Navigating various flexibility mechanisms under European burden-sharing

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Abstract
In July 2016, the European Commission presented its proposal for a regulation to reduce greenhouse gases emissions in sectors not covered by the emissions trading system with regard to post-2020 binding targets. The proposal extends the burden-sharing framework designed in 2008. This new burden-sharing, called by the European Commission as the Effort Sharing Regulation, is based on a GDP per capita rule and aims to reflect the economic capacity of each European Member State on the basis of its relative wealth. However, several papers have pointed out that this way of allocating emissions can result in great cost-inefficiencies, as the allocations do not take Member State abatement costs into account. The proposal acknowledges this issue and proposes a range of flexibility instruments (i.e., more than 15 flexibility options) that intend to enhance cost-effectiveness. This paper evaluates the proposal and analyzes the economic impacts of each flexibility option with respect to fairness and cost-effectiveness using a computable general equilibrium model. The performed analysis demonstrates that flexibility mechanisms that allow “inter-Member state flexibility” constitute the most efficient options. Specifically, they reduce compliance costs and, simultaneously, increase fairness between low-income Member States and high-income Member States.

Keywords  Effort Sharing Regulation · European Union · Climate policy · Computable general equilibrium model
1 Introduction

In July 2016, the European Commission (EC) presented its proposal for a regulation to reduce greenhouse gases (GHG) emissions in sectors not covered by the emissions trading system (ETS) with regard to post-2020 binding targets (European Commission 2016b). The proposal extends the burden-sharing framework designed in 2008 (Official Journal of the European Union 2009). This new burden-sharing is called by the EC as the Effort Sharing Regulation (ESR). The text proposes several new features of the European framework aimed at limiting GHG emissions for the period 2021–2030. As pointed out by Sartor et al. (2015), the proposal raises a new and critical challenge because it will be more difficult to comply with the 2030 targets than it was in 2020. This is mainly because the overall emissions cuts required are deeper in 2030 (− 30% with respect to 2005 levels) than they were in 2020 (− 10%). Moreover, the ESR, based on GDP per capita and not on abatement potentials, leads to the risk that a number of Member States (MS) may simply fail to meet their targets [see, for example, the analysis performed at the MS level by Sartor et al. (2015)]. If the EC still wants to use a GDP per capita rule for allocating a GHG budget across MSs, it requires the implementation of flexibility mechanisms to achieve the GHG abatement at a lower cost. The EC proposal acknowledges this issue and proposes a range of flexibility instruments (i.e., more than 15 flexibility options) that intend to augment cost-effectiveness. The aim of this paper is to evaluate the 2030 ESR and analyze the economic impacts of each of these flexibility options with respect to fairness and cost-effectiveness. I use the GEMINI-E3 model, which has been involved in the evaluation of the 2020 Effort Sharing Decision (Bernard and Vielle 2009; Böhringer et al. 2009), and more recently used in the assessment of the ESR 2030 within the context of the United Kingdom decision to leave the European Union (EU) (Babonneau et al. 2018).

The remainder of this paper is structured as follows. Section 2 presents the ESR proposal and details the flexibility mechanisms. Section 3 provides an overview of the computable general equilibrium model used to perform the simulations, and explains how the welfare cost is computed. Section 4 presents the scenario results. Section 5 concludes.

2 The effort sharing regulation

2.1 Overview

The “Energy–Climate” directive adopted in 2008 divided the European economy into two parts (Delreux and Ohler 2019; Böhringer 2014; Böhringer et al. 2009): (1) sectors subject to the European ETS were chosen from those most energy-intensive (primarily electricity generation); and (2) all other sectors (non-ETS), including the fossil energy consumption of households. The ETS constitutes an
exchange-tradable permits market for firms, characterized by one CO₂ price (Venmans 2012). The allocation of allowances is primarily based on free allowances with some auctioning. However, the Commission estimates that 57% of the total amount of allowances will be auctioned during 2013–2020, while the remaining allowances are available for free allocation. However, in the future, it is planned that auctioning will become the default method (Hepburn et al. 2006). For the non-ETS market, CO₂ abatement objectives are based on the so-called “Effort Sharing Decision”.

The ESR sets GHG emission targets for MSs according to their economic capacity, evaluated on the basis of their relative wealth measured by GDP per capita. Two rounds of burden-sharing were already defined, one for the year 2020 adopted in 2007 and the other one recently proposed for the year 2030 (European Commission 2016b). Table 1 shows these two burden-sharing.

### 2.2 Flexibility options

The EC proposal lists 19 flexibility options that are organized into five categories. The present paper adds two additional options (called F6 and F7) that extend the coverage of some EC options. All of these flexibility mechanisms are described in Table 2. It should be pointed out that if the EC used the term “flexibility instruments” in its legal documents, many of these options are more implementation choices and have a different meaning than the “flexibility mechanism” term that is used in economic literature. For example, the first category is related to what the EC calls the “target adjustment”, which is not a flexibility mechanism. Option T1 is the baseline option computed from GDP per capita and presented in Table 1. The European Council decided that these targets should be adjusted for high-income MSs, taking into account cost-effective reduction potential. The adjustment is related to MSs having a GDP per capita above the EU average in 2013 (see Table 1). It represents 11 countries, called “high-income MSs” in the proposal as namely: Luxembourg, Denmark, Sweden, Ireland, Netherlands, Austria, Finland, Belgium, Germany, France, and United Kingdom. These countries are together responsible for approximately 60% of GHG ESR emissions. This adjustment is computed from simulations performed with the PRIMES and GAINS models, in which the GHG abatements are implemented in a cost-effective manner. The PRIMES and GAINS models are two modeling tools funded and used by the EC in impact assessments and analysis of policy options. PRIMES (Capros et al. 2012) constitutes an energy systems model that simulates a market equilibrium for the EU energy system. GAINS (Amann et al. 2011) is an integrated assessment model of air pollutant and greenhouse gas emissions and their interactions. GAINS brings together data on economic development, the structure, control potential, and costs of emission sources, and the formation and dispersion of pollutants in the atmosphere. Their analysis lead to the definition of the following four groups:

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1 https://ec.europa.eu/clima/policies/ets/auctioning_en.
• Group 1: Germany, United Kingdom and France, where the gap between option 1 and the results from the simulations assuming a cost-effective implementation is below or around 5%;
• Group 2: Sweden and Finland, with a positive gap, but with some uncertainties around it;
• Group 3: Austria, Denmark, Belgium and Netherlands, with a significant gap below 15%;
• Group 4: Luxembourg and Ireland, with a gap above 15%.

| Country    | GDP per capita in €2013 | In % of 2005 levels | ESD target 2020 | ESR target 2030 |
|------------|-------------------------|---------------------|-----------------|-----------------|
| Bulgaria (BGR) | 5800 | 20% | 0% |
| Romania (ROU) | 7200 | 19% | -2% |
| Croatia (HRV) | 10,200 | 11% | -7% |
| Hungary (HUN) | 10,200 | 10% | -7% |
| Poland (POL) | 10,200 | 14% | -7% |
| Latvia (LAT) | 11,300 | 17% | -6% |
| Lithuania (LIT) | 11,800 | 15% | -9% |
| Slovakia (SVK) | 13,600 | 13% | -12% |
| Estonia (EST) | 14,400 | 11% | -13% |
| Czech Republic (CZE) | 14,900 | 9% | -14% |
| Portugal (POR) | 16,300 | 1% | -17% |
| Greece (GRE) | 16,500 | -4% | -16% |
| Slovenia (SVN) | 17,400 | 4% | -15% |
| Malta (MLT) | 18,100 | 5% | -19% |
| Cyprus (CYP) | 21,000 | -5% | -24% |
| Spain (SPN) | 22,100 | -10% | -26% |
| Italy (ITA) | 26,500 | -13% | -33% |
| United Kingdom (GBR) | 31,900 | -16% | -36% |
| France (FRA) | 32,100 | -14% | -36% |
| Germany (DEU) | 35,000 | -14% | -37% |
| Belgium (BEL) | 35,400 | -15% | -38% |
| Finland (FIN) | 37,400 | -16% | -39% |
| Austria (AUT) | 38,100 | -16% | -39% |
| Netherlands (NLD) | 38,700 | -16% | -39% |
| Ireland (IRL) | 39,000 | -20% | -39% |
| Sweden (SWE) | 45,400 | -17% | -40% |
| Denmark (DNK) | 45,500 | -20% | -40% |
| Luxembourg (LUX) | 85,600 | -20% | -40% |
| European Union | 26,700 | -10% | -30% |

These commitments refer to targets in the non-ETS part of the economy.
| Name | Definition | Source |
|------|------------|--------|
| **Target adjustment** | | |
| T1 | Baseline option | EC |
| T2 | Limited target adjustment for high-income MSs | EC |
| T3 | High target adjustment for high-income MSs | EC |
| T4a | 50% based on T1 and 50% based on a cost-effective emission reduction for high-income MSs (GHG40) | EC |
| T4b | 50% based on T1 and 50% based on a cost-effective emission reduction for high-income MSs (EUCO30) | EC |
| **One-off flexibility between ETS and non-ETS** | | |
| O1 | Baseline option, no flexibility between ETS and non-ETS | EC |
| O2 | One-off flexibility for eligible MSs with low access limits (from 2 to 4% of 2005 emissions per annum) | EC |
| O3 | One-off flexibility for eligible MSs with high access limits (from 4 to 8% of 2005 emissions per annum) | EC |
| O2b | Same as option O2 with additional MSs eligibility | EC |
| O3b | Same as option O3 with additional MSs eligibility | EC |
| **Options including LULUCF flexibility** | | |
| L1 | No use of LULUCF credits for compliance | EC |
| L2 | Use of up to 280 million tons of LULUCF credits for compliance | EC |
| **Options enhancing existing flexibility instruments** | | |
| F1 | Baseline option, i.e., inter-Member State flexibility equals 5% | EC |
| F2 | Increased permitted borrowing within the commitment period to 10% | EC |
| F3 | Central information site | EC |
| F4 | Central market place for AEA transfers | EC |
| F5 | Mandatory auctioning | EC |
| F6 | Increased inter-Member State flexibility to 10% | Own |
| F7 | Fully fungible ESR allocations | Own |
### Table 2 (continued)

| Name               | Definition                                | Source |
|--------------------|-------------------------------------------|--------|
| Options enhancing existing flexibility instruments |                                           |        |
| C1                 | Baseline option                           | EC     |
| C2                 | Biennial compliance checks                | EC     |
| C3                 | Compliance checks every fifth year        | EC     |
The adjustments must leave the total abatement of high-income MSs unchanged; which means that, if some MSs have to do less abatement, some others would have to mitigate more. Option T2 increases the ambition of group 1 by 1 percentage point, and decreases the ambition of group 3 and 4, respectively, by 3 and 9 percentage points. Group 2, however, remains unchanged. Option T3 sees high adjustments, in which the target of group 1 is increased by 2 percentage points, and 1 percentage point for group 2. In contrast, the target is decreased in group 3 and 4 by, respectively, 7 and 13 percentage points. Option T4 was suggested by Belgium, and assumes that the targets are based for 50% on option T1 and 50% on a target based on a cost-effective emission reduction computed from model runs. Two simulations were utilized to compute this latter target, the GHG40 projection [based on the 2013 reference scenario (European Commission 2013)] and the EUCO30 projection [based on the EU 2016 reference scenario (European Commission 2016b)], resulting in two options T4b and T4a, respectively. Figure 1 shows these changes in allocations.

Options O assume some flexibilities between ETS emissions and non-ETS emissions. Option O1 is the current situation, in which emission reductions under the ETS cannot be used for compliance in the non-ETS. However, the EC established a new possibility, in which allowances from ETS can be transferred to ESR allocations. These options are conditioned to the following two design parameters: (1) eligibility, i.e., which MS can use this one-off mechanism; and (2) limit of access, i.e., the amount of ETS allowances that can be transferred to ESR allocations.

Option O2 allows one-off flexibility for the following countries with low access limits:
• Luxembourg and Ireland (group A) have a limit equivalent to 4% of their 2005 emissions per year;
• Netherlands, Belgium, Austria, Denmark, Finland, Sweden, and Malta (group B) have a limit equivalent to 2% of their 2005 emissions per year.

Option O3 supposes high access limits. Luxembourg and Ireland can transfer up to 8% of their 2005 emissions. The countries listed in group B have a limit equivalent of 4%. Finally, the EC also considers two other options, in which France, Germany, and United Kingdom are also included in this mechanism with a 2% limit (option O2b) and a 4% limit (option O3b).

At present, credit generated in the land use, land-use change, and forestry (LULUCF) sector cannot be used in the ESR for compliance (option L1) (Ellison et al. 2014). Option L2 includes a limited use of credit coming from the LULUCF sector that is equal to a maximum of 280 million over the period 2021–2030. This amount is distributed to MSs on the basis of their share of agriculture non-CO$_2$ emissions in the ESR. Table 3 shows this repartition.

Options F aim at enhancing flexibility within ESR emissions through “inter-temporal flexibility” and “inter-Member state flexibility”. The extant rules already allow such a flexibility, with a maximum of 5% of their annual emission allocations (option F1). Option F2 increases permit borrowing to 10%, but only from the years 2021–2025. Options F3, F4, and F5 create new administrative tools or institutions that intend to facilitate flexibilities within ESR emissions. Option F3 creates a central information site that should record transfers. Option F4 involves establishing a central market place for inter-Member state transfers. Option F5 creates mandatory auctioning. In the current paper, two other options, F6 and F7 are added, which are detailed in Sect. 4.

Finally, options C consider compliance checks and periodicity of reporting. Option C1 assumes annual compliance checks, C2 biennial compliance checks, and C3 reports every fifth year.

Figure 2 provides a graphical representation of the flexibility options and compares them with a situation in which no flexibility options are allowed. I call this case the “EU architecture scenario”. Regarding the flexibility options listed in Table 2, this scenario uses options T1, O1, L1, and C1. However, option F1 is not taken into account in this scenario. Indeed, to be consistent with the other options “1” that consider no flexibility mechanism, no flexibility is assumed between the ETS market and ESR emissions. The EU architecture scenario considers 29 GHG targets: one for each ESR MS emissions (each represented by a green box), and one for the ETS market (represented by a blue box). Options T follow the same architecture, but assume that some reallocations are done within ESR emissions. The same logic is assumed with option L2, except that additional allowances (coming from LULUCF) are given to all MSs. Therefore, I do not represent option L2 in Fig. 2. Options O establish a link between the ETS market and ESR emissions by allowing MSs to use credits from the ETS market. Options F create a trading between ESR emissions. A red arrow indicates a MS that buys allowances, while a green arrow represents a MS that sells allowances.
The GEMINI-E3 model

3.1 Overview

GEMINI-E3 is a multi-country, multi-sector, recursive computable general equilibrium model (Bernard and Vielle 2008) comparable to other models of this class (EPPA, OECD-Env-Linkage, etc.), built and implemented by other modeling teams and institutions, and sharing the same long experience in the design of this class of economic models. The standard model is based on the assumption of total flexibility in all markets, i.e., both macroeconomic markets, such as capital and international
Fig. 2 Graphical representation of EU Architecture and flexibility options T3, O2 and F7 (Countries are sorted on the basis of GDP per capita)
trade markets (with associated prices being the real rate of interest and the real exchange rate, which are then endogenous), and microeconomic or sector markets (goods, factors of production, etc.).

