016) amounts to 22%. The marginal abatement cost in the NETS sector is simulated to 240 €/t CO_2 in this scenario. The CO_2 tax in the reference situation was 75 €/t CO_2, so the marginal abatement cost increase from the reference scenario is 165 €/t CO_2. For comparison, we have simulated a 22% reduction target in SNOW. The marginal abatement cost from the SNOW simulation is higher than in Aune and Fæhn (2016): 211 €/t CO_2. One explanation is that the LIBEMOD study accounts for the renewable target in 2030 through subsidised prices in the EU. This means that substitution of electricity for fossil fuels is stimulated.

The two models are different in many respects, so a discrepancy cannot be surprising. When we go more in detail on the emission compositions in the reference situations, and the 22% reduction target, we observe from Figure 6.4 that in SNOW the emissions from *Households* and *Other* constitute larger shares of the reference emissions than in Aune and Fæhn (2016), while *Transport* is correspondingly smaller. (We have included the *Primary* industries in *Transport* here, because their main CO_2 emissions arise from fishing boats, tractors etc.).

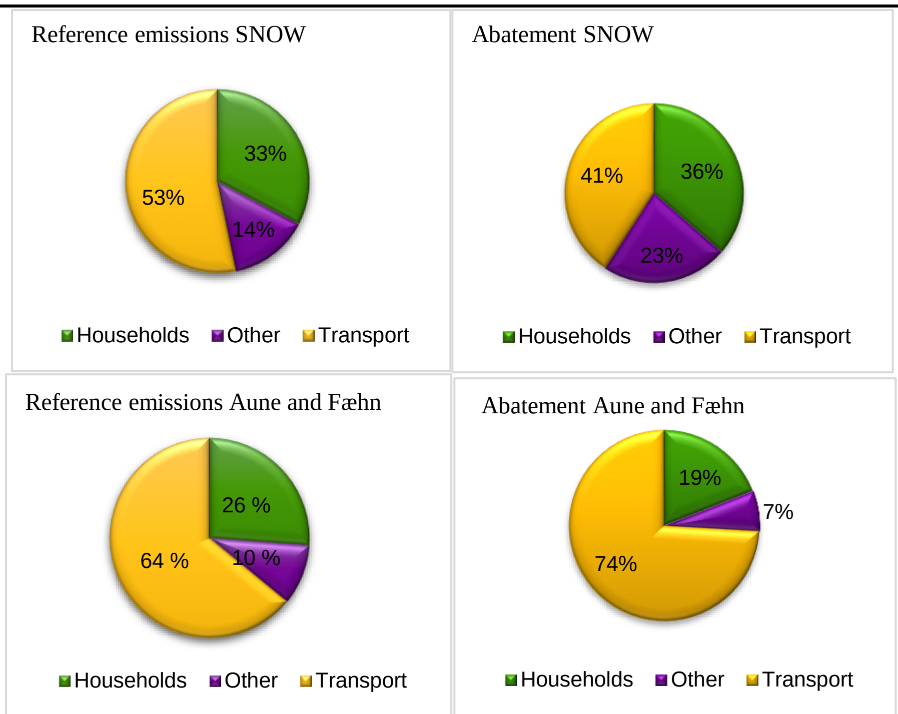
We see the same pattern in the shares in the abatement scenarios, which is reasonable. However, the abatement is not proportionally distributed. In Aune and Fæhn (2016) *Transport* has a larger share in the abatement scenario than in the reference as seen from Figure 6.4, implying that the percentage cut in *Transport* is smaller than for the NETS as a whole. In SNOW the opposite is true, i.e., *Transport* takes on a smaller reduction than 22%. A disproportionally smaller

[8] https://www.cree.uio.no/models/libemod/

emission cut in *Transport* in our study indicates that abating emissions in this sector is relatively expensive according to the SNOW model; see also Section 5.

It is important to note that the *Transport* abatement in Aune and Fæhn (2016) is exogenously estimated based on computations from IEA. For the EU, IEA (2012)'s 2-degree Celsius scenario by 2030 is fairly compatible with EU's 2030 mitigation target. However, the policy assumptions differ: IEA (2012) assumes a cost-effective solution for the EU, not separated ETS and NETS allowance markets as in Aune and Fæhn (2016). Also, the distance to the reference scenario is larger than in Aune and Fæhn (26% vs. 22%). Scrutinising the IEA (2012) analysis reveals that abatement in the EU's *Transport* sector in 2030 is of the same percentage magnitude as in the NETS as a whole. In that sense, the result falls in between those of this SNOW model analysis and Aune and Fæhn (2016).

