

Addressing emission transfers: carbon tariffs vs. clean-development financing

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Abstract

Net emission transfers via international trade from developing to developed countries have increased fourfold in the last two decades. As consumption demand in developed countries is one of the main driving forces of emission transfers, several proposals have been made to assign the responsibility for those emissions to the beneficiary, i.e. to the consumer. Such definitions of emission responsibility extend the reach of domestic climate policies across national borders and make carbon-border adjustments (via carbon tariffs) and clean-development financing in the emission-exporting developing countries a natural part of consumption-based accounts.

This study analyzes the effects of clean-development financing and carbon tariffs on energy-intensive emission transfers. The clean-development policy describes the offsetting of emission transfers of Annex I countries by funding abatement measures in the emission-exporting developing countries. The policy scenarios are implemented into an energy-economic model of the global economy. A general-equilibrium modeling approach combining output subsidies with domestic emissions taxes is used to represent the effects of clean-development investments in a sectorally consistent way.

Results indicate that carbon tariffs are effective in reducing emission transfers to Annex I countries, but they are ineffective in reducing emissions in general. At the same time, they lead to reductions in global consumption and GDP levels and an unequal burdening of Annex I and non-Annex I countries. In contrast, the clean-development policy does not lead to reductions in emission transfers, but its investments in clean development significantly reduce emissions in non-Annex I countries. Those emission reductions come at little expense to Annex I countries with only minor economic impacts. Accounting for emission transfers and connecting them to emission-offset responsibilities could be a promising policy that would have environmental benefits without being a burden economically when contained to a limited number of sectors.

1. Introduction

Net emission transfers via international trade from developing to developed countries have increased fourfold in the last two decades – from 0.4 GtCO₂ in 1990 to 1.6 GtCO₂ in 2008 (Peters et al., 2011). Consumption demand in developing countries is one of the main driving forces of those emission transfers (Hertwich and Peters, 2009; Davis and Caldeira, 2010). Therefore, several proposals have been made to assign the responsibility for those emissions to the beneficiary, i.e. to the consumer (Rose, 1990; Proops et al., 1993; Munksgaard and Pedersen, 2001; Ferng, 2003).

Consumption-based emission responsibilities extend the reach of domestic climate policies across national borders. This makes carbon-border adjustments (via carbon tariffs) and clean-development financing in emission-exporting (developing) countries a natural part of consumption-based accounts (Peters, 2008; Peters and Hertwich, 2008). Carbon tariffs indirectly places a cost of carbon on trading partner and thereby extends the domestic CO₂-price signal. In contrast, clean-development investments in trade-connected countries extend domestic mitigation efforts and therefore constitute, in political terms, a "carrot" rather than a "stick" (Dröge and Kemfert, 2005).

Past analyses paint a mixed picture of carbon tariffs and a more positive one of clean-development investments. Carbon-tariff policies have been found to be partially successful in reducing carbon leakage, i.e., the climate-policy-induced shift of production and/or consumption to countries without climate policies, but to result in only modest reductions of global emissions (e.g., Burniaux et al., 2010; Winchester et al., 2011; Böhringer et al., 2011). On the other hand, clean-development investments, e.g., through the Clean Development Mechanism (CDM) under the United Nations Framework Convention on Climate Change (UNFCCC), can achieve emission reductions in developing countries more cost-effectively than those would be achieved in developed countries (Anger et al., 2007) and, in addition, are being associated with lower carbon-leakage rates (Alexeeva-Talebi et al., 2008).

However, past assessments especially of carbon tariffs have so far focused mainly on the impact on carbon leakage instead of on emission transfers. While carbon leakage denotes the

climate-policy-induced shift of production and/or consumption away from countries implementing climate policies to countries without climate policies (Felder and Rutherford, 1993), emission transfers are seen as being based on preexisting policies and socioeconomic factors unrelated to climate policies (Peters et al., 2011) and are sometimes described as weak carbon leakage (Rothman, 1998; Peters and Hertwich, 2008; Davis and Caldeira, 2010). However, climate policies that affect trade patterns, such as carbon tariffs do, are likely to have a significant impact on emission transfers, which so far was left unstudied.

This study fills this gap by analyzing the effects of carbon tariffs, trade restriction, and clean-development investments on emission transfers. In general terms, the study is intended to highlight the connection of international climate policies with consumption-based emissions responsibilities and the emissions embodied in trade, and to clarify the relative environmental and economic trade-offs between the different policy options. For that purpose, we use an energy-economic model of the global economy. The model provides a comprehensive and microeconomically consistent representation of price-dependent market interactions, which allows us to analyse the policy-induced adjustment effects on regional production, consumption, and CO₂ emissions (see, e.g., Böhringer et al., 2011).

The study interprets emission transfers to developed (Annex I) countries as emission responsibilities of those countries due to their consumption demands. The clean-development-investment scenario is therefore constructed such that emission transfers are offset with investments in clean development in the emission-transferring developing countries. Instead of focusing on all emission transfers embodied in trade, this study concentrates on the energy-intensive sector (including refined-oil production) which constitutes a significant part of emission transfer, as well as 40% of all emissions embodied in the production of traded products (Peters et al., 2011). The focus on the energy-intensive sector increases the political and practical feasibility of the policies studied due to a narrow focus with finite demands on measuring and monitoring of emission flows.¹

The study is structured as follows. Section 2 describes the energy-economic model used in the study. Section 3 details the model scenarios implemented in the model. Section 4 presents the model results in terms of environmental and economic impacts. Section 5 concludes.

¹ The same focus has been adapted in past assessments of carbon tariffs for the same reasons and for competitiveness concerns of domestic energy-intensive industries.

2. Model description

This paper utilizes an energy-economic model of the global economy. It is based on the GTAP8inGAMS package (see Rutherford, 2010, for a description of GTAP7inGAMS) which is extended by an explicit representation of the energy sector and a carbon market in line with Rutherford and Paltsev (2000) and Böhringer et al. (2011). A detailed description of the basic framework and its energy extension can be found in the references above and in Appendix 1. In short, the model is a computable general equilibrium model based on optimizing behaviour of economic agents. Consumers maximize welfare subject to budget constraints and producers combine intermediate inputs and primary factors at least cost to produce output. Energy resources are included as primary factors whose use is associated with the emission of carbon dioxide (CO₂).