3.2 Key features of the model

The current version is built on the GTAP 9 data base (Aguiar et al. 2016), and the reference year is 2011. The spatial decomposition of this version of GEMINI-E3 describes each of the 28 EU MSs as individual regions, plus China and the rest of the world. As the number of countries/regions is high, and to have a tractable model and acceptable computation time, I limit the number of sectors described by GEMINI-E3 to 11. The classification is built to distinguish sectors participating in the ETS market from the others. ETS sectors are petroleum products, electricity generation, and energy-intensive industries. Energy-intensive industries comprises the iron and steel industries, the chemical industry, the non-ferrous metals industry, the non-metallic minerals products, and the paper and paper products. Three other energy goods are described by the model: coal, crude oil, and natural gas. Finally, the remaining five sectors are: agriculture, land transport, sea transport, air transport, and other goods and services that aggregates all other sectors.

For each sector, the model computes the demand of its production on the basis of household consumption, government consumption, exports, investment and intermediate uses. Total demand is then divided between domestic production and imports using the Armington assumption (Armington 1969), which assumes that domestic and imported goods are not perfectly homogenous. Production technologies are described by a nested Constant Elasticity of Substitution (CES) functions that is shown in Appendix 6.1.

Household’s behavior consists of three interdependent decisions: (1) labor supply; (2) savings; and (3) consumption of the various goods and services. In GEMINI-E3, I suppose that both labor supply and the rate of savings are exogenous. Demand in the different commodities has prices of consumption and income (more precisely “spent” income, income after savings) as arguments, and is derived from a nested CES utility function, that is described in Appendix 6.2.

The government collects taxes and distributes the resulting revenues to households and firms through transfers and subsidies. Wage is chosen as a numeraire in each region. The model is recursive dynamic, with backward looking (adaptive) expectations.

3.3 GHG emissions covered

Since I only consider CO₂ emissions from energy combustion, methane, nitrous oxide, and fluorinated gases are not covered. The representation of these gases requires a detailed modeling tool, such as the GAINS model (Amann et al. 2011), that represents the specificities of these emissions coming from very diverse sources (agriculture, industries, transport, etc.), and where emissions and mitigation options
must be represented at the bottom-up level. These non-CO\textsubscript{2} gases represent 19% of EU28 GHG emissions in 2016 (United Nations Framework Convention on Climate Change 2018). The agriculture sector contributes the most (52%), followed by the waste and wastewater sector (18%) and the energy sector (15%) (Höglund-Isaksson et al. 2012). Non-CO\textsubscript{2} GHG emissions included in the EU-ETS are nitrous oxide emissions from adipic and nitric acid production, and perfluorocarbons emissions from the aluminium industry. All other emission sources belong to ESR emissions. It is an important limitation of this paper to not consider the contribution of these non-CO\textsubscript{2} GHG. However, as pointed out by Höglund-Isaksson et al. (2012), important mitigation options in non-CO\textsubscript{2} GHG ESR emissions are available at a marginal cost below 5€. Moreover, such integration would require to couple GEMINI-E3 with a bottom-up model (e.g., GAINS), as done in the EU 2016 reference scenario (European Commission 2016b) or in Weitzel et al. (2019). Weitzel et al. (2019) indicate that excluding non-CO\textsubscript{2} abatement options could lead to 25% greater macroeconomic abatement cost in the EU.

3.4 Assessing welfare cost

Like other computable general equilibrium models, GEMINI-E3 assesses the welfare cost of policies through compensating variation of income. It is commonly acknowledged that this measure is preferable to change in GDP or change in households’ final consumption because these aggregates are measured at constant prices according to the methods of national accounting and do not capture the change in the structure of prices, which is a main effect of climate change policies. Moreover, it is informative to split the welfare cost between its two components, the domestic component or deadweight loss of taxation (DWL) and the imported component or gains from terms of trade (GTT). The GTT represent spill-over effects due to changes in international prices. In a climate change policy, these GTTs come mainly from the drop in fossil energy prices that results from the decrease of world energy demand.

Decomposition of the welfare cost into components is a complex issue that has been addressed in the literature, mainly by Böhringer and Rutherford (2002) in the case of climate change policy, and by Harrison et al. (2000) in a more general framework. Here, the aim is an approximate decomposition between domestic and imported cost, in order to obtain a general idea of their relative importance. This approach is justified by the fact that the change in prices, in particular the prices of foreign trade, is fairly small. In practice, compensative variation income is first calculated from the results of the model, and the specification and coefficients of the demand function. GTT are then calculated based on the results of the involved scenario using the following equation:

\[
\text{GTT} = \sum_i \Delta P_{\text{exp}i} \cdot \text{Export}_i - \sum_i \Delta P_{\text{imp}i} \cdot \text{Import}_i
\]
where $\Delta P_{\text{exp}i}$ and $\Delta P_{\text{imp}i}$ represent changes in the exports and imports prices (for product $i$), with respect to the reference scenario; and Export$_i$ and Import$_i$ represent the levels of exports and imports, respectively, in the reference scenario. Finally, the DWL is the difference between the compensative variation income and the GTT.

4 Numerical implementation

4.1 Reference scenario

The GEMINI-E3 reference scenario is built on the time period of 2011–2030 with yearly timesteps; all prices given in this paper are in €$_{2017}$ 2. From 2011 to 2015, based on historical population and international energy prices, I compute the technical progresses associated with labor and energy consumption that allow to reproduce historical GDP, energy consumption, and related CO$_2$ emissions. My reference scenario thus considers implicitly all previous policies implemented since 2015, and especially those related to energy and climate fields. After 2015, assumptions about population, GDP, and international energy prices are based on the EU reference scenario 2016 (European Commission 2016a). This projection supposes that European GDP will grow by 1.4% annually between 2015-2030. MS GDP growth rates are based on projections performed by DG ECFIN (European Commission 2015). Regarding energy consumption and CO$_2$ emissions after 2015, my reference scenario differs from the one computed in the EU reference scenario 2016, because I do not integrate additional climate abatements (like for example in the EU-ETS) and new climate and energy policies. The main difference lies in the ETS emissions; the EU reference scenario assumes that the ETS emissions cap decreases by 1.74% annually from 2013 throughout the projection period, whereas my reference scenario assumes that the ETS emissions are not subject to ETS price. ETS PRIMES emissions decrease by 22.7% from 2015 to 2030, while ETS CO$_2$ emissions computed by GEMINI-E3 grow by 2% during the same period. Regarding ESR emissions, the difference is less pronounced. In the EU reference scenario, these emissions decrease by 14% from 2015 to 2030, while the ones computed by GEMINI-E3 decrease only by 2%.

4.2 EU architecture scenario

First, a scenario is simulated called the “EU architecture scenario”. After 2015, the targets defined in the ESR proposal and also the ones related to the ETS market are implemented through carbon prices. Regarding the flexibility options listed in Table 2, this scenario uses options T1, O1, L1, and C1. However, option F1 is not

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2 The model is calibrated on the GTAP 9 data base, and therefore the economic variables are measured in US$$_{2011}$ . I compute figures in €$_{2017}$ by using the exchange rate between € and US$ for the year 2011, and the European GDP deflator between 2011 and 2017 provided by Eurostat.
taken into account in this scenario. Indeed, to be consistent with the other options “1” that consider no flexibility mechanism, no flexibility is assumed between ETS market and ESR emissions. However, option F1 is analyzed in the next section. The present scenario assumes that ETS sectors participate in a CO2 tradable market in which allowances are fully auctioned. This assumption certainly overestimates the amount of allowances that will be auctioned in the future. However, as I am mainly interested in the European burden-sharing in non-ETS emissions, this would probably not change the findings of this analysis. The revenue from ETS allowances are collected by EC and redistributed to MSs according to their ETS emissions. In this market, the CO2 target consists of a 21% (43%) reduction in 2020 (in 2030) with respect to 2005 levels. In non-ETS sectors, a wide variety of measures has been or will be implemented (fuel efficiency target for passenger cars, appliance subsidies, carbon taxes, etc.) which is very difficult to represent in such a model. Against this background, the aim of this paper is to determine the marginal cost in the non-ETS sectors associated with European burden-sharing. Therefore, I assume that in the non-ETS sectors, a domestic CO2 tax is implemented that is based on the ESR targets presented in Table 1. Firms included in the ESR emissions and households pay a domestic CO2 tax on their fossil energy consumption. The revenue of the CO2 tax is redistributed to household through a lump-sum transfer. Other redistributive rules could be envisaged but they do not constitute the scope of this study. The number of CO2 prices in EU is then one plus the number of MSs (i.e., 29 = 1 ETS price + 28 domestic carbon taxes).

Table 4 presents the results of this scenario for the year 2030. First, it is found that the ETS price is equal to 46 € in 2030, which is higher than the one computed by the European Commission (2016a), which is equal to 33 €. In non-ETS sectors, the average European CO2 price is equal to 209 €3, but with significant gaps among MSs. Regarding some low-income countries (e.g., Czech Republic, Greece, Hungary, Portugal, Slovakia, Bulgaria, Romania, and Croatia), the burden-sharing proposal does not require any abatement for ESR sectors, and thus the CO2 taxes are equal to zero. These overallocations may result in “hot air”4 that could be sold to other MSs. Table 5 shows that other studies find similar overallocations. These studies converge on the countries that are concerned, but differ on the amount of “hot air”. However, these overallocations highlight the weakness of the per capita rule to take into consideration existing situations (regarding current CO2 emissions) and also cost-effective abatement potential. Oppositely, “old” MSs (e.g., Austria, Denmark, Germany, Luxembourg, Netherlands and Sweden) with high-income levels have to implement significant abatements that require CO2 taxes that are higher than 300 €. The other countries are in a middle position, for example, France with a CO2 tax equals 226 €, Ireland with a CO2 tax that equals 275 € (Chiodi et al. (2013)

3 The average CO2 price is weighted with the emissions of the scenario.
4 The term “hot air” was first used when the Kyoto Protocol was negotiated. It refers to an emissions target that far exceeds the likely level of emissions (like the one defined for Russia in the Kyoto Protocol). If an emissions trading system between countries is established, the emissions surplus (corresponding to the difference between GHG commitment and the effective emissions level, called “hot air”) can be sold without any reduction in emissions (Victor et al. 2001).
Table 4 EU architecture scenario—year 2030

| Country               | Components of welfare cost<sup>a</sup> | CO₂ emissions<sup>b</sup> | CO₂ tax<sup>c</sup> | ESR emissions in % of 2005 levels (%) |
|-----------------------|----------------------------------------|---------------------------|---------------------|--------------------------------------|
|                       | Total (%) | GTT (%) | DWL (%) | ETS (%) | ESR (%) | Total (%) | ESR sectors |
| Austria               | −0.41     | −2.05   | 1.64    | −23.3   | −25.7   | −24.9     | 434         | −39        |
| Belgium               | −0.81     | −2.06   | 1.26    | −22.2   | −25.8   | −24.6     | 357         | −38        |
| Bulgaria              | 0.34      | −0.23   | 0.58    | −38.9   | 1.6     | −28.8     | 0           | −15        |
| Croatia               | −0.09     | −0.29   | 0.20    | −32.0   | 0.9     | −12.4     | 0           | −21        |
| Cyprus                | −0.48     | −0.91   | 0.43    | −9.9    | −9.3    | −9.6      | 71          | −24        |
| Czech Republic        | 0.79      | 0.05    | 0.74    | −46.9   | 1.1     | −32.4     | 0           | −20        |
| Denmark               | −0.13     | −1.84   | 1.72    | −44.3   | −26.0   | −33.6     | 399         | −40        |
| Estonia               | −3.28     | −5.80   | 2.51    | −10.5   | −19.1   | −13.9     | 225         | −13        |
| Finland               | 0.63      | −0.46   | 1.09    | −31.2   | −14.2   | −24.2     | 217         | −39        |
| France                | 0.17      | −0.60   | 0.78    | −23.4   | −20.0   | −20.9     | 226         | −36        |
| Germany               | 0.39      | −1.56   | 1.96    | −38.1   | −29.5   | −34.3     | 555         | −37        |
| Greece                | −0.25     | −0.33   | 0.08    | −30.2   | 2.7     | −15.1     | 0           | −44        |
| Hungary               | 0.29      | 0.09    | 0.21    | −28.6   | 0.7     | −10.8     | 0           | −15        |
| Ireland               | −0.14     | −2.39   | 2.25    | −33.8   | −28.4   | −30.5     | 275         | −39        |
| Italy                 | 0.17      | −0.15   | 0.32    | −27.5   | −7.3    | −16.2     | 74          | −33        |
| Latvia                | 0.48      | 0.46    | 0.02    | −17.3   | 0.8     | −5.6      | 0           | −7         |
| Lithuania             | −0.92     | −1.11   | 0.19    | −15.0   | −16.7   | −15.9     | 140         | −9         |
| Luxembourg            | −2.31     | −4.44   | 2.12    | −19.3   | −37.1   | −33.9     | 409         | −40        |
| Malta                 | 0.45      | −3.96   | 4.40    | −10.9   | −44.5   | −30.5     | 315         | −19        |
| Netherlands           | −1.11     | −3.23   | 2.12    | −26.4   | −26.2   | −26.3     | 390         | −39        |
| Poland                | 0.81      | 0.03    | 0.78    | −47.7   | −16.0   | −36.6     | 41          | −7         |
| Portugal              | 0.00      | −0.06   | 0.06    | −34.2   | 1.6     | −13.5     | 0           | −23        |
| Romania               | 0.86      | 0.43    | 0.43    | −37.0   | −1.2    | −23.6     | 0           | −6         |
| Slovakia              | 0.83      | 0.45    | 0.38    | −28.4   | 0.4     | −15.9     | 0           | −14        |
| Slovenia              | 0.37      | 0.13    | 0.23    | −33.5   | −2.5    | −16.4     | 25          | −15        |
| Spain                 | −0.04     | −0.11   | 0.07    | −31.9   | −0.4    | −15.7     | 10          | −26        |
| Sweden                | 0.18      | −1.25   | 1.42    | −23.3   | −22.1   | −22.5     | 455         | −40        |
| United Kingdom        | 0.32      | −0.18   | 0.50    | −37.6   | −17.5   | −26.3     | 158         | −36        |
| European Union        | 0.15      | −0.80   | 0.95    | −35.4   | −16.8   | −25.8     | 209<sup>d</sup> | −30        |
| ETS price<sup>c</sup> |           |         |         |         |         |           | 46          |            |

<sup>a</sup> In % of households consumption.

<sup>b</sup> Change in % with respect to the reference scenario.

<sup>c</sup> In €<sub>2017</sub> per ton of CO₂.