Figure 6.4 Shares of reference emissions and abatement emissions in the SNOW analysis and Aune and Fæhn (2016)



6.3. Discussion of the uncertainty

The reliability of the computed MACs will be stronger the less sensitive they are to potentially influential, uncertain assumptions in the analysis and the easier it is to explain their deviations from, or overlaps, with those of other, convincing studies.

Our conclusions from the sensitivity analyses in Section 6.1 are that for relatively small percentage emissions cuts, as in the 9% basic scenario, the sensitivity of the MACs to the trade elasticities is modest. The MAC falls by 15 €/t CO_2 (23%) when trade elasticities are quadrupled. When they are halved, the MAC increases with 8 €/t CO_2 (12%). These relatively small variations are reassuring, though we must bear in mind that the larger the abatement, the larger the sensitivity. The sensitivity with respect to the emission cap in the rest of the economy is found to be insignificant.

The comparisons we made in Section 6.2 shows that SNOW's computed MACs for the NETS sectors in the EU are higher than in Aune and Fæhn (2016). It seems reasonable, though, since the latter studies a simultaneous introduction of a cap and a renewable target, and this will tend to reduce the necessary emissions price, measured by the MAC. The comparison also showed that Aune and Fæhn (2016) found larger cuts in transportation than in other NETS sectors, indicating that the costs of abating within transportation are relatively low. The opposite is found in the present analysis. SNOW seems to be closer to IEA (2012), where abatement costs in the transportation sector was approximately on average. These findings lead us to conclude that SNOW produces recognisable cost levels and, also, that the sectoral distribution of costs is comparable with other results. It is important to bear in mind, however, that the basis of comparison is limited, and that projections of future conditions and policies are, per definition, uncertain. Also, the economic equilibrium approach is stylised and does not include all the technological details. Therefore, it is suitable to studying *trends*, not details, and broad changes caused by the policy in focus. Moreover, it is important to bear in mind that the policies introduced for computing the MACs are emission caps comprising all NETS emissions in all EU countries. This is unlikely to characterise the 2030 policies in the EU.

One particular uncertainty in climate policy projections is associated with the future technological development. We have used four approaches for assessing whether the technological assumptions inherent in the calibration to 2011 data are relevant for the analysis of 2030:

(i) Mapped potential discrepancies between the 2011 reference and the 2030 reference constructed by EC (2016) that accounts for the anticipated changes ahead. As shown in Section 3.3, the compositions of emission sources in the two references are fairly congruent. The emission levels deviate, which has led us to study relative changes from the reference instead of absolute values. Based on experience, the levels will not significantly affect relative effects of relative changes.

(ii) Compared the MAC results with related studies. As already concluded in Section 6.2, the MACs are fairly in line with Aune and Fæhn (2016).

(iii) Compared the sectoral composition of the responses to the emission cap policies. This is also done in Section 6.2, and the results are recognisable from previous studies.

(iv) Assessed the role of technological adaptation in the responses to the emission cap policies. This feature is especially relevant for assessing the technological assumptions. As reported in Section 5.1, more than 90 % of the abatement takes place by increasing energy efficiency and changing energy mix; the rest is explained by reductions of output and consumption. That is, even if the detailed technological measures are not specified and identifiable, technological adaptations take place at a large scale both in consumption and production.

One could argue that between 2011 and 2030 the advancement of climate-friendly technologies is expected to increase the inclination to choose technological abatement solutions. Based on the observations reported in (i) to (iv) above we do, however, assess the model to have sufficient technological flexibility despite its 2011 basis and have not found reasons to adjust this characteristic.

7. Conclusions

When assessing Norway's 2030 climate policy costs, the projected marginal costs of an EU-Norwegian joint effort-sharing regulation (ESR) of the NETS sectors are important inputs. If full flexibility across national borders is allowed, Norway's government could anticipate lower costs of fulfilling the Paris commitments. A previous study by Aune and Fæhn (2016) indicates that achieving the emission reduction targets solely within own borders can be costly – a marginal abatement cost of between 500 and 600 €/t CO_2 equivalent was computed. If it is possible to buy emission allowances in the EU, as proposed in the ESR, the costs may be substantially lower – between 25 and 158 €/t CO_2, depending on different flexibility assumptions, according to our computations. The main reason for the lower prices in the EU is that EU's *remaining* required abatement in NETS sectors is relatively modest: between 4 and 18 % from the projected reference emission level in 2030.