The energy-economic model is calibrated to the database version 8 of the Global Trade Analysis Project (GTAP). This database represents global production and trade for 129 countries/regions, 57 commodities and 5 primary factors for the benchmark years 2004 and 2007 (Narayanan et al., 2012). This study uses the benchmark data for the year 2007. The data include information on bilateral trade, intermediate demand, direct and indirect taxes on imports and exports, as well as CO₂ emissions from the combustion of fossil fuels. Elasticities of substitution across energy inputs and between energy and other inputs which are not represented in the database are adopted from Böhringer et al. (2011).²

For this study, the full GTAP database is aggregated such that it enables a comprehensive regional analysis of emission transfers and policies that aim at addressing those transfers. The broad regional blocks of interest are industrialized Annex I countries who have agreed to binding emissions reduction targets under the UNFCCC and developing non-Annex I countries who have not agreed to binding emissions reductions but who have stated the requirement of clean-development financing to undertake mitigation and adaptation measures. This paper uses an aggregation that explicitly resolves 4 Annex I and 7 non-Annex I countries/regions which are listed in Table 1.

² The GTAP consortium states that in order to construct a consistent global data set for a given year base, significant adjustments have been made to ensure that national input-output tables match external macroeconomic, trade, protection, and energy data (Narayanan and Walmsley, 2008, Chapters 7-8). While this ensures overall consistency, it also poses limits to accuracy, in particular of sectoral national details, which the reader should be aware of.

With respect to commodities, the model's aggregation includes five energy commodities (coal, natural gas, crude oil, refined oil, and electricity) and further differentiates between energy-intensive goods, transport services, and a composite of all other goods. The representation of transport services enables the calculation of total emissions embodied in trade (and therefore of emission transfers), while the differentiation between energy-intensive goods and all other goods allows for levying carbon tariffs only on the former as envisioned by most current policy proposals in the EU and US (van Asselt and Brewer, 2010; Monjon and Quirion, 2010).³

Table 1 Model regions

Annex I			
EUR	Europe (EU27 + EFTA)	JPN	Japan
USA	United States	RA1	Rest of Annex I
non-Annex I			
CHN	China and Hong Kong	ASI	Rest of Asia
CSM	Central and South America	MES	The Middle East
EEU	Rest of Eastern Europe	AFR	Africa
ROW	Rest of the World		

3. Model scenarios

This study assesses the effects of four policy scenarios. Those are a carbon-tariff scenario, a general scenario with no trade in energy-intensive goods, a clean-development scenario, and a scenario which adjusts Annex I countries' domestic emissions targets for emission transfers. The effect of those scenarios is assessed relative to a cap-and-trade reference (**REF**) scenario in which Annex I countries reduce their CO₂ emissions by 10% below their 2007-levels.⁴ The emissions reductions are implemented as an overall cap, which allows for trading among

³ Energy-intensive goods include iron and steel; chemicals, including plastics and petrochemical products; non-ferrous metals, including copper and aluminium; non-metallic minerals, including cement; and refined oil products.

⁴ The magnitude of emission reductions is in line with emission-reduction pledges submitted to United Nations Framework Convention on Climate Change (UNFCCC) during the 15th Conference of the Parties (COP 15) in Copenhagen in 2009 (see, e.g., Levin and Bradley, 2010).

Annex I countries. This leads to the formation of a uniform carbon price in Annex I countries and therefore eases the subsequent analysis of carbon tariffs by removing carbon price heterogeneities.

The carbon-tariff scenario (**BCA**) models the implementation of carbon tariffs by Annex I countries on energy-intensive imports (including refined oil products) from non-Annex I countries. The tariff level is determined endogenously in proportion to the carbon content of imports and the price of carbon in Annex I countries. The carbon content of imports consists of all direct and indirect emissions used for producing the goods in the country of origin plus the transportation services needed for exporting them to Annex I countries. Indirect emissions include the carbon contents of all imported and domestic intermediate inputs. The carbon contents are computed by a recursive diagonalization algorithm described by Böhringer et al. (2011).

Two alternative carbon-tariff specifications are considered in the sensitivity analysis. Those include the recycling of revenues to the exporting country (**BCR**) and the coupling of those revenues to clean-development finance (**BCM**). Those scenarios are intended to investigate the possibility of alleviating the detrimental impacts of carbon tariffs on developing countries without abandoning the instrument of carbon tariffs.

The no-trade scenario (**RSTR**) goes beyond inhibiting trade via carbon tariffs and implements more general trade restriction on energy-intensive goods. The restrictions are implemented as import tariffs of 1000% in both the Annex I countries and the non-Annex I countries. The Armington trade specification does not allow for a complete restriction of trade (Balistreri and Rutherford, 2011), so that this scenario can be considered illustrative in character. While this scenario illustrates the economic effects of inhibiting trade, it can also be seen as highlighting the gains of trade in energy-intensive goods as a counter-negative.

The clean-development scenario (**CDF**) allows Annex I countries to offset their consumption-based emissions responsibilities vis-à-vis non-Annex I countries by financing clean-development projects in those countries. We use a new, microeconomically consistent modelling framework to represent clean-development investments in non-Annex I countries as a combination of sectoral output subsidies and emissions taxes (Böhringer et al., 2013). The emissions taxes induce the adoption of more energy-efficient and more expensive

production technologies, while the output subsidies compensate the representative firm for the increase in production costs. We focus on clean-development investments in the electricity sector, which is in line with the sectoral distribution of projects under the Clean Development Mechanism (CDM) of the Kyoto Protocol (Gillenwater and Seres, 2011). The magnitude of clean-development investments is iterated until the bilateral net emissions embodied in energy-intensive imports to each Annex I countries are offset.

However, two modifications are considered for small-island states (ROW) and the Middle East (MES). Due to their geographical location, small-island states export a proportion of embodied emissions which amounts to about three quarters of their territorial emissions. There are no sufficient abatement options available to offset such a degree of emission transfers. We therefore cap clean-development investments for small-island states to its minimum value in all CDF scenarios. This has no significant effect on the results as the emissions from small-island states are negligible. For the Middle East, substitution possibilities to cleaner electricity production are limited due to the region's high reliance on fossil fuels. The sensitivity analysis therefore considers constraining the emission offsets from the Middle East to half of its emission transfers.

Finally, the domestic-adjustment scenario (**DOM**) adjusts Annex I countries' emissions-reduction targets for energy-intensive emission transfers from non-Annex I countries. The emissions embodied in net imports from a specific non-Annex country are subtracted from the importing Annex I country's emissions target. This results in more stringent targets for countries with net imports of embodied emissions. The embodied emissions are netted between the trading partners in Annex I and non-Annex I countries, but not across non-Annex I countries, i.e., net bilateral imports of embodied emissions from one non-Annex I country are not offset by net bilateral exports of embodied emissions to another non-Annex I country.