<sup>d</sup> The average ESR CO₂ price is weighted with the emissions of the scenario.
| Study                      | Countries with “hot air”                                                                 | Emissions covered       | Amount in Mt CO$_2$-eq |
|----------------------------|----------------------------------------------------------------------------------------|-------------------------|------------------------|
| European Commission (2016a) | Bulgaria, Croatia, Czech Republic, Greece, Hungary, Latvia, Lithuania, Portugal, Romania, Slovakia | GHG                     | 50.8                   |
| Sartor et al. (2015)       | Bulgaria, Croatia, Greece, Hungary, Portugal, Romania                                    | GHG                     | 24.5                   |
| GEMINI-E3                  | Bulgaria, Croatia, Czech Republic, Greece, Hungary, Latvia, Portugal, Romania, Slovakia  | CO$_2$ from energy combustion | 29.8                   |
also found a high CO₂ tax for Irish non-ETS emissions, which is equal to 158 €\textsubscript{2000} with a 20% abatement with respect to 2005 levels), and United Kingdom with a CO₂ tax that equals 158 €. As expected, Fig. 3 shows that a clear relationship exists between ESR CO₂ tax and GDP per capita.

The burden-sharing proposal results in an important disparity of effective CO₂ emission reductions that range from − 44.5 to + 2.4%. In contrast, effective abatements in the ETS sectors are more uniform and range from − 44.7 to − 11%. Of course, this leads to similar findings in terms of welfare costs. It is worth noting that, for some countries, GTTs counterbalance abatement costs. This is the reason why some countries are better off after the CO₂ policy. The GTT are positively correlated to trade openness and the ESR tax\textsuperscript{5}. These positive international spillovers have been well established since the Kyoto Protocol especially for energy-importing countries such as European countries [see Böhringer and Rutherford (2002); Bernard and Vielle (2003)]. Finally, when subtracting the GTT, all countries face a welfare cost.

### 4.3 Target adjustments

Options T2 to T4b are simulated and compared to the EU architecture scenario. When varying the T options, the other options (O, L, and C) are fixed at their level 1, except the F1 option that is not implemented in the EU architecture scenario. The aim of these target adjustments is to reallocate efforts within high-income MSs that take cost-efficiency and fairness into account. Allocations of MSs with a GDP per capita below 30,000 € are unchanged, and the simulations reveal that they are not impacted by these options. Therefore, I concentrate my analysis on high-income MSs\textsuperscript{6}. Table 3 gives

\textsuperscript{5} I estimate a linear regression between the GTT and these two variables. The following estimation is found: \(\text{GTT} = 0.0071 \cdot \text{Trade Openness} + 0.00005 \cdot \text{ESR tax} - 0.0096\) with \(R^2 = 0.67\).

\textsuperscript{6} The detailed simulation results of all scenarios presented in this paper are given in the Appendix.
welfare costs for the four groups identified in the proposal. Surprisingly, in contrast to what is assumed in the proposal, I find that groups 3 and 4 have welfare improvements when the EU climate policy is implemented (see also Table 4 that details the results at the MS level). By subtracting the GTT, I obtain a ranking that matches the initial intuition: countries with a high GDP per capita and therefore a high level of effort face high welfare cost. Nevertheless, considering the GTT and the results coming from GEMINI-E3, it can be concluded that the options T are not required, as groups 3 and 4 are better off. It is difficult to elaborate more on these options, as the results of the simulations conducted with the GEM-E3 and the GAINS models, that have been used to justify the target adjustments, have not been published. However, it can be concluded that options T2 to T4b effectively balance the DWL. In my simulations, option T4a equalizes the DWLs in % of household consumption and leads to a fair distribution of DWL across high-income MSs (see Table 6).

### 4.4 One-off flexibility between ETS and non-ETS

I consider now options that link ETS markets and ESR emissions by allowing MSs to use allowances coming from the ETS market in sectors covered by the ESR. Again, only high-income MSs are allowed to use this flexibility mechanism. However, in contrast to target adjustment options, this mechanism could impact the other MSs (having a GDP per capita lower than 30,000 €) by increasing the ETS price and the compliance cost of energy-intensive industries and electricity generation sector. Table 7 presents the results of these simulations. Options O2 and O3 have very limited impacts on the results. This is not the case of option O3b and to a lesser extent option O2b, the main reason for which is that these two options allow the main European CO₂ emitters (France, Germany, and the United Kingdom which account for 45% of ESR emissions in 2015) to participate in such mechanism. In this case,
Table 7 One-off flexibility between ETS and ESR emissions scenarios—year 2030

| Welfare cost<sup>d</sup> | EU architecture option O1 | Option O2 | Option O3 | Option O2b | Option O3b |
|--------------------------|---------------------------|-----------|-----------|------------|------------|
| Austria                  | −0.41%                    | −0.38%    | −0.34%    | −0.36%     | −0.30%     |
| Belgium                  | −0.81%                    | −0.75%    | −0.68%    | −0.77%     | −0.73%     |
| Bulgaria                 | 0.34%                     | 0.31%     | 0.28%     | 0.29%      | 0.26%      |
| Croatia                  | −0.09%                    | −0.05%    | −0.02%    | 0.02%      | 0.13%      |
| Cyprus                   | −0.48%                    | −0.47%    | −0.46%    | −0.43%     | −0.38%     |
| Czech Republic           | 0.79%                     | 0.79%     | 0.79%     | 0.81%      | 0.84%      |
| Denmark                  | −0.13%                    | −0.08%    | −0.03%    | −0.08%     | −0.02%     |
| Estonia                  | −3.28%                    | −3.25%    | −3.22%    | −3.30%     | −3.31%     |
| Finland                  | 0.63%                     | 0.54%     | 0.46%     | 0.53%      | 0.45%      |
| France                   | 0.17%                     | 0.17%     | 0.17%     | 0.13%      | 0.09%      |
| Germany                  | 0.39%                     | 0.38%     | 0.37%     | 0.30%      | 0.22%      |
| Greece                   | −0.25%                    | −0.23%    | −0.21%    | −0.17%     | −0.09%     |
| Hungary                  | 0.29%                     | 0.28%     | 0.27%     | 0.29%      | 0.28%      |
| Ireland                  | −0.14%                    | −0.22%    | −0.25%    | −0.23%     | −0.27%     |
| Italy                    | 0.17%                     | 0.17%     | 0.16%     | 0.17%      | 0.17%      |
| Latvia                   | 0.48%                     | 0.46%     | 0.43%     | 0.43%      | 0.39%      |
| Lithuania                | −0.92%                    | −0.96%    | −0.99%    | −1.03%     | −1.13%     |
| Luxembourg               | −2.31%                    | −2.09%    | −1.84%    | −2.04%     | −1.74%     |
| Malta                    | 0.45%                     | 0.35%     | 0.27%     | 0.42%      | 0.39%      |
| Netherlands              | −1.11%                    | −0.99%    | −0.87%    | −1.01%     | −0.91%     |
| Poland                   | 0.81%                     | 0.82%     | 0.84%     | 0.87%      | 0.95%      |
| Portugal                 | 0.00%                     | 0.01%     | 0.01%     | 0.03%      | 0.05%      |
| Romania                  | 0.86%                     | 0.85%     | 0.85%     | 0.86%      | 0.88%      |
| Slovakia                 | 0.83%                     | 0.78%     | 0.74%     | 0.74%      | 0.65%      |
| Slovenia                 | 0.37%                     | 0.34%     | 0.32%     | 0.32%      | 0.28%      |
| Spain                    | −0.04%                    | −0.04%    | −0.04%    | −0.03%     | −0.02%     |
| Sweden                   | 0.18%                     | 0.14%     | 0.12%     | 0.13%      | 0.09%      |
| United Kingdom           | 0.32%                     | 0.31%     | 0.31%     | 0.27%      | 0.23%      |
| European Union           | 0.15%                     | 0.15%     | 0.15%     | 0.12%      | 0.11%      |
| MSs by GDP per capita in € < 10,000 | 0.68%     | 0.68%     | 0.68%     | 0.71%      | 0.75%      |
| 10,000−20,000            | 0.26%                     | 0.26%     | 0.25%     | 0.27%      | 0.27%      |
| 20,000−30,000            | 0.06%                     | 0.06%     | 0.06%     | 0.07%      | 0.08%      |
| > 30,000                 | 0.13%                     | 0.13%     | 0.14%     | 0.08%      | 0.05%      |
| High<sup>h</sup> income MSs by group |                       |           |           |            |            |
| Group 1                  | 0.31%                     | 0.30%     | 0.29%     | 0.24%      | 0.19%      |
| Group 2                  | 0.34%                     | 0.28%     | 0.24%     | 0.27%      | 0.22%      |
| Group 3                  | −0.72%                    | −0.65%    | −0.57%    | −0.66%     | −0.59%     |
| Group 4                  | −0.70%                    | −0.70%    | −0.66%    | −0.70%     | −0.65%     |
| ETS price<sup>b</sup>    | 46                        | 47        | 49        | 51         | 57         |
| Average ESR CO<sub>2</sub> price<sup>b,c</sup> | 209                    | 199        | 190        | 179        | 152        |
the welfare cost of high-income MSs and average ESR CO\textsubscript{2} price are divided by two. Using ETS allowances within ESR sectors increases the ETS price (by 25\% with option O3b, for example), and therefore penalizes the countries that do not participate in this flexibility mechanism. Low-income MSs are the most impacted, with a welfare cost that shifts from 0.68\% of household consumption to 0.75\%, because in these countries, the ETS sectors constitute a larger part of the economy (Brink et al. 2016). In contrast, regarding the overall efficiency of the EU climate change policy, option Ob3 cuts the EU welfare cost by one-third. Figure 4 shows the spread of ESR CO\textsubscript{2} prices for the different options. If the average ESR CO\textsubscript{2} price drops from 209 to 145 \euro, the degree of carbon prices dispersion is also significantly reduced within option O3b.

4.5 Land use, land-use change, and forestry

In this scenario (i.e., option L2), the credits coming from LULUCF increase ESR allocations. Starting from 2021, these credits are gradually used with the assumption that the total amount of LULUCF from 2021 to 2030 is equal to the amounts given in Table 3. The credits used in year \( t > 2020 \) are equal to \( (t - 2020) \times \frac{2 \times \text{LULUCF}}{2030-2021} \) where LULUCF is the total amount of LULUCF.

The credits from LULUCF will be accounted using the concept of Forest Reference Level (FRL), which represents at the country level the future forest emissions

| Table 7 (continued) |
|---------------------|-----------------|-----------------|-----------------|
| a In \% of household consumption |
| b In \euro\textsubscript{2017} per ton of CO\textsubscript{2} |
| c The average ESR CO\textsubscript{2} price is weighted with the emissions of the scenario |

Fig. 4 Box and whisker plot of the ESR CO\textsubscript{2} prices in \euro-Year 2030
and removals in the reference scenario. The evaluation of the cost associated with these LULUCF credits requires the use of a complex forest land model such as the GTM model (Favero et al. 2018), and first works at the European level concentrate on the evaluation of the FRL (Grassi and Pilli 2017). However, several studies (Nabuurs et al. 2017; Michetti and Rosa 2012) demonstrate that the cost savings from carbon sequestration by LULUCF could be significant, up to 65% (Elofsson and Gren 2018). Favero et al. (2018) show that the LULUCF credit planned by the EC could probably be reached with a carbon tax below 50 US$. The European Commission evaluated the cost of abatement for agriculture non-CO2 sector emissions with or without the use of LULUCF credits (European Commission 2016c). They simulated a 20% reduction in 2030 compared to 2005 for these agricultural emissions. Without LULUCF credits, the marginal cost of abatement is 78.6 € per ton CO2 equivalent. If the credits listed in Table 3 are added to the target, the marginal cost of mitigation in the agriculture non-CO2 sector fall to 7.3 €. Therefore, in the simulation performed with GEMINI-E3, I assume that the credits from LULUCF are free.

For all MSs, their DWL decrease as their ESR allocations increase, and the average ESR CO2 price drops from 209 to 173 €. The impact on the welfare cost depends on the change in GTT. For some countries, less abatement means less gains in terms of trade and an increase in the welfare cost (see, e.g., Lithuania, and Estonia). However, at the EU level, the incorporation of LULUCF credits reduces the welfare cost slightly, with a shift from 0.15 to 0.12% of household consumption. It is worth noting that this incorporation benefits only high-income MSs (see Table 8).

### 4.6 Inter-Member State flexibility

I next analyse flexibility mechanisms that allow a MS to transfer allowances to another MS. In my EU architecture scenario, the existing rule, which is currently limited to 5% of allowances is not assumed. Therefore, option F1, representing the current situation, is simulated alone and compared to the EU architecture scenario in Table 9. Moreover, one other scenario (named F6) is simulated that increase the percentage of allowance to 10%. Finally, a scenario (named F7), which assumes that ESR allowances are fully fungible is also presented.

When inter-Member State flexibility is implemented, the EU abatement cost decreases significantly. Option F1 decreases the EU cost by approximately 5.7 billion €, from 0.15 to 0.10% of household consumption with respect to the EU architecture scenario. High-income MSs buy CO2 quotas from low-income MSs, which implement CO2 abatement measures or only sell “hot air”. In 2030, quotas from “hot air” represent 8.4 Mt CO2 sold by Greece, Portugal, Czech Republic, Hungary, Bulgaria and Croatia. Main buyers are Germany and France, which purchase, respectively, 11.2 and 9.4 Mt CO2. 26 countries reach their 5% trading constraint, and only Finland and Lithuania could buy and sell more, respectively. This option benefits mainly low-income MSs (with a GDP per capita lower than 20,000 €), who can sell quotas and therefore benefit from additional revenue. In contrast, if high-income MSs can buy cheap quotas and decrease their DWL, they suffer from less gains in terms of trade. This result confirms that emissions trading is not always
Table 8  Land use, land-use change, and forestry scenarios—year 2030

| Welfare cost\(^a\) | EU architecture option L1 | Option L2 |
|---------------------|---------------------------|-----------|
| Austria             | −0.41%                    | −0.40%    |
| Belgium             | −0.81%                    | −0.80%    |
| Bulgaria            | 0.34%                     | 0.27%     |
| Croatia             | −0.09%                    | −0.02%    |
| Cyprus              | −0.48%                    | −0.36%    |
| Czech Republic      | 0.79%                     | 0.76%     |
| Denmark             | −0.13%                    | 0.03%     |
| Estonia             | −3.28%                    | −2.84%    |
| Finland             | 0.63%                     | 0.48%     |
| France              | 0.17%                     | 0.09%     |
| Germany             | 0.39%                     | 0.32%     |
| Greece              | −0.25%                    | −0.19%    |
| Hungary             | 0.29%                     | 0.28%     |
| Ireland             | −0.14%                    | −0.16%    |
| Italy               | 0.17%                     | 0.15%     |
| Latvia              | 0.48%                     | 0.45%     |
| Lithuania           | −0.92%                    | 0.13%     |
| Luxembourg          | −2.31%                    | −2.23%    |
| Malta               | 0.45%                     | 0.55%     |
| Netherlands         | −1.11%                    | −1.00%    |
| Poland              | 0.81%                     | 0.80%     |
| Portugal            | 0.00%                     | 0.02%     |
| Romania             | 0.86%                     | 0.81%     |
| Slovakia            | 0.83%                     | 0.73%     |
| Slovenia            | 0.37%                     | 0.45%     |
| Spain               | −0.04%                    | −0.02%    |
| Sweden              | 0.18%                     | 0.11%     |
| United Kingdom      | 0.32%                     | 0.26%     |
| European Union      | 0.15%                     | 0.12%     |
| < 10,000            | 0.68%                     | 0.72%     |
| 10,000−20,000       | 0.26%                     | 0.27%     |
| 20,000−30,000       | 0.06%                     | 0.06%     |
| > 30,000            | 0.13%                     | 0.08%     |
| ETS price\(^b\)     | 46                        | 46        |
| Average ESR CO\(_2\) price\(^b,c\) | 209          | 173       |