The proposed ESR provides different flexibility mechanisms. This analysis quantifies the EU's and Norway's 2030 marginal abatement costs for the NETS sectors in a regime with the following flexibility assumptions: i) buying and selling is assumed fully flexible in the EU-Norwegian NETS sector, the assumptions concerning ii) flexibility vis-á-vis ETS and iv) flexibility vis-á-vis LULUCF are interpreted in various ways resulting in 12 scenarios for CO_2 emissions reductions in the NETS sectors, while we disregard any iv) banking and borrowing across years.

The SNOW model for the global economy is used to simulate the 12 scenarios for CO_2 emissions reductions in the NETS sectors with corresponding MACs. The computations are used to construct a MAC curve that can be exploited to assess the MACs for the EU of meeting different emission reduction targets in 2030. The MAC curve is convex, implying that a relative increase in the abatement ambition increases the MAC relatively more.

We have analysed two of the scenarios in detail: 9% and 18% emission reduction target. The 9% target is the necessary reduction in NETS from the 2030 reference scenario in EC (2016) if we disregard flexibilities proposed vis-á-vis the ETS and LULUCF sectors; it can be regarded as a base scenario. The 18% target represents the largest emission reduction target of the 12 specified scenarios.

The computed MACs of abating 9% and 18% in NETS amount to 64 €/t CO_2 and 158 €/t CO_2, respectively. In both these scenarios the *Transport* sector and *Household* sector (which includes private transportation) reduce their emissions less than average, while the *Primary* and the *Other* industries cut correspondingly more. This reflects the variation in marginal abatement costs in the sectors. Comparing the two scenarios reveals that the composition of the NETS abatements across sectors is quite insensitive to the ambition level. This indicates relatively equal steepness of the MAC curves across the NETS sectors. More than 90% of the abatement is due to increased energy efficiency and fuel switching (change in energy mix) within the sectors. The remaining mitigation is attained by downscaling of production in the sectors.

The reliability of the computed MACs will be stronger the less sensitive they are to potentially influential, uncertain assumptions and the easier it is to explain their deviations from or overlaps with those of other, convincing studies. From sensitivity analyses and comparisons, we conclude that the MAC results seem fairly robust to variations in the model's degree of flexibility and to the price in ETS, and that using 2011 data in the reference does not seem to produce too small technological responses or unrealistic sectoral composition of abatement in 2030. Both the MACs and the abatement allocation computed are comparable with results found in previous studies for the period.

These findings lead us to conclude that the MAC computations are indicative for the range of minimum costs that the EU can expect to face in 2030 in order to achieve its mitigation target for the NETS emissions compared to a business-as-usual reference. The main reasons for careful interpretations of the results are that the perspective is forward-looking, that the MAC concept is built on least costs and that the general equilibrium outcomes of CGE models like SNOW cannot be expected to be observed in any particular future year. Nevertheless, such analyses are useful tools for projecting future trends and comparing economic potentials under different policy restrictions.

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Appendix A: The task from the Norwegian Environment Agency

A.1. The contractual task

Statistics Norway (SSB) will give an assessment of the costs of reducing emissions in the EU for the sectors comprised by the EU's Effort Sharing Regulation (henceforth the ESR sectors) under different assumptions. For this task SSB will use the global Computable General Equilibrium (CGE) model (SNOW), where the EU is aggregated to one region. SNOW only includes CO_2 emissions. From a given reference situation in 2030, the model will be used to simulate data for percentage CO_2-emission reductions in the ESR sectors and corresponding marginal abatement costs (uniform carbon prices). Based on these data, a Marginal Abatement Costs (MAC) curve will be constructed. This can be exploited to assess the marginal costs for the EU of meeting different interpretations of how the ESR will affect the ESR emission reductions in 2030.

The following interpretations are to be included:

1a. A reduction in the CO_2 emissions in the ESR sectors in 2030 as for total greenhouse gas (GHG) emissions, i.e. 30% compared to the 2005 level.

1b. A reduction in the CO_2-emissions in ESR sufficient to meet the target in 2030 even if no reductions take place of other GHGs in ESR. (Most other GHG emissions are related to the agricultural sector.)

2a. As 1a, but the ESR-target is adjusted for possible flexibility vis-á-vis the European Emissions Trading Scheme (EU ETS) sectors (100 Mt) and vis-á-vis the Land Use, Land Use-Change and Forestry (LULUCF) sector (280 Mt), i.e. a total of 380 Mt. Since SNOW only model from a given reference situation in 2030, 2a. assumes that the extra ESR emission budget is added linearly. This implies an extra budget of 76 Mt in 2030 (380 Mt x 2/10).