4. Results

The following presents the policy scenarios' environmental and economic impacts. This section first shows the emission transfers in the reference scenario as those serve as inputs in the other policy scenarios considered. Then the policy scenarios' effects on those emission

transfers, but also on carbon leakage and regional emissions are assessed. Finally, the economic impacts are analyzed in terms of changes in GDP.

4.1. Emissions transfers

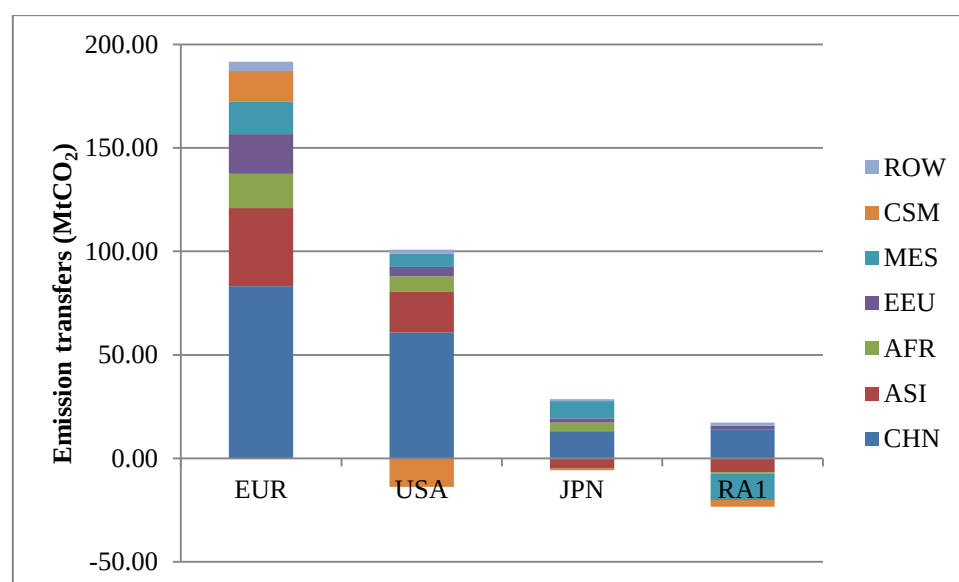


Figure 1. Emission transfers via trade in energy-intensive goods between Annex I countries and non-Annex I countries. Regional abbreviations are listed in Table 1.

The net emission transfers from non-Annex I to Annex I countries amount to 1640 MtCO₂ in the reference cap-and-trade scenario,⁵ 295 MtCO₂ (18%) of which are embodied in the trade of energy-intensive goods.⁶ Figure 1 details the regional distribution of the emission transfers embodied in energy-intensive goods. Europe imports a large portion of embodied EIT emissions (65%) which primarily stem from China and other Asian countries. The other large importers of embodied EIT emissions, USA (29%) and Japan (8%), show similar tendencies, but also export a portion of embodied EIT emissions to non-Annex I countries in Central and South America and Asia. The aggregate of other Annex I countries (Russia, Ukraine, Australia, New Zealand, among others) export slightly more embodied emissions to non-Annex I countries than they import. Taking into account the gross flows of embodied emissions (i.e., without netting positive and negative contributions across countries) increases

⁵ The benchmark values are 1513 MtCO₂ and 228 MtCO₂ for emissions-intensive sectors, respectively. Those agree with Peters et al. (2011).

⁶ Other significant emission transfers are embodied in crude-oil products and transport services with about 100 MtCO₂ (6%) each. However, most emission transfers (1100 MtCO₂, 66%) are embodied in the aggregate of all other goods.

the EIT emission transfers by 17% to 346 MtCO₂. Since the focus in this study is on the bilateral emission responsibilities of Annex I countries vis-à-vis specific non-Annex I countries, it will be those gross flows that are focused on in the following.

4.2. Environmental impacts

Figure 2 shows the change in emission transfers in the four model scenarios. The carbon-tariff scenario (BCA) reduces emission transfers to Annex I countries by 14% and the no-trade scenario (RSTR) by 93%. In contrast, emission transfers increase (by 3%) in the domestic-adjustment scenario (DOM), and they remain unchanged in the clean-development scenario (CDF) which instead offsets those emissions.

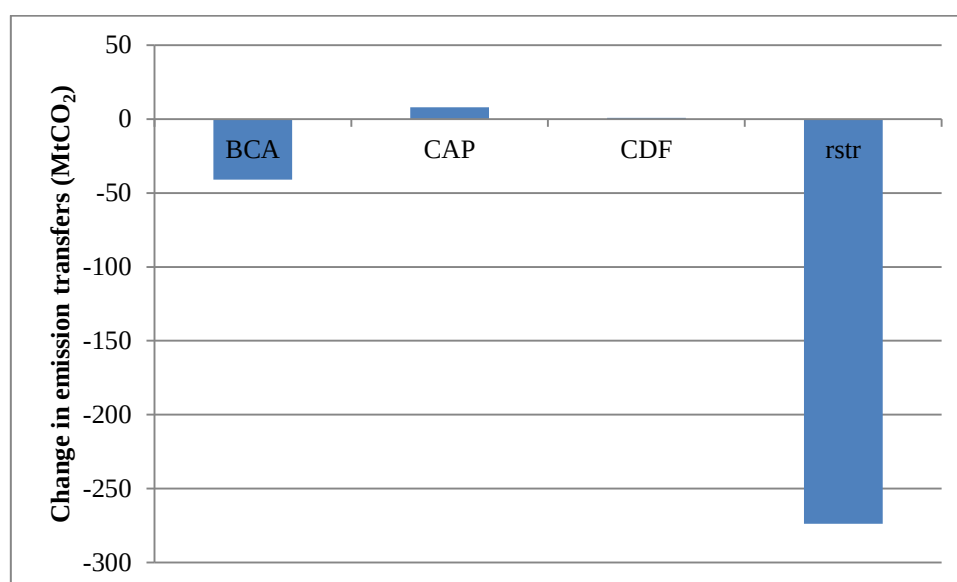


Figure 2. Change in emission transfers relative to the cap-and-trade reference scenario. Emission transfers in the reference scenario are displayed in Figure 1.