\(^a\) In % of households consumption  
\(^b\) In €\(_{2017}\) per ton of CO\(_2\)  
\(^c\) The average ESR CO\(_2\) price is weighted with the emissions of the scenario
### Table 9  Inter-Member State flexibility scenarios—year 2030

| Welfare cost| EU architecture | Option F1 | Option F6 | Option F7 |
|-------------|-----------------|-----------|-----------|-----------|
| Austria     | $-0.41\%$      | $-0.22\%$ | $-0.01\%$ | $0.35\%$  |
| Belgium     | $-0.81\%$      | $-0.59\%$ | $-0.32\%$ | $-0.05\%$ |
| Bulgaria    | $0.34\%$       | $-0.37\%$ | $-1.00%$  | $-4.95\%$ |
| Croatia     | $-0.09\%$      | $-0.42\%$ | $-0.66\%$ | $-0.88\%$ |
| Cyprus      | $-0.48\%$      | $-0.88\%$ | $-1.11\%$ | $-1.04\%$ |
| Czech Republic | $0.79\%$ | $0.35\%$  | $0.18\%$  | $-1.19\%$ |
| Denmark     | $-0.13\%$      | $0.10\%$  | $0.29\%$  | $0.55\%$  |
| Estonia     | $-3.28\%$      | $-2.19\%$ | $-2.00\%$ | $-1.88\%$ |
| Finland     | $0.63\%$       | $0.59\%$  | $0.54\%$  | $0.47\%$  |
| France      | $0.17\%$       | $0.25\%$  | $0.25\%$  | $0.24\%$  |
| Germany     | $0.39\%$       | $0.37\%$  | $0.38\%$  | $0.56\%$  |
| Greece      | $-0.25\%$      | $-0.54\%$ | $-0.76\%$ | $-2.54\%$ |
| Hungary     | $0.29\%$       | $-0.17\%$ | $-0.42\%$ | $-1.61\%$ |
| Ireland     | $-0.14\%$      | $-0.03\%$ | $0.11\%$  | $0.20\%$  |
| Italy       | $0.17\%$       | $0.03\%$  | $-0.01\%$ | $0.01\%$  |
| Latvia      | $0.48\%$       | $-0.21\%$ | $-0.75\%$ | $-1.94\%$ |
| Lithuania   | $-0.92\%$      | $-1.21\%$ | $-1.22\%$ | $-1.27\%$ |
| Luxembourg  | $-2.31\%$      | $-1.84\%$ | $-1.47\%$ | $-0.19\%$ |
| Malta       | $0.45\%$       | $0.47\%$  | $0.51\%$  | $0.80\%$  |
| Netherlands | $-1.11\%$      | $-0.71\%$ | $-0.38\%$ | $0.06\%$  |
| Poland      | $0.81\%$       | $0.41\%$  | $0.06\%$  | $-0.26\%$ |
| Portugal    | $0.00\%$       | $-0.28\%$ | $-0.42\%$ | $-1.24\%$ |
| Romania     | $0.86\%$       | $0.51\%$  | $0.07\%$  | $-0.65\%$ |
| Slovakia    | $0.83\%$       | $0.40\%$  | $-0.03\%$ | $-0.77\%$ |
| Slovenia    | $0.37\%$       | $-0.34\%$ | $-0.91\%$ | $-1.10\%$ |
| Spain       | $-0.04\%$      | $-0.29\%$ | $-0.47\%$ | $-0.57\%$ |
| Sweden      | $0.18\%$       | $0.22\%$  | $0.30\%$  | $0.40\%$  |
| United Kingdom | $0.32\%$ | $0.29\%$  | $0.28\%$  | $0.28\%$  |
| European Union | $0.15\%$ | $0.10\%$  | $0.07\%$  | $0.02\%$  |
| $< 10,000$  | $0.68\%$       | $0.27\%$  | $-0.11\%$ | $-0.81\%$ |
| $10,000-20,000$ | $0.26\%$ | $-0.09\%$ | $-0.32\%$ | $-1.23\%$ |
| $20,000-30,000$ | $0.06\%$ | $-0.14\%$ | $-0.25\%$ | $-0.42\%$ |
| $> 30,000$  | $0.13\%$       | $0.18\%$  | $0.23\%$  | $0.34\%$  |
| ETS price$^b$ | 46            | 46        | 46        | 47        |
| Average ESR CO$_2$ price$^{b,c}$ | 209         | 177       | 174       | 145       |

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$^a$ In % of households consumption

$^b$ In €$_{2017}$ per ton of CO$_2$

$^c$ The average ESR CO$_2$ price is weighted with the emissions of the scenario
beneficial, as pointed out by Babiker et al. (2004). In addition, the average ESR CO$_2$ price drops from 209 to 177 €, while the ETS price is unchanged.

When the trading limit is increased, the EU marginal benefit decreases. Shifting from 5 to 10% trading limit induces a 3 billion € gain at the EU level.

If I assume fully fungible allocations within ESR emissions, the EU cost equals only 3 billion €, which represents 0.02% of household consumption in 2030. For all MSs, the ESR price is equal to 145 €. This option creates significant amounts of trading. In relative terms, the top buyer is Luxembourg, which purchases 29% of its emissions allocation, and the top seller is Greece with a selling rate that equals 43% of its emissions allocation. In absolute terms, Germany is the highest buyer (53.5 Mt CO$_2$), and Greece is the top seller (18.8 Mt CO$_2$). As can be seen in Fig. 4, allowing trading within MSs not only decreases the average ESR CO$_2$ price, but also assists to reduce the dispersion of these prices.

5 Conclusion

In its new proposal, the EC has allocated an emissions target for non-ETS sectors by MSs according to GDP per capita. This proposal raises several questions, as the targets do not take into account cost-effective potentials. The EC has acknowledged this issue by proposing several flexibility mechanisms. The current article, to the best of the author’s knowledge, constitutes a first assessment of these flexibility mechanisms allowed within the EU Effort Sharing Decision for the year 2030. Figure 5 summarizes my main findings.

In term of overall efficiency, i.e., aggregated EU welfare cost, the most promising mechanism is the one that allows “inter-Member state flexibility”. Indeed, it tends to equalize CO$_2$ taxes, and in this way, marginal abatement costs among MSs. The downside of this mechanism is the use of “hot air” from several MSs and therefore less EU CO$_2$ emissions abatements in 2030. Using offsetting from LULUCF reduces the EU welfare cost slightly by 4.4 billion € in 2030 (representing 0.03% of the European consumption). Allowing trading between ETS and non-ETS allocations

![Graph 5](image)

**Fig. 5** EU welfare cost in million € (right) and welfare cost in % of household consumption per MS income level (left)—year 2030

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also reduces the EU welfare cost if large CO\textsubscript{2} emitters (Germany, United Kingdom, and France) can participate in this mechanism (options Ob2 and Ob3). In contrast, the present study finds that options T increase the EU welfare cost and fail to balance the burden among high-income MSs. Unfortunately, the way that the policy options T were designed is rather nontransparent, as the scenarios used to design the options have not been published. However, the current analysis demonstrates that the design of this policy option strongly depends on baseline assumptions and abatement costs by countries. Indeed, target adjustment mechanisms open up the Pandora’s Box of lobbying and bargaining powers (Viguier et al. 2006) between European actors (firms, States, NGOs). In addition, this option cannot take into account unforeseen future events, such as economic downturns or energy price shocks, that would alter the cost hierarchy between countries and necessitate a redefinition of burden-sharing. Finally, allowing fully fungible ESR allocations (option F7) results in very low aggregated EU welfare cost, estimated at 3.5 billion €. In this scenario, the ESR CO\textsubscript{2} taxes are equal to 145 € with an ETS price that equals 47 €.

If we are concerned about fairness among MSs and their economic capacities to implement decarbonization policies, the “inter-Member state flexibility” mechanism is the most attractive one. With this mechanism, the welfare of low-income MSs is improving and the richest MSs bear the cost of the climate policy. As can been seen in Fig. 5, the other options do not change the distribution of burden-sharing significantly.

To conclude, with respect to efficiency and equity, it is essential to promote trading between MS ESR emissions. The existing limit of 5% trading is too small and must be increased. My simulations show that a 10% limit can significantly reduce the EU’s mitigation cost and capture most of the gain from allowances trading. This conclusion is in line with further assessments of EU burden-sharing (Böhringer et al. 2009, 2016; De Cara and Jayet 2011; Capros et al. 2011; Tol 2009; Bernard and Vielle 2009). However, as the required GHG emissions abatements increase (from 10% in 2020 to 30% in 2030), some MSs may not be able to meet their targets or may bear welfare costs that are too high. As pointed out by Sartor et al. (2015), such a failure would throw into question the credibility of the European Effort Sharing Decision.

Finally, I compare my results with other models (i.e., macro-economic ones) and find similar carbon prices. Indeed, Capros et al. (2014) report a CO\textsubscript{2} price ranging from 91 (GEM-E3 model) to 60 €\textsubscript{2005} (NEMESIS model) in a “basic decarbonisation scenario” assuming that all technological decarbonisation options are available and used according to cost optimality. With GEMINI-E3, this scenario means that a uniform carbon price is implemented across MSs and emissions (ETS and ESR). In this case\textsuperscript{7}, I find a CO\textsubscript{2} price that equals 70 €\textsubscript{2017}. Moreover, it should be noted that the European welfare cost is lower under differentiated carbon prices between ETS and non-ETS (option F7) than with a uniform carbon tax. While this result is counterintuitive from economic theory, there exist a couple of papers that explain this

\textsuperscript{7} See Table 22 in the Appendix.
feature [e.g. Boeters (2014)], especially when distortions through taxes and international trade are integrated in the analysis.

The EC adopted the ESR regulation on 14 May 2018, after the writing of this paper. Within the flexibility options that were envisaged in 2016, only two new mechanisms are endorsed. The first new instrument allows one-off flexibility between ETS and non-ETS, as it was designed in option O2. The second flexibility provides an access to LULUCF credits as it was planned in option L2. It is likely that in the future when the GHG abatements will become more binding, the need for more flexibility mechanisms will be more pressing. Thus, the flexibility mechanisms listed in May 2016 would probably be reconsidered.

A number of caveats should be raised mainly regarding the modeling part. First, I do not consider other non-CO$_2$ GHG emissions that are mainly included in non-ETS emissions. Introducing such gases and their contributions to the mitigation would probably change the numerical results, but I think that the main insights of this analysis would remain the same. I also do not assume any cost to LULUCF credits that are implemented within option L2. However, several researches Favero et al. (2018) concerning such sinks found that their costs are rather limited. Finally, I do not take into consideration a rapid and significant penetration of new CO$_2$ free technologies (e.g., electric vehicles, smart grids, etc.) that will reduce the cost of European climate policies. CGE models that do not explicitly represent these technologies have difficulties to capture their strong increase in market share. However, within the short timeframe, i.e., less that one decade, it is difficult to assume such rapid penetration especially taking into consideration the new infrastructures that will be required.

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**Appendix**

**Nested CES production function**

Domestic production technologies are described through nested CES functions which differ according to the sector. Figure 6 shows the nested CES production structure of the non-fossil energy sector. Production is done with four aggregates: Capital, labor, material and energy. In a second step (nest), material and energy are decomposed in individual goods using again CES functions.

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Coal, crude oil and natural gas sectors include a fixed factor that represents the non-renewable resource associated with each fossil fuel energy. For these sectors, I suppose that the domestic production is realized with this fixed factor and the other standard inputs (i.e., capital, labor, material, and energy) through again a nested CES function. Finally, refined petroleum products are produced from the basic input, that is crude oil. The model considers this specificity with a CES function between crude oil and other standard inputs at the top level of the nested CES structure.

**Nested CES household function**

Figure 7 shows the nested CES structure of the household consumption. At the first level of the consumption function, households choose between three aggregates: housing, transport, and other consumptions. Energy consumption is divided between transportation and housing purposes. In each nest, energy can be substituted by
spending more on capital goods, cars in the first case and shelter in the second one, in other words, by purchasing more energy-efficient but also more expensive cars and housing units.

**Scenario detailed results**

See Tables 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21 and 22.

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**Fig. 7** Nested CES structure of household consumption
Table 10  Scenario option T2—year 2030

| Components of welfare cost\(^a\) | \(\text{CO}_2\) emissions\(^b\) | \(\text{CO}_2\) tax\(^c\) | ESR emissions in % of 2005 levels |
|----------------------------------|---------------------------------|-------------------------|---------------------------------|
|                                  | Total | GTT | DWL | ETS | ESR | Total | ESR sectors |                      |
| Austria                         | 0.39% | 1.67% | 1.28% | 22.8% | 22.1% | 22.3% | 343 | −39% |
| Belgium                         | 0.71% | 1.68% | 0.97% | 21.8% | 22.3% | 22.2% | 282 | −38% |
| Bulgaria                        | 0.32% | 0.25% | 0.57% | 38.9% | 1.6% | 28.8% | 0 | −15% |
| Croatia                         | 0.08% | 0.29% | 0.21% | 31.9% | 0.9% | 12.5% | 0 | −21% |
| Cyprus                          | 0.49% | 0.93% | 0.44% | 9.9% | 9.4% | 9.6% | 72 | −24% |
| Czech Republic                  | 0.78% | 0.04% | 0.74% | 46.8% | 1.1% | 32.4% | 0 | −20% |
| Denmark                         | 0.07% | 1.47% | 1.39% | 44.2% | 22.4% | 31.4% | 314 | −40% |
| Estonia                         | 3.30% | 5.83% | 2.53% | 10.5% | 19.2% | 13.9% | 226 | −13% |
| Finland                         | 0.62% | 0.47% | 1.09% | 31.2% | 14.3% | 24.2% | 219 | −39% |
| France                          | 0.20% | 0.66% | 0.86% | 23.6% | 21.3% | 21.9% | 249 | −36% |
| Germany                         | 0.43% | 1.67% | 2.10% | 38.2% | 30.7% | 34.9% | 597 | −37% |
| Greece                          | 0.26% | 0.34% | 0.08% | 30.2% | 2.7% | 15.1% | 0 | −44% |
| Hungary                         | 0.28% | 0.08% | 0.20% | 28.5% | 0.7% | 10.8% | 0 | −15% |
| Ireland                         | 0.23% | 1.41% | 1.18% | 33.2% | 17.9% | 23.8% | 139 | −39% |
| Italy                           | 0.17% | 0.15% | 0.32% | 27.4% | 7.4% | 16.2% | 75 | −33% |
| Latvia                          | 0.46% | 0.44% | 0.02% | 17.3% | 0.8% | 5.6% | 0 | −7% |
| Lithuania                       | 0.93% | 1.13% | 0.19% | 15.0% | 16.8% | 16.0% | 141 | −9% |
| Luxembourg                      | 1.88% | 2.94% | 1.06% | 19.0% | 27.8% | 26.2% | 252 | −40% |
| Malta                           | 0.45% | 3.97% | 4.42% | 10.9% | 44.6% | 30.5% | 315 | −19% |
| Netherlands                     | 0.94% | 2.62% | 1.68% | 26.1% | 22.7% | 24.1% | 309 | −39% |
| Poland                          | 0.80% | 0.02% | 0.78% | 47.7% | 16.1% | 36.6% | 41 | −7% |
| Portugal                        | 0.00% | 0.06% | 0.06% | 34.2% | 1.6% | 13.5% | 0 | −23% |
| Romania                         | 0.85% | 0.42% | 0.43% | 37.0% | 1.2% | 23.6% | 0 | −6% |
Table 10 (continued)

| Components of welfare cost<sup>a</sup>         | CO₂ emissions<sup>b</sup> | CO₂ tax<sup>c</sup> | ESR emissions in % of 2005 levels |
|-----------------------------------------------|---------------------------|---------------------|----------------------------------|
| Total GTT DWL                                | ETS ESR Total             | ESR sectors         |
| Slovakia                                     | 0.79% 0.43% 0.37%         | −28.3% 0.4% −15.9%  | 0  −14%                          |
| Slovenia                                     | 0.35% 0.11% 0.24%         | −33.4% −2.6% −16.4% | 26  −15%                          |
| Spain                                        | −0.04% −0.11% 0.07%      | −31.9% −0.5% −15.8% | 11  −26%                          |
| Sweden                                       | 0.17% −1.25% 1.43%       | −23.3% −22.2% −22.5%| 454  −40%                         |
| United Kingdom                               | 0.34% −0.22% 0.56%       | −37.8% −18.9% −27.2%| 177  −36%                         |
| European Union ETS price<sup>c</sup>         | 0.17% −0.77% 0.95%       | −35.4% −16.8% −25.8%| 209<sup>d</sup> −31%                 |