2b. As 1b, but the ESR-target is adjusted for possible flexibility vis-á-vis the European Emissions Trading Scheme (EU ETS) sectors (100 Mt) and vis-á-vis the Land Use, Land Use-Change and Forestry (LULUCF) sector (280 Mt), i.e. a total of 380 Mt. Since SNOW only model from a given reference situation in 2030, 2b. assumes that the extra ESR emission budget is added linearly. This implies an extra budget of 76 Mt in 2030 (380 Mt x 2/10).

3a. As 1a, but the ESR-target is adjusted for possible flexibility vis-á-vis the European Emissions Trading Scheme (EU ETS) sectors (100 Mt) and vis-á-vis the Land Use, Land Use-Change and Forestry (LULUCF) sector (280 Mt), i.e. a total of 380 Mt. Since SNOW only model from a given reference situation in 2030, 3a. assumes that 1/10 of the flexibility is used each budget year, i.e. 38 Mt (380 Mt/10) in 2030.

3b. As 1b, but the ESR-target is adjusted for possible flexibility vis-á-vis the European Emissions Trading Scheme (EU ETS) sectors (100 Mt) and vis-á-vis the Land Use, Land Use-Change and Forestry (LULUCF) sector (280 Mt), i.e. a total of 380 Mt. Since SNOW only model from a given reference situation in 2030, 3b. assumes that 1/10 of the flexibility is used each budget year, i.e. 38 Mt (380 Mt/10) in 2030.

All the shifts will be analysed as percentage changes from a reference situation R1: The 2030 solution of the European Commission (EC, 2016).

Shift 1a og 1b will also be analysed as percentage changes from a reference situation R2: A scenario for 2030 consistent with the updated country-specific scenarios.

The Norwegian Environment Agency (NEA) will provide SSB with the targets for 2030 in Mt for all the policy shifts, as well as the percentage change from the reference scenarios (and/or the reference levels in Mt for 2030).

The deliverable will contain a report from the analysis with a description of how the MAC curve for the EU's ESR sectors is estimated, of the reference path and of the cost implications of the different interpretations of the ESR with uncertainty assessments. An excel file with the data basis for the MAC will also be provided.

A.2 More on the quantifications and interpretations of the percentage reduction targets

The data from NEA is provided in Table A.1. NEA has also given some supplementary information on the quantifications:

In Scenario 1a. CO_2 as well as other GHGs are reduced by 30% from 2005. Irrespective of the reference being R1 or R2, the CO_2 emissions then amount to 1 380 Mt in 2030.

In Scenario 1b.no reductions are assumed to take place of other GHGs. Large reductions have already taken place in these emissions from 2005 until today, and in the references R1 and R2 even more is expected to come from 2015-2030 according to the European Commission (EC) and the country-wise projections. In order to account for these, the targets for CO_2 emissions are calculated based on the assumption that no additional reductions in other GHGs in the ESR sectors will come on top of those already included in the two scenarios.

For Scenario R1 (based on EC) this implies a reduction of 32% in the CO_2 emissions, which renders the 2030 level at 1 341 Mt. For Scenario R2 (from the country-wise projections) this corresponds to a reduction of 33,8% for the CO_2 emissions by 2030 or to a level of 1 305 Mt.

Flexibility outside NETS (shifts 2 and 3) lowers the emission reduction target. Shifts 1-3 correspond to policy scenarios 1-3 in Table 1.1.

Table A.1 The scenarios and shifts (reduction targets, Mt CO_2 and %)

	a: Same % reduction in all GHG gases						b: No reduction in non-CO_2 emissions					
	from R1: 1515			from R2: 1595			from R1: 1515			From R2: 1595		
	target	red.	%	Target	red.	%	target	red.	%	Target	red.	%
Shift 1: 2030 target corresponding to 30% reduction from 2005	1380	135	9 %	1380	215	13 %	1341	174	11 %	1305	290	18 %
Shift 2: Adjusted with ETS and LULUCF flexibility linearly (76 Mt.)	1456	59	4 %	1456	139	9 %	1417	98	6 %	1381	214	13 %
Shift 3: Adjusted with ETS and LULUCF equally each year (38 Mt.)	1418	97	6 %	1418	177	11 %	1379	136	9 %	1343	252	16 %

Source: The Norwegian Environment Agency (Miljødirektoratet).

Appendix B: The data for the MAC curve

Table B-1 shows the numbers behind the MAC curve shown in Figure 4.1. These are the results of simulating the SNOW model.

Table B.1 MAC curve data: CO_2 abatement and CO_2 price in the NETS sectors

Abatement (%)	CO2 price (€/t CO_2)
0	0
2	12
4	25
6	40
9	64
11	82
13	102
16	134
18	158
22	212
25	258
30	350

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