Table 2 lists the effects on carbon leakage and CO₂ emissions for the four model scenarios. The clean-development scenario and the domestic-adjustment scenario result in similar global emissions reductions of about 1%. Those are achieved through emissions reductions in Annex I countries in the domestic-adjustment scenario, and through sponsored emissions reductions in non-Annex I countries in the clean-development scenario. Carbon leakage is therefore reduced significantly only in the clean-development scenario. The carbon-tariff scenario and the no-trade scenario result in negligible emissions reductions of 0.1%. Thus,

while carbon tariffs and full trade restrictions of energy-intensive goods reduce emission transfers to Annex I countries, they do not address the actual concern of emission reductions.⁷

Table 2. Change in regional emissions and carbon leakage. The basis for comparison is the reference scenario in which Annex I countries reduce their emissions by 10% with respect to their 2007-levels, while non-Annex I countries increase their emissions by 1.47%; the associated carbon leakage to non-Annex I counties is 13.3%.

Item	Model scenarios			
	BCA	DOM	CDF	RSTR
Carbon leakage (%)	-1.83	-0.32	-25.51	-0.94
Annex I emissions (%)	0.00	-2.50	0.00	0.00
Non-Annex I emissions (%)	-0.20	0.32	-2.81	-0.10
Global emissions (%)	-0.10	-1.16	-1.34	-0.05

4.3. Economic impacts

Figure 3 details the economic effects of the four model scenarios. It shows the changes in GDP relative to the cap-and-trade reference scenario. Changes in the equivalent variation of income show similar qualitative trends and are listed in Table A3 in the appendix. Because the benefits associated with lower CO₂ emissions are not monetized in this study, the focus here lays solely on the economic costs.

The carbon-tariff scenario is associated with an unequal distribution of economic burden. GDP in the tariff-implementing Annex I countries increases slightly, in particular due to the influx of tariff revenues which amount to USD 7.8 billion in total. On the other hand, non-Annex I countries experience significant GDP losses due to the new tariff barrier. Recycling the tariff revenues can alleviate part of those losses, but a negative net impact remains. Global GDP losses increase, because the losses in non-Annex I countries are up to an order of magnitude larger than the gains in Annex I countries.

⁷ Instead, the production of all other goods increases in the carbon-tariff scenario, and domestic production of energy-intensive goods replaces imports in the no-trade scenario, see Tables A1 and A2 in the appendix.

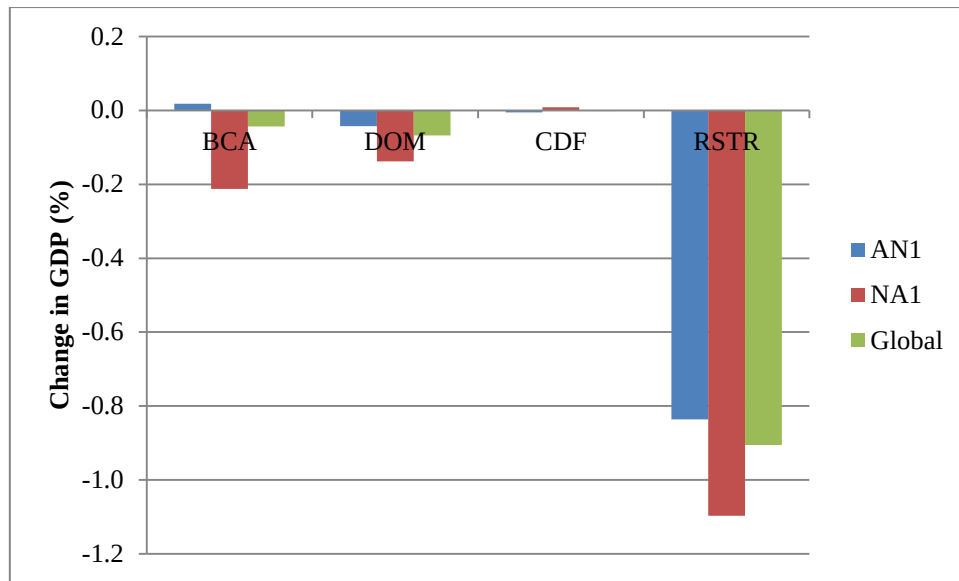


Figure 2. Economic impacts in terms of changes in gross domestic product (GDP). The basis for comparison is the reference scenario which implements a cap-and-trade system in Annex I countries (see Table A9 for the GDP impacts of the reference scenario).

In the domestic-adjustment scenario all additional emissions reductions are shouldered by Annex I countries. As a result, the domestic CO₂ price increases by 33% to 27 USD/tCO₂ from 21 USD/tCO₂ in the reference scenario. Higher CO₂ prices in Annex I countries increase domestic prices and reduces consumption. This also affects non-Annex I countries through increased export prices and reduced import demand, especially of carbon-intensive fossil fuels (see Tables A4 and A5 in the appendix). Consequently, both Annex I and non-Annex I countries experience GDP losses and global GDP decreases below the reference level.

The clean-development scenario causes no significant changes in regional and global GDP levels and is therefore associated with the least negative GDP impacts of the scenarios considered. Its impact on non-Annex I countries is slightly positive, while its impact on Annex I countries is slightly negative. Table 3 lists the scenario's clean-development investments. Total investments amount to USD 2 billion. In line with the distribution of emission transfers, Europe is the largest investor, followed by the USA and Japan. The Middle East receives more than half of all investments due to the high abatement costs in its electricity sector. Other significant investments go to China, and countries in Eastern Europe and Central and South America. Constraining the emissions offsets from the Middle East to

half of its emission transfers reduces the total clean-development investments to USD 1.2 billion (see Table A6 in the appendix).

The economic effects of the no-trade scenario contrast with those of the other scenarios. Implementing mutual trade restrictions on energy-intensive goods leads to high welfare losses in all regions. Global GDP losses are 10 to 20 times larger than in the domestic-adjustment and carbon-tariff scenarios, respectively.

Table 3. Clean-development investments needed to offset emission transfers embodied in the energy-intensive goods imported by Annex I countries from non-Annex I countries (in million USD). Clean-development investments are capped for small-island states (ROW) due to physical constraints on abatement.

non-Annex I regions	Annex I regions				<i>Total</i>
	EUR	USA	JPN	RA1	
MES	565	237	367	0	1,170
CHN	183	133	29	31	376
EEU	158	37	16	19	230
CSM	104	0	0	0	104
AFR	49	22	12	1	84
ASI	25	13	2	1	42
ROW	11	5	2	3	21
<i>Total</i>	1,094	447	429	56	2,026

4.4. Sensitivity analysis

The sensitivity analysis extends the main scenarios' analysis in two ways. First, it considers two alternative carbon-tariff specifications, one in which the carbon-tariff revenues are recycled back to the exporting non-Annex I countries as lump-sum transfers that are used to maximize consumption (BCR); and one in which carbon-tariff revenues are recycled back as clean-development investments (BCM) (see Springmann, 2013, for an analysis of this policy with a simpler method). Second, the sensitivity analysis extends the main scenarios' focus on emission transfers in the EIT sectors to the total emission transfers summed over all sectors.