<sup>a</sup> In % of households consumption

<sup>b</sup> Change in % with respect to the reference scenario

<sup>c</sup> In €<sub>2017</sub> per ton of CO₂

<sup>d</sup> The average ESR CO₂ price is weighted with the emissions of the scenario
| Components of welfare cost<sup>a</sup> | CO₂ emissions<sup>b</sup> | CO₂ tax<sup>c</sup> | ESR emissions in % of 2005 levels |
|-----------------------------------|--------------------------|----------------------|----------------------------------|
|                                   | Total        | G TT      | DWL       | ETS         | ESR         | Total        | ETS         | ESR         | ESR sectors |
| Austria                           | -0.33%       | -1.22%    | 0.89%     | -22.2%      | -17.3%      | -19.0%       | 242         | -22.2%      | -32%        |
| Belgium                           | -0.55%       | -1.22%    | 0.67%     | -21.4%      | -17.7%      | -19.0%       | 199         | -21.4%      | -31%        |
| Bulgaria                          | 0.29%        | -0.28%    | 0.57%     | -38.9%      | 1.6%        | -28.8%       | 0           | -38.9%      | -15%        |
| Croatia                           | -0.06%       | -0.28%    | 0.22%     | -31.9%      | 0.8%        | -12.5%       | 0           | -31.9%      | -22%        |
| Cyprus                            | -0.51%       | -0.95%    | 0.44%     | -9.9%       | -9.5%       | -9.7%        | 73          | -9.9%       | -24%        |
| Czech Republic                   | 0.77%        | 0.04%     | 0.73%     | -46.8%      | 1.0%        | -32.3%       | 0           | -46.8%      | -20%        |
| Denmark                           | 0.03%        | -1.03%    | 1.05%     | -44.1%      | -17.6%      | -28.5%       | 221         | -44.1%      | -33%        |
| Estonia                           | -3.35%       | -5.90%    | 2.54%     | -10.4%      | -19.3%      | -13.9%       | 227         | -10.4%      | -13%        |
| Finland                           | 0.66%        | -0.54%    | 1.20%     | -31.3%      | -15.8%      | -24.8%       | 249         | -31.3%      | -40%        |
| France                            | 0.23%        | -0.72%    | 0.95%     | -23.7%      | -22.6%      | -22.9%       | 273         | -23.7%      | -38%        |
| Germany                           | 0.47%        | -1.78%    | 2.25%     | -38.3%      | -31.9%      | -35.4%       | 641         | -38.3%      | -39%        |
| Greece                            | -0.28%       | -0.35%    | 0.08%     | -30.1%      | 2.7%        | -15.0%       | 0           | -30.1%      | -44%        |
| Hungary                           | 0.26%        | 0.07%     | 0.20%     | -28.5%      | 0.7%        | -10.8%       | 0           | -28.5%      | -15%        |
| Ireland                           | -0.21%       | -1.08%    | 0.86%     | -33.0%      | -13.3%      | -20.9%       | 96          | -33.0%      | -26%        |
| Italy                             | 0.16%        | -0.16%    | 0.32%     | -27.4%      | -7.5%       | -16.3%       | 76          | -27.4%      | -33%        |
| Latvia                            | 0.44%        | 0.43%     | 0.02%     | -17.2%      | 0.8%        | -5.6%        | 0           | -17.2%      | -7%         |
| Lithuania                         | -0.95%       | -1.14%    | 0.19%     | -15.0%      | -16.9%      | -16.0%       | 141         | -15.0%      | -9%         |
| Luxembourg                        | -1.65%       | -2.40%    | 0.74%     | -18.9%      | -23.7%      | -22.8%       | 199         | -18.9%      | -27%        |
| Malta                             | 0.43%        | -4.00%    | 4.43%     | -10.8%      | -44.6%      | -30.5%       | 315         | -10.8%      | -19%        |
| Netherlands                       | -0.71%       | -1.91%    | 1.20%     | -25.8%      | -17.9%      | -21.2%       | 219         | -25.8%      | -32%        |
| Poland                            | 0.79%        | 0.01%     | 0.78%     | -47.6%      | -16.2%      | -36.6%       | 42          | -47.6%      | -7%         |
| Portugal                          | -0.01%       | -0.07%    | 0.06%     | -34.2%      | 1.6%        | -13.5%       | 0           | -34.2%      | -23%        |
| Romania                           | 0.83%        | 0.41%     | 0.43%     | -37.0%      | -1.1%       | -23.6%       | 0           | -37.0%      | -6%         |
| Slovakia                          | 0.75%        | 0.40%     | 0.35%     | -28.2%      | 0.4%        | -15.8%       | 0           | -28.2%      | -14%        |
| Slovenia                          | 0.33%        | 0.10%     | 0.24%     | -33.4%      | -2.7%       | -16.5%       | 26          | -33.4%      | -15%        |
| Spain                             | -0.05%       | -0.12%    | 0.07%     | -31.9%      | -0.6%       | -15.8%       | 11          | -31.9%      | -26%        |
| Sweden                            | 0.18%        | -1.37%    | 1.55%     | -23.5%      | -23.6%      | -23.5%       | 495         | -23.5%      | -41%        |
| United Kingdom                    | 0.36%        | -0.26%    | 0.62%     | -37.9%      | -20.3%      | -28.0%       | 198         | -37.9%      | -38%        |
| European Union                   | 0.21%        | -0.76%    | 0.96%     | -35.4%      | -16.8%      | -25.8%       | 210<sup>d</sup> | -35.4%      | -31%        |

ETS price<sup>c</sup> 45

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<sup>a</sup> In % of households consumption  
<sup>b</sup> Change in % with respect to the reference scenario  
<sup>c</sup> In €<sub>2017</sub> per ton of CO₂  
<sup>d</sup> The average ESR CO₂ price is weighted with the emissions of the scenario
Table 12 Scenario option T4a—year 2030

| Components of welfare cost<sup>a</sup> | CO<sub>2</sub> emissions<sup>b</sup> | CO<sub>2</sub> tax<sup>c</sup> | ESR emissions in % of 2005 levels |
|---------------------------------------|----------------------------------|-------------------------------|----------------------------------|
| Total                                 | GTT                              | DWL                           | ETS                             | ESR                             | Total | ESR sectors |
| Austria                               | -0.38%                           | -1.55%                        | 1.17%                           | -22.7%                          | -20.8% | -21.4% | 314 | -35%       |
| Belgium                                | -0.61%                           | -1.43%                        | 0.81%                           | -21.6%                          | -19.9% | -20.5% | 235 | -33%       |
| Bulgaria                               | 0.32%                            | -0.25%                        | 0.57%                           | -38.9%                          | 1.7%   | -28.7% | 0   | -15%       |
| Croatia                                | -0.09%                           | -0.29%                        | 0.21%                           | -31.9%                          | 0.9%   | -12.4% | 0   | -21%       |
| Cyprus                                 | -0.51%                           | -0.94%                        | 0.43%                           | -9.9%                           | -9.3%  | -9.6%  | 72  | -24%       |
| Czech Republic                         | 0.79%                            | 0.05%                         | 0.74%                           | -46.8%                          | 1.1%   | -32.3% | 0   | -20%       |
| Denmark                                | -0.07%                           | -1.46%                        | 1.39%                           | -44.2%                          | -22.3% | -31.3% | 312 | -37%       |
| Estonia                                | -3.21%                           | -5.74%                        | 2.52%                           | -10.5%                          | -19.1% | -13.9% | 222 | -13%       |
| Finland                                | 0.52%                            | -0.29%                        | 0.81%                           | -30.9%                          | -10.0% | -22.2% | 141 | -36%       |
| France                                 | 0.18%                            | -0.60%                        | 0.78%                           | -23.4%                          | -20.0% | -20.9% | 225 | -36%       |
| Germany                                | 0.53%                            | -1.86%                        | 2.39%                           | -38.4%                          | -32.9% | -35.9% | 680 | -40%       |
| Greece                                 | -0.28%                           | -0.35%                        | 0.07%                           | -30.1%                          | 2.7%   | -15.0% | 0   | -44%       |
| Hungary                                | 0.28%                            | 0.08%                         | 0.20%                           | -28.5%                          | 0.7%   | -10.8% | 0   | -15%       |
| Ireland                                | -0.23%                           | -1.60%                        | 1.37%                           | -33.3%                          | -20.2% | -25.2% | 163 | -32%       |
| Italy                                  | 0.17%                            | -0.15%                        | 0.32%                           | -27.4%                          | -7.3%  | -16.2% | 74  | -33%       |
| Latvia                                  | 0.47%                            | 0.45%                         | 0.02%                           | -17.3%                          | 0.8%   | -5.6%  | 0   | -7%        |
| Lithuania                               | -0.91%                           | -1.11%                        | 0.19%                           | -15.0%                          | -16.7% | -15.9% | 139 | -9%        |
| Luxembourg                              | -1.92%                           | -3.07%                        | 1.15%                           | -19.0%                          | -28.8% | -27.0% | 264 | -32%       |
| Malta                                   | 0.43%                            | -3.98%                        | 4.41%                           | -10.8%                          | -44.5% | -30.5% | 314 | -19%       |
| Netherlands                             | -0.88%                           | -2.42%                        | 1.54%                           | -26.1%                          | -21.4% | -23.3% | 282 | -35%       |
| Poland                                  | 0.80%                            | 0.02%                         | 0.78%                           | -47.6%                          | -16.0% | -36.6% | 41  | -7%        |
| Portugal                                | 0.00%                            | -0.06%                        | 0.06%                           | -34.2%                          | 1.6%   | -13.5% | 0   | -23%       |
| Romania                                 | 0.85%                            | 0.42%                         | 0.43%                           | -37.0%                          | -1.1%  | -23.6% | 0   | -6%        |
| Slovakia                                | 0.80%                            | 0.44%                         | 0.37%                           | -28.3%                          | 0.4%   | -15.9% | 0   | -14%       |
| Slovenia                                | 0.36%                            | 0.13%                         | 0.23%                           | -33.4%                          | -2.6%  | -16.4% | 25  | -15%       |
| Spain                                   | -0.04%                           | -0.11%                        | 0.07%                           | -31.9%                          | -0.4%  | -15.7% | 10  | -26%       |
| Sweden                                  | 0.17%                            | -1.25%                        | 1.42%                           | -23.3%                          | -22.1% | -22.5% | 451 | -40%       |
| United Kingdom                          | 0.34%                            | -0.22%                        | 0.56%                           | -37.7%                          | -18.8% | -27.1% | 175 | -37%       |
| European Union                          | 0.20%                            | -0.79%                        | 0.98%                           | -35.4%                          | -16.8% | -25.8% | 212d| -31%       |

<sup>a</sup> In % of households consumption

<sup>b</sup> Change in % with respect to the reference scenario

<sup>c</sup> In €<sub>2017</sub> per ton of CO<sub>2</sub>

<sup>d</sup> The average ESR CO<sub>2</sub> price is weighted with the emissions of the scenario
Table 13  Scenario option T4b—year 2030

| Components of welfare cost | CO₂ emissions | CO₂ tax | ESR emissions in % of 2005 levels |
|---------------------------|---------------|---------|----------------------------------|
|                           | ETS | DWL | ETS | DWL | Total | ETS | DWL | Total | ESR sectors |
| Austria                   | 0.41% | 1.92% | 1.51% | -23.1% | -24.5% | -24.0% | 402 | -38% |
| Belgium                   | 0.67% | 1.55% | 0.88% | -21.7% | -21.1% | -21.3% | 257 | -34% |
| Bulgaria                  | 0.30% | 0.27% | 0.57% | -38.9% | 1.7% | -28.7% | 0 | -15% |
| Croatia                   | 0.08% | 0.29% | 0.21% | -31.9% | 0.9% | -12.4% | 0 | -21% |
| Cyprus                    | 0.50% | 0.94% | 0.44% | -9.9% | -9.3% | -9.6% | 72 | -24% |
| Czech Republic            | 0.78% | 0.04% | 0.74% | -46.8% | 1.1% | -32.3% | 0 | -20% |
| Denmark                   | -0.05% | 1.34% | 1.29% | -44.2% | -21.1% | -30.6% | 287 | -36% |
| Estonia                   | -3.32% | 5.84% | 2.51% | -10.4% | -19.1% | -13.8% | 225 | -13% |
| Finland                   | 0.66% | 0.53% | 1.19% | -31.3% | -15.6% | -24.8% | 246 | -40% |
| France                    | 0.15% | 0.56% | 0.70% | -23.2% | -18.8% | -20.0% | 205 | -35% |
| Germany                   | 0.42% | 1.67% | 2.09% | -38.2% | -30.7% | -34.8% | 595 | -38% |
| Greece                    | -0.27% | 0.34% | 0.08% | -30.1% | 2.6% | -15.1% | 0 | -44% |
| Hungary                   | 0.28% | 0.07% | 0.20% | -28.5% | 0.7% | -10.8% | 0 | -15% |
| Ireland                   | -0.24% | 1.33% | 1.09% | -33.1% | -16.7% | -23.0% | 128 | -29% |
| Italy                     | 0.16% | 0.16% | 0.32% | -27.4% | -7.3% | -16.2% | 75 | -33% |
| Latvia                    | 0.45% | 0.43% | 0.02% | -17.3% | 0.8% | -5.6% | 0 | -7% |
| Lithuania                 | -0.94% | 1.13% | 0.19% | -14.9% | -16.7% | -15.9% | 140 | -9% |
| Luxembourg                | -1.64% | 2.37% | 0.73% | -18.9% | -23.5% | -22.7% | 197 | -27% |
| Malta                     | 0.39% | 4.01% | 4.41% | -10.8% | -44.5% | -30.4% | 316 | -19% |
| Netherlands               | -0.81% | 2.22% | 1.41% | -25.9% | -20.2% | -22.6% | 260 | -34% |
| Portugal                  | 0.79% | 0.01% | 0.78% | -47.6% | -16.0% | -36.6% | 41 | -7% |
| Portugal                  | -0.01% | 0.07% | 0.06% | -34.2% | 1.6% | -13.5% | 0 | -23% |
| Romania                   | 0.84% | 0.41% | 0.43% | -37.0% | -1.1% | -23.6% | 0 | -6% |
| Slovenia                  | 0.79% | 0.42% | 0.37% | -28.3% | 0.4% | -15.9% | 0 | -14% |
| Spain                     | 0.34% | 0.11% | 0.23% | -33.4% | -2.6% | -16.4% | 25 | -15% |
| Sweden                    | -0.05% | 0.12% | 0.07% | -31.9% | 0.4% | -15.7% | 0 | -26% |
| United Kingdom            | 0.43% | -0.32% | 0.76% | -38.2% | -22.7% | -29.5% | 239 | -40% |
| European Union            | 0.18% | 0.76% | 0.94% | -35.4% | -16.8% | -25.8% | 209 | -31% |