Table 4 lists the effects of the alternative scenario specifications. The BCR scenario leads to similar global welfare impacts as the standard BCA scenario, but it alleviates part of the negative GDP impacts from non-Annex I countries. While consumption levels may increase above their reference levels in non-Annex I countries, their GDP levels are still 24% below the reference values. The BCM scenario yields less relative GDP and consumption gains for non-Annex I countries than the BCR scenario. However, as a result of using carbon-tariff revenues for clean-development investments (about USD 7.8 billion), it increases global emissions reductions from 0.1% in the BCA scenario to 3.4%. Thus, the difference in emissions levels complicates a strict economic welfare comparison (as the benefits of emissions abatement are not valued in this study).

Table 4. Economic and environmental impacts for alternative carbon-tariff scenarios (BCR, BCM) and for scenario with full sectoral coverage of emission transfers (_f). The basis for comparison is the reference scenario which implements a cap-and-trade system in Annex I countries.⁸

Item	Region	Model scenarios					
		BCA	BCR	BCM	BCA_f	CAP_f	CDF_f
GDP (%)	AN1	0.018	-0.013	-0.019	0.076	-0.311	-0.181
	NA1	-0.213	-0.119	-0.155	-0.789	-0.817	0.341
	Global	-0.043	-0.041	-0.055	-0.154	-0.446	-0.042
Emissions (%)	AN1	0.000	0.000	0.000	0.000	-12.393	0.000
	NA1	-0.202	-0.176	-7.083	-0.268	1.662	-13.464
	Global	-0.096	-0.084	-3.368	-0.127	-5.711	-6.401

Extending the policies' sectoral coverage from the EIT sectors to all sectors has the following impacts. First, the higher tariff levels in the carbon-tariff scenarios lead to greater GDP losses in non-Annex I countries and, with the exception of the standard carbon-tariff scenario with full coverage, also to greater GDP losses in Annex I countries. Global GDP losses increase by 41-65% compared to the BCA scenario with EIT coverage. Second, emissions reductions

⁸ The offsets from the Middle East are constrained to half of its emission transfers as substitution possibilities to cleaner electricity production are limited due to the region's high reliance on fossil fuels. Clean-development investments in small-island states (ROW) are capped at their minimum value due to physical constraints on abatement (see Section 3).

roughly double in the BCM, CAP, and CDF scenarios with full sectoral coverage. GDP losses in the full CAP scenario increase threefold for Annex I countries and twofold for non-Annex I countries. In the full CDF scenario, GDP losses in Annex I countries increase twofold, but they decrease in non-Annex I countries. Global GDP losses remain lower in the full CDF scenario than in the BCA and CAP scenarios with EIT coverage. In sum, broadening the policy's coverage of emission transfers from the energy-intensive ones to all emission transfers preserves the relative impacts vis-à-vis the alternative policy options. Clean-development investments increase to about USD 50 billion (see Table A7 in the appendix).

While the numerical results presented above hold strictly only for a specific set of parameters, a comprehensive sensitivity analysis indicates that the relative and directional effects of the model scenarios considered are robust with respect to changes in key model parameters, such as the fossil-fuel supply elasticities, trade elasticities, and emissions-reduction targets (see Tables A8-A14 in the appendix).

5. Conclusion

This study focused on emission transfers embodied in the trade of energy-intensive goods between non-Annex I and Annex I countries. It interpreted the emission transfers to Annex I countries as consumption responsibilities and therefore assessed four policy options for Annex I countries that could address those transfers. Those were a standard carbon-tariff policy in which Annex-I countries implement carbon tariffs on energy-intensive imports from non-Annex I countries; a domestic-adjustment policy in which Annex I countries increase the stringency of their emissions reduction targets in proportion to the net imports of embodied emissions from non-Annex I countries; a clean-development policy in which Annex I countries offset the emission transfers from non-Annex I countries by investing in clean-development projects in those countries; and, finally, a no-trade policy which completely restricts the trade in energy-intensive goods between Annex I and non-Annex I countries. An energy-economic model of the global economy formed the basis for the analysis.

While both the carbon-tariff and the no-trade policies are effective in reducing emission

transfers to Annex I countries, they are ineffective in reducing emissions in general. At the same time, they lead to reductions in global consumption and GDP levels and an unequal burdening of Annex I and non-Annex I countries – the carbon-tariff policies place a considerable economic burden on non-Annex I countries, while the no-trade policy has a negative economic effect for both Annex I and non-Annex I countries. Similarly, adjusting domestic emissions targets for emission transfers could entail GDP losses for both the adjusting and the non-adjusting regions. In contrast, the clean-development policy does not lead to reductions in emission transfers, but its investments in clean development significantly reduce emissions in non-Annex I countries. Those emission reductions come at little expense to Annex I countries and therefore have only minor economic impacts.

These results suggest that addressing emission responsibilities through trade restrictions (as in the carbon-tariff and no-trade scenarios) is ill-focused and could lead to potentially significant economic losses for both Annex I and non-Annex I countries and even to higher emissions in some cases. The increase in emission transfers from non-Annex I to Annex I countries as found by Peters et al. (2011) is therefore not necessarily a reason for concern, but a sign for an increased integration of the global economy. Reducing emission transfers would therefore head in the wrong way. Instead, a more positive approach of accounting for emission transfers and connecting them to emission-offset responsibilities (as exemplified by the clean-development scenario) could be a promising policy that would have environmental benefits without being a burden economically (at least not when focusing on the energy-intensive sectors).

The political institutions for such offsets already exist in the form of the Clean Development Mechanism (CDM) under the UNFCCC. However, while the CDM offsets national emission responsibilities, an offset scheme based on consumption responsibilities as contemplated here would be connected to offsets of emission transfers or emissions embodied in trade to Annex-I countries. Unlike for the CDM, there would be a clear definition of emission reductions that would need to be achieved and those emission reductions would not be bound to projects, but could be also be achieved through sectoral approaches or National Appropriate Mitigation Actions (NAMAs) if financing contributions can be separated.⁹

⁹ For such a policy, the need for accurately measuring and monitoring of emissions embodied in trade becomes an important aspect which would need to be improved. However, the academic field active in estimating

However, there are several critical issues with connecting clean-development financing to emission transfers. First, trade-active countries, such as China, would receive a high proportion of financing, while least-developed countries with low export volumes would receive very little. Second, some non-Annex I countries could be incentivised to increase the carbon content of their traded goods for receiving more investments. The first issue could be addressed by channelling part of the investments through a global climate fund, such as the Green Climate Fund established by the Cancun Agreements, and the second could be dealt with by agreeing on specific reference years or periods.