ETS price  45

a In % of households consumption
b Change in % with respect to the reference scenario
c In €2017 per ton of CO₂
d The average ESR CO₂ price is weighted with the emissions of the scenario
Table 14  Scenario option O2—year 2030

| Components of welfare cost<sup>a</sup> | CO<sub>2</sub> emissions<sup>b</sup> | CO<sub>2</sub> tax<sup>c</sup> | ESR emissions in % of 2005 levels |
|---------------------------------------|---------------------------------|----------------|----------------------------------|
|                                       | Total | GGT | DWL | ETS | ESR | Total | ESR sectors |
| Austria                               | 0.38% | 1.78% | 1.40% | 23.4% | 23.3% | 23.3% | 370 | 37% |
| Belgium                                | 0.75% | 1.81% | 1.06% | 22.3% | 23.5% | 23.1% | 305 | 36% |
| Bulgaria                               | 0.31% | 0.29% | 0.60% | 39.5% | 1.6% | 29.3% | 0 | 16% |
| Croatia                                | 0.05% | 0.29% | 0.23% | 32.4% | 0.8% | 12.7% | 0 | 22% |
| Cyprus                                 | 0.47% | 0.90% | 0.43% | 10.2% | -9.3% | 9.7% | 71 | 24% |
| Czech Republic                         | 0.79% | 0.03% | 0.76% | 47.5% | 1.0% | 32.8% | 0 | 20% |
| Denmark                                | 0.08% | 1.58% | 1.50% | 44.8% | 23.6% | 32.3% | 339 | 37% |
| Estonia                                | 3.25% | 5.77% | 2.52% | 10.8% | 19.1% | 14.0% | 222 | 13% |
| Finland                                | 0.54% | 0.36% | 0.90% | 31.5% | 11.4% | 23.2% | 165 | 37% |
| France                                 | 0.17% | 0.61% | 0.78% | 23.8% | 20.0% | 21.0% | 225 | 36% |
| Germany                                | 0.38% | 1.58% | 1.96% | 38.7% | 29.5% | 34.6% | 553 | 37% |
| Greece                                 | 0.23% | 0.32% | 0.09% | 30.8% | 2.5% | 15.4% | 0 | 44% |
| Hungary                                | 0.28% | 0.07% | 0.21% | 29.0% | 0.6% | 11.0% | 0 | 15% |
| Ireland                                | 0.22% | 1.93% | 1.71% | 34.0% | 23.7% | 27.7% | 207 | 35% |
| Italy                                  | 0.17% | 0.16% | 0.32% | 27.9% | 7.3% | 16.4% | 74 | 33% |
| Latvia                                 | 0.46% | 0.44% | 0.02% | 17.7% | 0.8% | 5.8% | 0 | 7% |
| Lithuania                               | 0.96% | 1.14% | 0.19% | 15.2% | 16.7% | 16.0% | 139 | 9% |
| Luxembourg                             | 2.09% | 3.67% | 1.58% | 19.6% | 33.0% | 30.5% | 331 | 36% |
| Malta                                  | 0.35% | 3.74% | 4.09% | 11.1% | 43.2% | 29.8% | 296 | 17% |
| Netherlands                            | 0.99% | 2.80% | 1.81% | 26.5% | 23.8% | 24.9% | 333 | 37% |
| Poland                                 | 0.82% | 0.02% | 0.81% | 48.3% | 16.0% | 37.0% | 41 | 7% |
| Portugal                               | 0.01% | 0.06% | 0.07% | 34.7% | 1.5% | 13.8% | 0 | 24% |
| Romania                                | 0.85% | 0.41% | 0.44% | 37.6% | 1.2% | 24.0% | 0 | 6% |
| Slovakia                               | 0.78% | 0.40% | 0.38% | 28.8% | 0.4% | 16.2% | 0 | 14% |
| Slovenia                                | 0.34% | 0.10% | 0.24% | 34.1% | 2.5% | 16.6% | 25 | 15% |
| Spain                                  | -0.04% | -0.11% | 0.07% | 32.4% | 0.4% | 15.9% | 9 | 26% |
| Sweden                                 | 0.14% | 1.05% | 1.20% | 23.3% | 19.5% | 20.7% | 379 | 38% |
| United Kingdom                         | 0.31% | 0.19% | 0.50% | 38.1% | 17.5% | 26.6% | 157 | 36% |
| European Union                         | 0.15% | 0.76% | 0.91% | 35.9% | 16.4% | 25.8% | 199<sup>d</sup> | 31% |

ETS price<sup>c</sup> 47

<sup>a</sup>In % of households consumption
<sup>b</sup>Change in % with respect to the reference scenario
<sup>c</sup>In €<sub>2017</sub> per ton of CO<sub>2</sub>
<sup>d</sup>The average ESR CO<sub>2</sub> price is weighted with the emissions of the scenario
Table 15 Scenario option O3—year 2030

| Components of welfare cost^a | CO₂ emissions^b | CO₂ tax^c | ESR emissions in % of 2005 levels |
|------------------------------|-----------------|-----------|----------------------------------|
|                              | Total | GTT | DWL | ETS | ESR | Total | ESR sectors |
| Austria                      | -0.34%| -1.52%| 1.18%| -23.5%| -20.8%| -21.7%| 313 | -35% |
| Belgium                      | -0.68%| -1.57%| 0.89%| -22.5%| -21.1%| -21.6%| 258 | -34% |
| Bulgaria                     | 0.28% | -0.34%| 0.62%| -40.1%| 1.5% | -29.7%| 0  | -16% |
| Croatia                      | -0.02%| -0.28%| 0.26%| -32.9%| 0.6% | -13.0%| 0  | -22% |
| Cyprus                       | -0.46%| -0.89%| 0.44%| -10.5%| -9.3% | -9.8%| 70  | -24% |
| Czech Republic               | 0.79% | 0.01%| 0.78%| -48.1%| 1.0% | -33.2%| 0  | -20% |
| Denmark                      | -0.03%| -1.34%| 1.31%| -45.3%| -21.1%| -31.1%| 285 | -36% |
| Estonia                      | -3.22%| -5.75%| 2.53%| -11.1%| -19.1%| -14.2%| 220 | -13% |
| Finland                      | 0.46% | -0.27%| 0.73%| -31.8%| -8.6% | -22.2%| 118 | -35% |
| France                       | 0.17% | -0.61%| 0.78%| -24.1%| -20.0%| -21.1%| 224 | -36% |
| Germany                      | 0.37% | -1.59%| 1.96%| -39.3%| -29.5%| -35.0%| 552 | -37% |
| Greece                       | -0.21%| -0.31%| 0.10%| -31.3%| 2.4%  | -15.8%| 0  | -44% |
| Hungary                      | 0.27% | 0.05%| 0.22%| -29.4%| 0.5%  | -11.2%| 0  | -15% |
| Ireland                      | -0.25%| -1.53%| 1.28%| -34.2%| -19.1%| -24.9%| 151 | -31% |
| Italy                        | 0.16% | -0.16%| 0.33%| -28.3%| -7.3% | -16.5%| 73  | -33% |
| Latvia                       | 0.43% | 0.41%| 0.02%| -18.0%| 0.7%  | -5.9% | 0  | -7%  |
| Lithuania                    | -0.99%| -1.18%| 0.18%| -15.4%| -16.7%| -16.1%| 139 | -9%  |
| Luxembourg                   | -1.84%| -2.99%| 1.15%| -19.9%| -28.8%| -27.2%| 266 | -32% |
| Malta                        | 0.27% | -3.53%| 3.80%| -11.4%| -41.8%| -29.1%| 278 | -15% |
| Netherlands                  | -0.87%| -2.41%| 1.54%| -26.7%| -21.4%| -23.6%| 283 | -35% |
| Poland                       | 0.84% | 0.01%| 0.83%| -49.0%| -16.0%| -37.4%| 41  | -7%  |
| Portugal                     | 0.01% | -0.06%| 0.08%| -35.2%| 1.3%  | -14.1%| 0  | -24% |
| Romania                      | 0.85% | 0.40%| 0.45%| -38.1%| -1.3% | -24.4%| 0  | -6%  |
| Slovakia                     | 0.74% | 0.36%| 0.38%| -29.2%| 0.4%  | -16.4%| 0  | -14% |
| Slovenia                     | 0.32% | 0.08%| 0.24%| -34.7%| -2.5% | -16.9%| 24  | -15% |
| Spain                        | -0.04%| -0.12%| 0.08%| -32.8%| -0.4% | -16.1%| 9  | -26% |
| Sweden                       | 0.12% | -0.87%| 0.99%| -23.4%| -17.0%| -19.0%| 311 | -36% |
| United Kingdom               | 0.31% | -0.20%| 0.50%| -38.7%| -17.5%| -26.8%| 156 | -36% |
| European Union               | 0.15% | -0.72%| 0.88%| -36.4%| -15.9%| -25.8%| 190d| -31% |

^a In % of households consumption
^b Change in % with respect to the reference scenario
^c In €_{2017} per ton of CO₂
^d The average ESR CO₂ price is weighted with the emissions of the scenario
Table 16  Scenario option O2b—year 2030

| Components of welfare cost<sup>a</sup> | CO<sub>2</sub> emissions<sup>b</sup> | CO<sub>2</sub> tax<sup>c</sup> | ESR emissions in % of 2005 levels |
|--------------------------------------|----------------------------------|-----------------|---------------------------------|
|                                       | ETS   | DWL  | ETS | ESR | Total | ESR sectors |
| Total                                |       |      |     |     |       |            |
| Austria                              | −0.36% | −1.76% | 1.40% | −24.3% | −23.3% | −23.6% | 367 | −37% |
| Belgium                              | −0.77% | −1.83% | 1.06% | −23.3% | −23.5% | −23.4% | 304 | −36% |
| Bulgaria                             | 0.29%  | −0.37% | 0.67% | −41.0% | 1.4%  | −30.4% | 0   | −16% |
| Croatia                              | 0.02%  | −0.28% | 0.29% | −33.5% | 0.5%  | −13.3% | 0   | −22% |
| Cyprus                               | −0.43% | −0.87% | 0.44% | −11.0% | −9.3% | −10.0% | 69  | −24% |
| Czech Republic                       | 0.81%  | −0.01% | 0.82% | −48.9% | 0.9%  | −33.8% | 0   | −20% |
| Denmark                              | −0.08% | −1.59% | 1.52% | −46.1% | −23.6% | −32.8% | 337 | −38% |
| Estonia                              | −3.30% | −5.83% | 2.54% | −11.6% | −19.1% | −14.5% | 222 | −13% |
| Finland                              | 0.53%  | −0.38% | 0.91% | −32.7% | −11.4% | −23.9% | 164 | −37% |
| France                               | 0.13%  | −0.51% | 0.64% | −24.4% | −17.5% | −19.4% | 185 | −34% |
| Germany                              | 0.30%  | −1.42% | 1.72% | −40.0% | −27.3% | −34.3% | 479 | −35% |
| Greece                               | −0.17% | −0.29% | 0.12% | −32.1% | 2.2%  | −16.3% | 0   | −45% |
| Hungary                              | 0.29%  | 0.05%  | 0.24% | −30.0% | 0.5%  | −11.5% | 0   | −15% |
| Ireland                              | −0.23% | −1.94% | 1.70% | −35.1% | −23.7% | −28.1% | 205 | −35% |
| Italy                                | 0.17%  | −0.17% | 0.34% | −28.9% | −7.3% | −16.8% | 72  | −33% |
| Latvia                                | 0.43%  | 0.41%  | 0.02% | −18.6% | 0.7%  | −6.2%  | 0   | −7%  |
| Lithuania                            | −1.03% | −1.21% | 0.18% | −15.8% | −16.7% | −16.3% | 139 | −9%  |
| Luxembourg                           | −2.04% | −3.62% | 1.58% | −20.6% | −33.0% | −30.7% | 329 | −36% |
| Malta                                | 0.42%  | −3.66% | 4.08% | −11.9% | −43.2% | −30.1% | 293 | −17% |
| Netherlands                          | −1.01% | −2.83% | 1.81% | −27.3% | −23.8% | −25.3% | 332 | −37% |
| Poland                               | 0.87%  | 0.01%  | 0.87% | −49.9% | −16.0% | −38.0% | 41  | −7%  |
| Portugal                             | 0.03%  | −0.06% | 0.09% | −35.8% | 1.1%  | −14.4% | 0   | −24% |
| Romania                              | 0.86%  | 0.39%  | 0.47% | −38.9% | 1.4%  | −24.9% | 0   | −6%  |
| Slovakia                             | 0.74%  | 0.34%  | 0.39% | −29.8% | 0.3%  | −16.8% | 0   | −14% |
| Slovenia                             | 0.32%  | 0.07%  | 0.25% | −35.5% | −2.5% | −17.3% | 24  | −15% |
| Spain                                | −0.03% | −0.12% | 0.09% | −33.4% | −0.4% | −16.4% | 8   | −26% |
| Sweden                               | 0.13%  | −1.07% | 1.19% | −24.1% | −19.5% | −21.0% | 378 | −38% |
| United Kingdom                       | 0.27%  | −0.14% | 0.41% | −39.1% | −15.0% | −25.6% | 123 | −34% |
| European Union                       | 0.12%  | −0.71% | 0.83% | −37.1% | −15.3% | −25.8% | 179d| −30% |