While there may be further issues with broadening the policy from the emissions embodied in energy-intensive goods to all goods, such a broadening could also present an opportunity as the consumption and offset responsibilities of Annex I countries may provide another rationale for climate financing of the order currently discussed – in the Copenhagen Accord (2009), Annex I countries have pledged to mobilize USD 100 billion of annual climate finance for non-Annex I countries by 2020, the exact modalities of which remain to be determined.

Acknowledgements

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Appendix

A.1. CGE model description

The basic energy-economic model includes five energy goods (crude oil (CRU), refined oil (OIL), coal (COL), gas (GAS), and electricity (ELE)) and three aggregated commodities (energy-intensive goods (EIT), transport services (TRN), all other goods (AOG)). Those are produced with inputs of intermediate goods and primary factors (skilled labour, unskilled labour, capital, resources, and land). Secondary energy inputs (refined oil, electricity) are produced with constant returns to scale, whereas primary energy goods (crude oil, natural gas, and coal) exhibit decreasing returns to scale with resource input. Capital and labour are intersectorally mobile, but crude oil, natural gas and coal resources are sector-specific.

The production of energy and other goods is described by nested constant-elasticity-of-substitution (CES) cost functions which characterize substitution possibilities between inputs

(see Supplementary Figure S1). For all goods except fossil fuels, the CES cost functions are arranged in multiple levels. The top-level nest combines an aggregate of capital, labour, and energy inputs (KLE) with a composite of material inputs (M); the second-level nest combines an aggregate of energy inputs (E) with a value-added composite of capital and labour inputs (VA) in the KLE-nest, as well as non-energy material inputs (P(1) to P(N)) in the M-nest; the third level captures the substitution possibilities between capital (PK) and labour (PL) in the VA-nest, and the trade-off between electricity and a CES composite of fossil fuels (coal, refined oil, gas) (P(FE)) with their associated CO₂ emissions (PCARB) in the FE-nest. CO₂ emissions are linked in fixed proportions to the use of fossil fuels, with CO₂ coefficients differentiated by the specific fuel's carbon content. The production of fossil fuels combines sector-specific fossil-fuel resources with an aggregate of all other inputs which enter in fixed proportions.

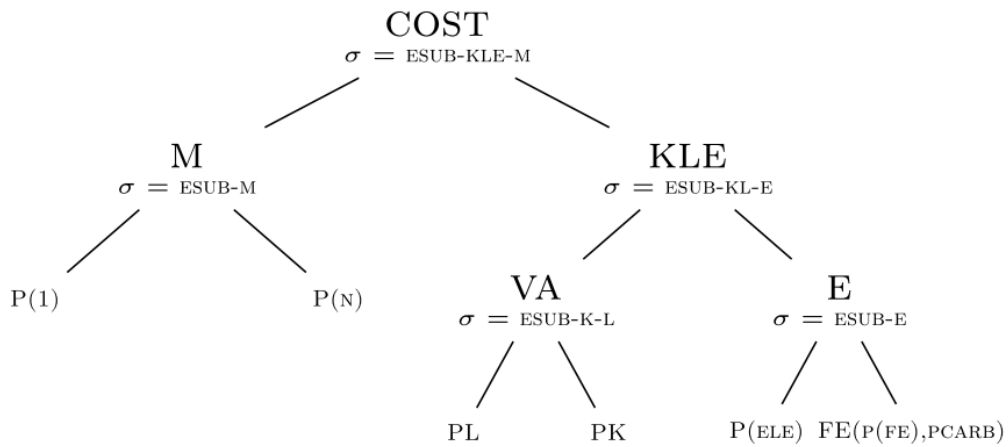


Figure A1. Nesting structure of CES production functions (except for fossil fuels).

The representation of international trade follows the Armington approach of differentiating goods by country of origin: goods that satisfy domestic demand are represented as a CES aggregate of domestically produced goods and imported goods. A balance-of-payment constraint incorporates the base-year trade deficit or surplus for each region.

Final consumption in each region is determined by a representative agent who maximizes consumptions subject to its budget constraint. Consumption is represented as a CES aggregate of non-energy goods and energy inputs. The budget constraint is determined by factor and tax incomes with fixed investment and public expenditure.

A.2. Additional model results

Table A1. Changes in the exports, imports, and output of the aggregate of all other goods (AOG) in Annex I (AN1) and non-Annex I (NA1) countries and globally for the four model scenarios. The carbon-tariff scenario is denoted by BCA, the domestic-adjustment scenario by DOM, the clean-development scenario by CDF, and the no-trade scenario by RSTR. The basis for comparison is the reference scenario which implements a cap-and-trade system in Annex I countries.

Item	Region	Model scenarios			
		BCA	DOM	CDF	RSTR
AOG exports (%)	AN1	-0.433	-0.052	0.078	1.511
	NA1	0.619	-0.113	-0.105	-2.664
	Total	0.036	-0.079	-0.004	-0.351
AOG imports (%)	AN1	0.286	-0.077	-0.051	-0.908
	NA1	-0.347	-0.083	0.069	0.501
	Total	0.036	-0.079	-0.004	-0.351
AOG output (%)	AN1	-0.033	-0.027	0.003	-0.151
	NA1	0.078	-0.024	-0.018	-1.347
	Total	-0.004	-0.026	-0.003	-0.467

Table A2. Changes in the exports, imports, and output of energy-intensive goods (EIT) in Annex I (AN1) and non-Annex I (NA1) countries and globally for the four model scenarios. The carbon-tariff scenario is denoted by BCA, the domestic-adjustment scenario by DOM, the clean-development scenario by CDF, and the no-trade scenario by RSTR. The basis for comparison is the reference scenario which implements a cap-and-trade system in Annex I countries.

Item	Region	Model scenarios			
		BCA	DOM	CDF	RSTR
EIT exports (%)	AN1	0.573	-0.884	-0.031	-30.666
	NA1	-4.788	1.046	0.046	-24.300
	Total	-1.432	-0.163	-0.002	-28.285
EIT imports (%)	AN1	-2.041	0.074	0.014	-23.657
	NA1	-0.707	-0.444	-0.022	-33.788
	Total	-1.432	-0.163	-0.002	-28.285
EIT output (%)	AN1	0.551	-0.343	-0.014	-1.620
	NA1	-0.863	0.351	0.017	7.269
	Total	-0.026	-0.060	-0.001	2.004

Table A3. Changes in the equivalent variation of income (EV) in Annex I (AN1) and non-Annex I (NA1) countries and globally for the four model scenarios. The carbon-tariff scenario is denoted by BCA, the domestic-adjustment scenario by DOM, the clean-development scenario by CDF, and the no-trade scenario by RSTR. The basis for comparison is the reference scenario which implements a cap-and-trade system in Annex I countries.

Item	Region	Model scenarios			
		BCA	DOM	CDF	RSTR
Change in EV (%)	AN1	0.031	-0.046	-0.013	-0.614

NA1	-0.109	-0.082	0.007	-2.503
Global	-0.002	-0.054	-0.008	-1.058

Table A4. Changes in the prices of energy-intensive (EIT) goods in Annex I (AN1) and non-Annex I (NA1) countries and globally for the four model scenarios. The carbon-tariff scenario is denoted by BCA, the domestic-adjustment scenario by DOM, the clean-development scenario by CDF, and the no-trade scenario by RSTR. The basis for comparison is the reference scenario which implements a cap-and-trade system in Annex I countries.

Item	Region	Model scenarios			
		BCA	DOM	CDF	RSTR
Change in EIT prices (%)	AN1	0.067	0.194	-0.009	0.824
	NA1	-0.198	-0.153	-0.008	1.900
	Global	-0.102	-0.027	-0.008	1.508

Table A5. Changes in fossil-fuel imports (crude oil, coal, gas) in Annex I (AN1) and non-Annex I (NA1) countries and globally for the four model scenarios. The carbon-tariff scenario is denoted by BCA, the domestic-adjustment scenario by DOM, the clean-development scenario by CDF, and the no-trade scenario by RSTR. The basis for comparison is the reference scenario which implements a cap-and-trade system in Annex I countries.

Item	Region	Model scenarios			
		BCA	DOM	CDF	RSTR
Imports of crude oil (%)	AN1	0.538	-0.859	-0.134	2.935
	NA1	-0.561	0.475	-0.053	-1.586
	Global	0.155	-0.394	-0.106	1.359
Imports of coal (%)	AN1	0.155	-3.689	1.091	2.053
	NA1	-0.697	2.371	-8.122	1.410
	Global	-0.124	-1.705	-1.925	1.843

	AN1	0.483	-0.503	0.837	-1.208
Imports of gas (%)	NA1	-1.107	0.934	-0.986	6.202
	Global	0.274	-0.314	0.597	-0.233

Table A6. Clean-development investments needed to offset emission transfers embodied in the energy-intensive goods imported by Annex I countries from non-Annex I countries (in million USD), with offsets from the Middle East constrained to half of its energy-intensive emission transfers. Clean-development investments are capped for small-island states (ROW) due to physical constraints on abatement (see Section 3).

non-Annex I regions	Annex I regions				
	EUR	USA	JPN	RA1	<i>Total</i>
MES	141	59	92	0	292
CHN	183	133	29	31	376
EEU	158	37	16	19	230
CSM	104	0	0	0	104
AFR	49	22	12	1	84
ASI	25	13	2	1	42
ROW	11	5	2	3	21
<i>Total</i>	670	269	153	56	1,148

Table A7. Clean-development investments needed to offset emission transfers embodied in all goods imported by Annex I countries from non-Annex I countries (in million USD). The offsets from the Middle East are constrained to half of its emission transfers as substitution possibilities to cleaner electricity production are limited due to the region’s high reliance on fossil fuels. Clean-development investments in small-island states (ROW) are capped at their minimum value due to physical constraints on abatement (see Section 3).

non-Annex I regions	Annex I regions				<i>Total</i>
	EUR	USA	JPN	RA1	
MES	2,220	931	1,443	0	4,593
CHN	7,613	5,552	1,205	1,289	15,659
EEU	11,639	3,246	1,224	3,934	20,044
CSM	2,432	2,716	165	115	5,428
AFR	1,281	584	157	66	2,088
ASI	2,650	1,388	196	150	4,385
ROW	194	109	54	60	418
<i>Total</i>	28,027	14,526	4,445	5,615	52,614

Table A8. Changes in the environmental and economic impacts in the reference and policy scenarios with respect to the no-policy baseline. The table serves as basis for comparison for the sensitivity analyses presented in the Tables A9-A14.

Item	Region	Model scenarios				
		REF	BCA	DOM	CDF	RSTR
EIT emission transfers (%)	AN1	29.353	11.407	33.449	29.636	-90.478
Carbon leakage (%)	NA1	13.287	11.457	12.970	-12.223	12.343
Emissions (%)	AN1	-10.000	-10.000	-12.501	-10.000	-10.000
	NA1	1.466	1.264	1.789	-1.349	1.362
	Global	-4.549	-4.645	-5.707	-5.887	-4.598
Change in GDP (%)	AN1	-0.092	-0.074	-0.134	-0.104	-0.928
	NA1	-0.488	-0.701	-0.626	-0.469	-1.585
	Global	-0.197	-0.241	-0.265	-0.201	-1.103
Change in EV (%)	AN1	-0.065	-0.034	-0.111	-0.078	-0.679
	NA1	-0.292	-0.402	-0.375	-0.285	-2.796
	Global	-0.119	-0.121	-0.173	-0.127	-1.177

Table A9. Changes in the environmental and economic impacts of the reference and policy scenarios with respect to the no-policy baseline, with Annex I countries' emissions-reduction target halved from 10% below 2007-levels to 5%.

Item	Region	Model scenarios				
		REF	BCA	DOM	CDF	RSTR
EIT emission transfers (%)	AN1	22.248	14.202	25.568	22.562	-90.389
Carbon leakage (%)	NA1	14.191	12.579	13.779	-34.967	13.586
Emissions (%)	AN1	-5.000	-5.000	-7.423	-5.000	-5.000
	NA1	0.783	0.694	1.129	-1.929	0.749
	Global	-2.251	-2.293	-3.357	-3.540	-2.266
Change in GDP (%)	AN1	-0.024	-0.016	-0.046	-0.034	-0.880
	NA1	-0.230	-0.325	-0.347	-0.213	-1.255
	Global	-0.079	-0.098	-0.126	-0.081	-0.980
Change in EV (%)	AN1	-0.011	0.003	-0.032	-0.023	-0.643
	NA1	-0.141	-0.190	-0.213	-0.137	-2.652
	Global	-0.042	-0.042	-0.075	-0.049	-1.116

Table A10. Changes in the environmental and economic impacts of the reference and policy scenarios with respect to the no-policy baseline, with Annex I countries' emissions-reduction target doubled from 10% below 2007-levels to 20%.