ETS price<sup>c</sup> 51

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<sup>a</sup> In % of households consumption

<sup>b</sup> Change in % with respect to the reference scenario

<sup>c</sup> In €<sub>2017</sub> per ton of CO<sub>2</sub>

<sup>d</sup> The average ESR CO<sub>2</sub> price is weighted with the emissions of the scenario
Table 17  Scenario option O3b—year 2030

| Components of welfare cost<sup>a</sup> | CO₂ emissions<sup>b</sup> | CO₂ tax<sup>c</sup> | ESR emissions in % of 2005 levels |
|--------------------------------------|-------------------------|------------------|----------------------------------|
| Total | GTT | DWL | ETS | ESR | Total | ESR sectors |
|--------|------|------|-----|------|------|------------|
| Austria | −0.30% | −1.50% | 1.20% | −25.4% | −20.8% | −22.4% | 307 | −35% |
| Belgium | −0.73% | −1.61% | 0.88% | −24.4% | −21.1% | −22.3% | 256 | −34% |
| Bulgaria | 0.26% | −0.52% | 0.77% | −43.1% | 1.2% | −32.0% | 0 | −16% |
| Croatia | 0.13% | −0.26% | 0.39% | −35.0% | 0.0% | −14.2% | 0 | −22% |
| Cyprus | −0.38% | −0.83% | 0.45% | −12.1% | −9.3% | −10.5% | 66 | −24% |
| Czech Republic | 0.84% | −0.07% | 0.91% | −50.9% | 0.7% | −35.3% | 0 | −21% |
| Denmark | −0.02% | −1.37% | 1.35% | −47.8% | −21.1% | −32.1% | 282 | −36% |
| Estonia | −3.31% | −5.87% | 2.57% | −12.8% | −19.1% | −15.3% | 218 | −13% |
| Finland | 0.45% | −0.31% | 0.76% | −34.1% | −8.6% | −23.6% | 115 | −35% |
| France | 0.09% | −0.43% | 0.52% | −25.3% | −15.0% | −17.8% | 148 | −32% |
| Germany | 0.22% | −1.29% | 1.51% | −41.8% | −25.1% | −34.4% | 411 | −33% |
| Greece | −0.09% | −0.24% | 0.15% | −34.1% | 1.7% | −17.6% | 0 | −45% |
| Hungary | 0.28% | 0.01% | 0.27% | −31.4% | 0.2% | −12.2% | 0 | −15% |
| Ireland | −0.27% | −1.56% | 1.28% | −36.4% | −19.1% | −25.8% | 148 | −31% |
| Italy | 0.17% | −0.18% | 0.35% | −30.3% | −7.3% | −17.4% | 70 | −33% |
| Latvia | 0.39% | 0.36% | 0.03% | −19.9% | 0.5% | −6.7% | 0 | −7% |
| Lithuania | −1.13% | −1.30% | 0.18% | −16.6% | −16.7% | −16.6% | 138 | −9% |
| Luxembourg | −1.74% | −2.89% | 1.14% | −22.0% | −28.8% | −27.6% | 262 | −32% |
| Malta | 0.39% | −3.38% | 3.77% | −13.0% | −41.8% | −29.8% | 273 | −15% |
| Netherlands | −0.91% | −2.46% | 1.54% | −28.3% | −21.4% | −24.3% | 280 | −35% |
| Poland | 0.95% | −0.01% | 0.95% | −52.0% | −16.0% | −39.4% | 40 | −7% |
| Portugal | 0.05% | −0.07% | 0.12% | −37.3% | 0.7% | −15.3% | 0 | −24% |
| Romania | 0.88% | 0.36% | 0.52% | −40.8% | 1.6% | −26.1% | 0 | −6% |
| Slovakia | 0.65% | 0.24% | 0.41% | −31.3% | 0.3% | −17.6% | 0 | −14% |
| Slovenia | 0.28% | 0.01% | 0.27% | −37.6% | −2.5% | −18.2% | 22 | −15% |
| Spain | −0.02% | −0.13% | 0.10% | −34.8% | −0.4% | −17.1% | 6 | −26% |
| Sweden | 0.09% | −0.90% | 0.99% | −24.9% | −17.0% | −19.5% | 309 | −36% |
| United Kingdom | 0.23% | −0.11% | 0.34% | −40.7% | −12.4% | −24.8% | 93 | −32% |
| European Union | 0.11% | −0.63% | 0.74% | −38.7% | −13.8% | −25.9% | 152<sup>d</sup> | −29% |

<sup>a</sup> In % of households consumption

<sup>b</sup> Change in % with respect to the reference scenario

<sup>c</sup> In €<sub>2017</sub> per ton of CO₂

<sup>d</sup> The average ESR CO₂ price is weighted with the emissions of the scenario
Table 18  Scenario option L2—year 2030

|                  | Components of welfare cost\(^a\) | CO\(_2\) emissions\(^b\) | CO\(_2\) tax\(^c\) | ESR emissions in % of 2005 levels |
|------------------|-----------------------------------|--------------------------|---------------------|----------------------------------|
|                  | Total | GTT | DWL | ETS | ESR | Total | ESR sectors |
| Austria          | -0.40% | -1.91% | 1.51% | -23.3% | -24.5% | -24.1% | 400 | -38% |
| Belgium          | -0.80% | -1.94% | 1.14% | -22.2% | -24.7% | -23.8% | 327 | -37% |
| Bulgaria         | 0.27%  | -0.30% | 0.57% | -39.1% | 1.4% | -29.0% | 0 | -16% |
| Croatia          | -0.02% | -0.27% | 0.25% | -32.1% | 0.6% | -12.7% | 0 | -22% |
| Cyprus           | -0.36% | -0.68% | 0.32% | -10.1% | -6.7% | -8.1% | 52 | -22% |
| Czech Republic   | 0.76%  | 0.02%  | 0.74% | -47.0% | 0.9% | -32.5% | 0 | -20% |
| Denmark          | 0.03%  | -0.96% | 0.99% | -44.2% | -16.7% | -28.0% | 203 | -32% |
| Estonia          | -2.84% | -4.85% | 2.01% | -10.6% | -16.6% | -13.0% | 185 | -10% |
| Finland          | 0.48%  | -0.32% | 0.80% | -31.0% | -10.1% | -22.4% | 142 | -36% |
| France           | 0.09%  | -0.43% | 0.53% | -23.0% | -15.5% | -17.5% | 155 | -32% |
| Germany          | 0.32%  | -1.48% | 1.80% | -38.2% | -28.2% | -33.7% | 509 | -36% |
| Greece           | -0.19% | -0.28% | 0.09% | -30.4% | 2.2% | -15.4% | 0 | -45% |
| Hungary          | 0.28%  | 0.06%  | 0.22% | -28.7% | 0.5% | -11.0% | 0 | -15% |
| Ireland          | -0.16% | -0.72% | 0.57% | -33.0% | -7.9% | -17.6% | 53 | -22% |
| Italy            | 0.15%  | -0.14% | 0.29% | -27.5% | -6.2% | -15.6% | 61 | -32% |
| Latvia           | 0.45%  | 0.43%  | 0.02% | -17.4% | 0.5% | -5.8% | 0 | -7% |
| Lithuania        | 0.13%  | 0.10%  | 0.03% | -13.8% | 0.3% | -6.0% | 0 | 10% |
| Luxembourg       | -2.23% | -4.27% | 2.04% | -19.4% | -36.6% | -33.5% | 394 | -40% |
| Malta            | 0.55%  | -3.81% | 4.36% | -11.0% | -44.3% | -30.4% | 307 | -19% |
| Netherlands      | -1.00% | -2.75% | 1.76% | -26.2% | -23.5% | -24.6% | 324 | -37% |
| Poland           | 0.80%  | 0.07%  | 0.73% | -47.8% | -12.5% | -35.5% | 28 | -3% |
| Portugal         | 0.02%  | -0.05% | 0.08% | -34.4% | 1.1% | -13.9% | 0 | -24% |
| Romania          | 0.81%  | 0.38%  | 0.42% | -37.2% | -1.2% | -23.7% | 0 | -6% |
| Slovakia         | 0.73%  | 0.36%  | 0.37% | -28.5% | 0.3% | -16.0% | 0 | -14% |
| Slovenia         | 0.45%  | 0.28%  | 0.17% | -33.6% | 0.5% | -14.8% | 2 | -12% |
| Spain            | -0.02% | -0.08% | 0.06% | -32.0% | 0.9% | -15.1% | 0 | -25% |
| Sweden           | 0.11%  | -1.04% | 1.16% | -23.1% | -19.3% | -20.5% | 367 | -38% |
| United Kingdom   | 0.26%  | -0.18% | 0.44% | -37.6% | -16.2% | -25.6% | 138 | -35% |
| European Union   | 0.12%  | -0.68% | 0.80% | -35.4% | -14.5% | -24.7% | 173\(^d\) | -29% |

\(^a\) In % of households consumption
\(^b\) Change in % with respect to the reference scenario
\(^c\) In €\(_{2017}\) per ton of CO\(_2\)
\(^d\) The average ESR CO\(_2\) price is weighted with the emissions of the scenario
Table 19 Scenario option F1—year 2030

| Components of welfare cost | CO₂ emissions | CO₂ tax | ESR emissions in % of 2005 levels |
|---------------------------|---------------|---------|----------------------------------|
|                           | Total         | GTT     | CO₂ Trade | DWL | ETS | ESR | Total | ESR sectors |
| Austria                   | −0.22%        | −1.61%  | 0.10%     | 1.28% | −22.9% | −21.9% | −22.3% | 311 | −36%         |
| Belgium                   | −0.59%        | −1.66%  | 0.11%     | 0.96% | −21.7% | −22.1% | −22.0% | 269 | −35%         |
| Bulgaria                  | −0.37%        | −0.50%  | −0.34%    | 0.47% | −38.5% | 1.7%  | −28.5% | 0   | −15%         |
| Croatia                   | −0.42%        | −0.40%  | −0.26%    | 0.24% | −31.9% | 0.9%  | −12.4% | 0   | −22%         |
| Cyprus                    | −0.88%        | −1.39%  | −0.16%    | 0.67% | −9.8%  | −13.8% | −12.1% | 65  | −28%         |
| Czech Republic            | −0.35%        | −0.08%  | −0.24%    | 0.68% | −46.9% | 1.2%  | −32.4% | 0   | −20%         |
| Denmark                   | 0.10%         | 1.43%   | 0.09%     | 1.42% | −44.5% | −22.3% | −31.4% | 281 | −37%         |
| Estonia                   | −2.19%        | 4.30%   | 0.34%     | 1.78% | −10.7% | −15.0% | −12.4% | 163 | −9%          |
| Finland                   | 0.59%         | −0.35%  | 0.07%     | 0.88% | −31.3% | −11.1% | −22.9% | 159 | −37%         |
| France                    | 0.25%         | −0.42%  | 0.09%     | 0.57% | −23.2% | −16.0% | −17.9% | 162 | −33%         |
| Germany                   | 0.37%         | −1.28%  | 0.09%     | 1.56% | −37.9% | −26.0% | −32.6% | 363 | −34%         |
| Greece                    | −0.54%        | −0.41%  | −0.18%    | 0.05% | −30.0% | 2.2%  | −15.2% | 0   | −45%         |
| Hungary                   | −0.17%        | −0.04%  | −0.27%    | 0.14% | −28.6% | 0.9%  | −10.7% | 0   | −14%         |
| Ireland                   | −0.03%        | −2.02%  | 0.15%     | 1.84% | −33.7% | −24.8% | −28.2% | 199 | −36%         |
| Italy                     | 0.03%         | −0.34%  | −0.11%    | 0.47% | −28.0% | −11.9% | −19.0% | 132 | −36%         |
| Latvia                    | −0.21%        | −0.03%  | −0.18%    | 0.00% | −16.8% | −3.6%  | −8.3%  | 75  | −11%         |
| Lithuania                 | −1.21%        | −1.38%  | −0.04%    | 0.20% | −14.5% | −17.8% | −16.4% | 159 | −10%         |
| Luxembourg                | −1.84%        | −3.69%  | 0.15%     | 1.70% | −19.5% | −34.0% | −31.3% | 336 | −37%         |
| Malta                     | 0.47%         | −3.47%  | 0.13%     | 3.81% | −11.0% | −41.7% | −28.9% | 241 | −15%         |
| Netherlands               | −0.71%        | −2.51%  | 0.15%     | 1.65% | −25.9% | −22.5% | −23.9% | 277 | −36%         |
| Poland                    | 0.41%         | −0.21%  | −0.22%    | 0.83% | −47.7% | −20.2% | −38.1% | 107 | −12%         |
| Portugal                  | −0.28%        | −0.14%  | −0.17%    | 0.02% | −34.3% | 1.5%  | −13.6% | 0   | −24%         |
| Romania                   | 0.51%         | 0.29%   | −0.19%    | 0.41% | −37.1% | −2.5%  | −24.2% | 72  | −7%          |
Table 19 (continued)

| Components of welfare cost\(^{a}\) | CO\(_2\) emissions\(^{b}\) | CO\(_2\) tax\(^{c}\) | ESR emissions\(^{d}\) |
|-----------------------------------|------------------|------------------|------------------|
|                                   | Total | GTT   | CO\(_2\) Trade | DWL   | ETS   | ESR   | Total | ESR sectors | ESR emissions in % of 2005 levels |
| Slovakia                          | 0.40% | 0.23% | −0.17%          | 0.34% | −28.3%| −2.2% | −17.0%| 83          | −16%                        |
| Slovenia                          | −0.34%| −0.48%| −0.19%          | 0.33% | −33.6%| −7.4% | −19.1%| 69          | −19%                        |
| Spain                             | −0.29%| −0.33%| −0.12%          | 0.16% | −32.4%| −5.4% | −18.5%| 71          | −30%                        |
| Sweden                            | 0.22% | −0.94%| 0.07%           | 1.09% | −22.9%| −18.2%| −19.7%| 293         | −37%                        |
| United Kingdom                    | 0.29% | −0.21%| 0.00%           | 0.50% | −37.8%| −17.5%| −26.4%| 159         | −36%                        |
| European Union                    | 0.10% | −0.71%| 0.00%           | 0.81% | −35.4%| −16.2%| −25.5%| 177\(^{d}\)  | −31%                        |
| ETS price\(^{c}\)                |       |       |                 |       | 46    |       |       |             |                             |
| ESR quota price\(^{c}\)          |       |       |                 |       |       |       |       | 159         |                             |

\(^{a}\) in % of households consumption

\(^{b}\) change in % with respect to the reference scenario

\(^{c}\) in €\(_{2017}\) per ton of CO\(_2\)