Item	Region	Model scenarios				
		REF	BCA	DOM	CDF	RSTR
EIT emission transfers (%)	AN1	48.353	1.201	54.914	48.619	-90.744
Carbon leakage (%)	NA1	12.685	10.271	12.690	-0.827	10.836
Emissions (%)	AN1	-20.000	-20.000	-22.707	-20.000	-20.000
	NA1	2.799	2.266	3.179	-0.183	2.391
	Global	-9.160	-9.414	-10.400	-10.578	-9.354
Change in GDP (%)	AN1	-0.363	-0.325	-0.453	-0.375	-1.168
	NA1	-1.163	-1.723	-1.369	-1.141	-2.444
	Global	-0.575	-0.696	-0.697	-0.578	-1.507
Change in EV (%)	AN1	-0.329	-0.255	-0.451	-0.343	-0.905
	NA1	-0.675	-0.961	-0.799	-0.666	-3.149
	Global	-0.410	-0.421	-0.533	-0.419	-1.433

Table A11. Changes in the environmental and economic impacts of the reference and policy scenarios with respect to the no-policy baseline, with the Armington-trade elasticities halved. The Armington elasticities determine the substitution potential between imported goods, and between domestic goods and imported ones. Lower Armington elasticities decrease the trade responsiveness to price changes.

Item	Region	Model scenarios				
		REF	BCA	DOM	CDF	RSTR
EIT emission transfers (%)	AN1	23.893	14.724	26.232	23.889	-90.379
Carbon leakage (%)	NA1	9.818	8.686	9.556	-14.859	-2.310
Emissions (%)	AN1	-10.000	-10.000	-12.444	-10.000	-10.000
	NA1	1.083	0.958	1.312	-1.639	-0.255
	Global	-4.731	-4.790	-5.904	-6.025	-5.367
Change in GDP (%)	AN1	-0.007	0.017	-0.009	-0.022	-2.214
	NA1	-0.741	-0.979	-0.937	-0.705	-2.787
	Global	-0.202	-0.247	-0.256	-0.203	-2.366
Change in EV (%)	AN1	-0.026	0.006	-0.059	-0.040	-1.575
	NA1	-0.406	-0.515	-0.520	-0.392	-5.685
	Global	-0.115	-0.116	-0.168	-0.122	-2.542

Table A12. Changes in the environmental and economic impacts of the reference and policy scenarios with respect to the no-policy baseline, with the Armington-trade elasticities doubled. The Armington elasticities determine the substitution potential between imported goods, and between domestic goods and imported ones. Higher Armington elasticities increase the trade responsiveness to price changes.

Item	Region	Model scenarios				
		REF	BCA	DOM	CDF	RSTR
EIT emission transfers (%)	AN1	40.530	6.300	48.330	41.271	21.341
Carbon leakage (%)	NA1	18.481	15.291	18.151	-7.907	20.409
Emissions (%)	AN1	-10.000	-10.000	-12.619	-10.000	-10.000
	NA1	2.039	1.687	2.527	-0.872	2.252
	Global	-4.276	-4.443	-5.418	-5.660	-4.175
Change in GDP (%)	AN1	-0.130	-0.112	-0.192	-0.140	-0.483
	NA1	-0.360	-0.570	-0.469	-0.350	-1.111
	Global	-0.191	-0.234	-0.265	-0.196	-0.650
Change in EV (%)	AN1	-0.090	-0.055	-0.146	-0.103	-0.351
	NA1	-0.230	-0.359	-0.294	-0.227	-1.725
	Global	-0.123	-0.126	-0.181	-0.132	-0.674

Table A13. Changes in the environmental and economic impacts of the reference and policy scenarios with respect to the no-policy baseline, with the fossil-fuel supply elasticities halved. The fossil-fuel supply elasticities determine the responsiveness of the fossil-fuel supply to demand reductions. Lower fossil-fuel supply elasticities reduce the responsiveness of the fossil-fuel supply to demand reductions.

Item	Region	Model scenarios				
		REF	BCA	DOM	CDF	RSTR
EIT emission transfers (%)	AN1	30.275	11.383	34.511	31.151	-90.484
Carbon leakage (%)	NA1	18.914	17.139	17.961	-17.931	16.127
Emissions (%)	AN1	-10.000	-10.000	-12.512	-10.000	-10.000
	NA1	2.087	1.891	2.479	-1.978	1.779
	Global	-4.253	-4.347	-5.384	-6.186	-4.400
Change in GDP (%)	AN1	-0.067	-0.048	-0.103	-0.085	-0.929
	NA1	-0.521	-0.746	-0.664	-0.493	-1.606
	Global	-0.188	-0.233	-0.252	-0.193	-1.109
Change in EV (%)	AN1	-0.047	-0.013	-0.088	-0.067	-0.680
	NA1	-0.333	-0.449	-0.424	-0.322	-2.805
	Global	-0.114	-0.116	-0.167	-0.127	-1.180

Table A14. Changes in the environmental and economic impacts of the reference and policy scenarios with respect to the no-policy baseline, with the fossil-fuel supply elasticities doubled. The fossil-fuel supply elasticities determine the responsiveness of the fossil-fuel supply to demand reductions. Higher fossil-fuel supply elasticities increase the responsiveness of the fossil-fuel supply to demand reductions.

Item	Region	Model scenarios				
		REF	BCA	DOM	CDF	RSTR
EIT emission transfers (%)	AN1	28.491	11.525	32.433	28.725	-90.475
Carbon leakage (%)	NA1	8.856	7.004	8.897	-27.463	9.629
Emissions (%)	AN1	-10.000	-10.000	-12.491	-10.000	-10.000
	NA1	0.977	0.773	1.226	-3.030	1.062
	Global	-4.781	-4.878	-5.969	-6.686	-4.740
Change in GDP (%)	AN1	-0.116	-0.101	-0.164	-0.129	-0.928
	NA1	-0.453	-0.653	-0.585	-0.432	-1.565
	Global	-0.206	-0.247	-0.276	-0.210	-1.097
Change in EV (%)	AN1	-0.083	-0.054	-0.132	-0.099	-0.678
	NA1	-0.252	-0.354	-0.326	-0.246	-2.785
	Global	-0.123	-0.125	-0.178	-0.133	-1.173