\(^{d}\) The average ESR CO\(_2\) price is weighted with the emissions of the scenario
Table 20  Scenario option F6—year 2030

| Components of welfare cost<sup>a</sup> | CO<sub>2</sub> emissions<sup>b</sup> | CO<sub>2</sub> tax<sup>c</sup> | ESR emissions in % of 2005 levels |
|--------------------------------------|----------------------------------|-----------------|----------------------------------|
| Total | GTT | CO<sub>2</sub> Trade | DWL | ETS | ESR | Total ESR sectors | |
| Austria | −0.01% | −1.21% | 0.20% | 1.00% | −22.5% | −18.2% | −19.7% | 239 | −33% |
| Belgium | −0.32% | −1.27% | 0.22% | 0.73% | −21.5% | −18.4% | −19.5% | 206 | −32% |
| Bulgaria | −1.00% | −0.73% | −0.67% | 0.41% | −38.5% | 1.9% | −28.5% | 0 | −15% |
| Croatia | −0.66% | −0.47% | −0.51% | 0.32% | −31.9% | 0.8% | −12.5% | 0 | −22% |
| Cyprus | −1.11% | −1.75% | −0.32% | 0.96% | −9.8% | −18.4% | −14.8% | 102 | −32% |
| Czech Republic | 0.18% | −0.13% | −0.34% | 0.65% | −46.9% | 1.2% | −32.4% | 155 | −20% |
| Denmark | 0.29% | −1.08% | 0.20% | 1.17% | −44.5% | −18.6% | −29.3% | 219 | −34% |
| Estonia | −2.00% | −4.05% | 0.39% | 1.66% | −10.8% | −14.3% | −12.1% | 155 | −8% |
| Finland | 0.54% | −0.38% | 0.07% | 0.85% | −31.2% | −10.9% | −22.8% | 155 | −37% |
| France | 0.25% | −0.40% | 0.10% | 0.55% | −23.1% | −15.5% | −17.5% | 155 | −32% |
| Germany | 0.38% | −1.03% | 0.17% | 1.24% | −37.7% | −22.5% | −30.9% | 291 | −31% |
| Greece | −0.76% | −0.44% | −0.36% | 0.04% | −30.0% | 2.1% | −15.2% | 0 | −45% |
| Hungary | −0.42% | −0.11% | −0.41% | 0.10% | −28.5% | 0.9% | −10.7% | 155 | −14% |
| Ireland | 0.11% | −1.67% | 0.28% | 1.50% | −33.6% | −21.2% | −26.0% | 167 | −33% |
| Italy | −0.01% | −0.40% | −0.14% | 0.53% | −28.1% | −13.4% | −19.9% | 155 | −37% |
| Latvia | −0.75% | −0.42% | −0.34% | 0.02% | −16.8% | −8.7% | −11.6% | 108 | −15% |
| Lithuania | −1.22% | −1.39% | −0.03% | 0.19% | −14.5% | −17.6% | −16.2% | 155 | −10% |
| Luxembourg | −1.47% | −3.12% | 0.29% | 1.36% | −19.5% | −30.8% | −28.8% | 283 | −34% |
| Malta | 0.51% | −3.03% | 0.25% | 3.29% | −11.0% | −39.0% | −27.3% | 217 | −11% |
| Netherlands | −0.38% | −1.94% | 0.28% | 1.28% | −25.8% | −18.8% | −21.7% | 217 | −33% |
| Poland | 0.06% | −0.45% | −0.42% | 0.92% | −47.8% | −24.4% | −39.6% | 121 | −16% |
| Portugal | −0.42% | −0.18% | −0.25% | 0.01% | −34.3% | 1.5% | −13.6% | 155 | −24% |
| Romania | 0.07% | 0.02% | −0.37% | 0.41% | −37.3% | −7.7% | −26.2% | 89 | −12% |
Table 20 (continued)

| Components of welfare cost<sup>a</sup> | CO<sub>2</sub> emissions<sup>b</sup> | CO<sub>2</sub> tax<sup>c</sup> | ESR emissions in % of 2005 levels |
|--------------------------------------|---------------------------------|-----------------|-------------------------------|
|                                      | Total | GTT  | CO<sub>2</sub> Trade | DWL | ETS  | ESR  | Total | ESR sectors |
| Slovakia                             | −0.03%| −0.04%| −0.33% | 0.34%| −28.4%| −7.3%| −19.3%| 94 | −21% |
| Slovenia                              | −0.91%| −1.03%| −0.38% | 0.50%| −33.7%| −12.3%| −21.8%| 104 | −24% |
| Spain                                 | −0.47%| −0.53%| −0.23% | 0.28%| −32.8%| −10.3%| −21.3%| 105 | −33% |
| Sweden                                | 0.30% | −0.67%| 0.14%  | 0.83%| −22.5%| −14.3%| −16.9%| 223 | −34% |
| United Kingdom                        | 0.28% | −0.21%| 0.01%  | 0.49%| −37.8%| −17.2%| −26.3%| 155 | −36% |
| European Union                        | 0.07% | −0.64%| 0.00%  | 0.72%| −35.4%| −15.9%| −25.4%| 174<sup>d</sup> | −31% |

ETS Price<sup>c</sup> | 46
ESR quota price<sup>c</sup> | 155

<sup>a</sup> In % of households consumption
<sup>b</sup> Change in % with respect to the reference scenario
<sup>c</sup> In €<sub>2017</sub> per ton of CO<sub>2</sub>
<sup>d</sup> The average ESR CO<sub>2</sub> price is weighted with the emissions of the scenario
Table 21  Scenario option F7—year 2030

| Components of welfare cost<sup>a</sup> | CO<sub>2</sub> emissions<sup>b</sup> | CO<sub>2</sub> tax<sup>c</sup> | ESR emissions in % of 2005 levels |
|--------------------------------------|---------------------------------|----------------------------|----------------------------------|
|                                      | Total GTT CO<sub>2</sub> Trade DWL | ETS ESR Total ESR sectors |                                  |
| Austria                              | 0.35% -0.63% 0.33% 0.64% | -21.8% -12.1% -15.4% | 145 -28%                        |
| Belgium                              | -0.05% -0.87% 0.33% 0.50% | -21.2% -13.9% -16.5% | 145 -28%                        |
| Bulgaria                             | -4.95% -3.13% -2.04% 0.22% | -38.9% -20.3% -34.2% | 145 -34%                        |
| Croatia                              | -0.88% -1.63% -1.20% 1.95% | -33.4% -11.1% -20.2% | 145 -31%                        |
| Cyprus                               | -1.04% -1.73% -0.31% 1.00% | -9.9% -19.0% -15.2% | 145 -32%                        |
| Cyprus                               | -1.19% -1.20% -1.06% 1.07% | -47.2% -17.8% -38.3% | 145 -35%                        |
| Denmark                              | 0.55% -0.64% 0.32% 0.88% | -44.4% -13.0% -25.9% | 145 -29%                        |
| Estonia                              | -1.88% -3.83% 0.42% 1.53% | -10.9% -13.5% -11.9% | 145 -7%                         |
| Finland                              | 0.47% -0.38% 0.08% 0.78% | -31.0% -10.2% -22.4% | 145 -36%                        |
| France                               | 0.24% -0.37% 0.11% 0.50% | -23.0% -14.6% -16.9% | 145 -32%                        |
| Germany                              | 0.56% -0.44% 0.37% 0.62% | -37.3% -12.6% -26.3% | 145 -22%                        |
| Greece                               | -2.54% -1.30% -1.42% 0.18% | -30.4% -12.4% -22.1% | 145 -52%                        |
| Hungary                              | -1.61% -1.22% -1.08% 0.69% | -29.7% -15.1% -20.8% | 145 -28%                        |
| Ireland                              | 0.20% -1.43% 0.36% 1.27% | -33.5% -18.5% -24.3% | 145 -31%                        |
| Italy                                | 0.01% -0.38% -0.11% 0.50% | -28.1% -12.6% -19.5% | 145 -37%                        |
| Latvia                               | -1.94% -1.46% -0.67% 0.19% | -16.9% -20.3% -19.1% | 145 -26%                        |
| Lithuania                            | -1.27% -1.43% -0.01% 0.18% | -14.9% -17.1% -16.1% | 145 -10%                        |
| Luxembourg                           | -0.19% -1.48% 0.77% 0.52% | -19.1% -18.9% -18.9% | 145 -23%                        |
| Malta                                | 0.80% -1.56% 0.73% 1.63% | -11.0% -27.1% -20.4% | 145 6%                          |
| Netherlands                          | 0.06% -1.23% 0.46% 0.83% | -25.4% -13.2% -18.3% | 145 -28%                        |
| Poland                               | -0.26% -0.77% -0.61% 1.12% | -48.2% -29.4% -41.6% | 145 -22%                        |
| Portugal                             | -1.24% -1.17% -0.66% 0.59% | -35.4% -14.5% -23.3% | 145 -36%                        |
| Romania                              | -0.65% -0.56% -0.69% 0.60% | -38.2% -18.5% -30.8% | 145 -22%                        |
|                | Components of welfare cost<sup>a</sup> | CO<sub>2</sub> emissions<sup>b</sup> | CO<sub>2</sub> tax<sup>c</sup> | ESR emissions in % of 2005 levels |
|----------------|----------------------------------------|--------------------------------------|--------------------------------|----------------------------------|
|                | Total | GTT | CO<sub>2</sub> Trade | DWL | ETS | ESR | Total | ESR sectors |
| Slovakia       | - 0.77% | - 0.71% | - 0.65% | 0.59% | - 29.0% | - 19.3% | - 24.8% | 145 | - 31% |
| Slovenia       | - 1.10% | - 1.26% | - 0.40% | 0.57% | - 33.8% | - 13.8% | - 22.8% | 145 | - 25% |
| Spain          | - 0.57% | - 0.71% | - 0.30% | 0.44% | - 33.1% | - 14.9% | - 23.8% | 145 | - 37% |
| Sweden         | 0.40% | - 0.35% | 0.22% | 0.54% | - 22.0% | - 9.1% | - 13.2% | 145 | - 30% |
| United Kingdom | 0.28% | - 0.20% | 0.03% | 0.45% | - 37.7% | - 16.3% | - 25.7% | 145 | - 35% |
| European Union | 0.02% | - 0.55% | 0.00% | 0.58% | - 35.4% | - 15.2% | - 25.0% | 145 | - 30% |
| ETS price<sup>c</sup> | 47 | | | | | | | |
| ESR quota price<sup>c</sup> | | | | | | | | 145 |

<sup>a</sup> In % of households consumption

<sup>b</sup> Change in % with respect to the reference scenario

<sup>c</sup> In €<sub>2017</sub> per ton of CO<sub>2</sub>
| Country          | Total (%) | GTT (%) | DWL (%) | CO2 emissions (a) | ETS (%) | ESR (%) | Total (%) | ESR sectors |
|------------------|-----------|---------|---------|------------------|---------|---------|-----------|-------------|
| Austria          | 0.04      | -0.37   | 0.41    | -26.3            | -7.3    | -13.8   | 70        | -39         |
| Belgium          | -0.38     | -0.64   | 0.26    | -25.9            | -8.1    | -14.3   | 70        | -38         |
| Bulgaria         | -0.71     | -1.69   | 0.98    | -46.7            | -14.0   | -38.5   | 70        | -15         |
| Croatia          | 0.65      | -0.66   | 1.31    | -38.4            | -7.9    | -20.3%  | 70        | -21         |
| Cyprus           | -0.30     | -0.83   | 0.53    | -14.3            | -11.0   | -12.4   | 70        | -24         |
| Czech Republic   | 0.70      | -0.62   | 1.32    | -54.2            | -11.9   | -41.4   | 70        | -20         |
| Austria          | 0.04      | -0.37   | 0.41    | -26.3            | -7.3    | -13.8   | 70        | -39         |
| Belgium          | -0.38     | -0.64   | 0.26    | -25.9            | -8.1    | -14.3   | 70        | -38         |
| Bulgaria         | -0.71     | -1.69   | 0.98    | -46.7            | -14.0   | -38.5   | 70        | -15         |
| Croatia          | 0.65      | -0.66   | 1.31    | -38.4            | -7.9    | -20.3%  | 70        | -21         |
| Cyprus           | -0.30     | -0.83   | 0.53    | -14.3            | -11.0   | -12.4   | 70        | -24         |
| Czech Republic   | 0.70      | -0.62   | 1.32    | -54.2            | -11.9   | -41.4   | 70        | -20         |
| Denmark          | 0.28      | -0.42   | 0.70    | -50.6            | -7.7    | -25.3   | 70        | -40         |
| Estonia          | -1.72     | -2.54   | 0.82    | -15.4            | -7.3    | -12.2   | 70        | -13         |
| Finland          | 0.27      | -0.36   | 0.63    | -36.8            | -6.0    | -24.0   | 70        | -39         |
| France           | 0.03      | -0.25   | 0.28    | -26.9            | -8.7    | -13.7   | 70        | -36         |
| Germany          | 0.01      | -0.44   | 0.46    | -44.2            | -7.6    | -27.9   | 70        | -37         |
| Greece           | 0.08      | -0.32   | 0.40    | -37.6            | -7.6    | -23.8   | 70        | -44         |
| Hungary          | 0.11      | -0.55   | 0.67    | -34.4            | -9.8    | -19.5   | 70        | -15         |
| Ireland          | -0.26     | -1.03   | 0.77    | -38.9            | -11.0   | -21.8   | 70        | -39         |
| Italy            | 0.16      | -0.25   | 0.40    | -32.9            | -7.7    | -18.8   | 70        | -33         |
| Latvia           | -0.36     | -0.49   | 0.13    | -22.4            | -12.9   | -16.2   | 70        | -7          |
| Lithuania        | -0.98     | -1.03   | 0.06    | -17.6            | -11.4   | -14.2   | 70        | -9          |
| Luxembourg       | -0.56     | -0.73   | 0.17    | -24.4            | -11.1   | -13.5   | 70        | -40         |
| Malta            | -0.46     | -0.87   | 0.41    | -14.6            | -15.8   | -15.3   | 70        | -19         |
| Netherlands      | -0.35     | -0.87   | 0.52    | -29.5            | -7.5    | -16.7   | 70        | -39         |
| Poland           | 1.08      | -0.20   | 1.28    | -55.7            | -22.1   | -43.9   | 70        | -7          |
| Portugal         | 0.00      | -0.48   | 0.48    | -40.6            | -9.0    | -22.3   | 70        | -23         |
| Romania          | 0.69      | -0.04   | 0.73    | -44.4            | -12.4   | -32.4   | 70        | -6          |
| Slovakia         | 0.16      | -0.42   | 0.58    | -33.9            | -13.1   | -24.9   | 70        | -14         |
| Slovenia         | -0.17     | -0.63   | 0.46    | -41.2            | -8.3    | -23.0   | 70        | -15         |
| Spain            | -0.05     | -0.38   | 0.33    | -37.8            | -9.2    | -23.1   | 70        | -26         |
| Sweden           | 0.05      | -0.27   | 0.32    | -25.6            | -5.1    | -11.6   | 70        | -40         |
| United Kingdom   | 0.17      | -0.13   | 0.30    | -43.6            | -10.3   | -24.9   | 70        | -36         |
| European Union   | 0.08      | -0.35   | 0.44    | -41.4            | -9.6    | -25.0   | 70        | -25         |
| ETS price (c)    |           |         |         |                  |         |         | 70        |             |

*a* In % of households consumption  
*b* Change in % with respect to the reference scenario.  
*c* In €2017 per ton of CO2
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