Carbon tariffs for financing clean development

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Abstract

In order to address carbon leakage and preserve the competitiveness of domestic industries, some industrialized Annex-I countries have proposed to levy carbon tariffs on energy-intensive imports from developing non-Annex-I countries which have not agreed to binding emissions reductions. This could have detrimental welfare impacts, especially on those developing countries, and might not lead to significant reductions in leakage. A possible remedy recently proposed is to use the revenues from carbon tariffs for clean-development financing in the exporting non-Annex-I countries. This study analyses this policy proposal by using an energy-economic model of the global economy. It supplements the model by marginal-abatement-cost curves and bottom-up information on abatement potentials to represent the emission-reduction effects of clean-development financing. The results indicate that US$3.5-24.5 billion (with a central value of US$9.8 billion) could be raised for clean-development financing. This financing could reduce non-Annex-I countries' emissions by 5-15%, while still leaving funds available for other purposes, such as adaptation. Recycling the revenues from carbon tariffs back to the exporting

country could alleviate some of the negative welfare impacts associated with carbon tariffs, but a net negative impact especially on developing countries' welfare and GDP levels would remain.

Keywords: border adjustments; carbon leakage; climate finance; climate and trade; development and climate; global economic model

1. Introduction

Current negotiations within the United Nations Framework Convention on Climate Change (UNFCCC) are stalling. The negotiating positions are divided between developing and industrialized countries on issues of financial burden sharing and greenhouse gas emissions reduction targets. Climate policies therefore continue to be nationally differentiated and to proceed on sub-global levels.

In this context, carbon tariffs have been raised as a policy option by some industrialized countries which have adopted, or are in the process of adopting, binding climate policies. Two main reasons are generally put forward in favour of carbon tariffs. Levying an import tariff in proportion to the carbon content of the imported good is thought to reduce carbon leakage, i.e. the shift of production and/or consumption to countries without binding climate policies, and to preserve the competitiveness of domestic industries vis-à-vis international imports whose producers operate in countries without comparable climate policies (van Asselt and Biermann, 2007).

Economic analyses of carbon tariffs paint a mixed picture. Some find that carbon border tax adjustments can be partially successful in reducing carbon leakage (Böhringer et al., 2011; Burniaux et al., 2010; Winchester et al., 2011) and in restoring the competitiveness of domestic industries (Alexeeva-Talebi et al., 2010; Kuik and Hofkes, 2010; Fischer and Fox, 2009; Manders and Veenedaal, 2008). Others find only small overall effects (McKibbin and Wilcoxen, 2008; Dong and Whalley, 2009) and little potential for reducing leakage (Böhringer et al., 2010; Peterson and Schleich, 2007) or improving domestic competitiveness (Babiker and Rutherford, 2005; Burniaux et al., 2010). However, many studies agree that carbon tariffs place considerable burden with significant welfare losses on developing countries against whose products the tariffs are imposed (Babiker and Rutherford, 2005; Dröge and Kemfert, 2005; Mattoo et al., 2009; Böhringer et al., 2011; Winchester et al., 2011).

Despite those mixed results, carbon tariffs are likely to remain on the agenda. They found entry in all major US climate bills proposed in either the House of Representatives, such as the Waxman-Markey bill, or in the Senate, such as the Kerry-Boxer and the Cantwell-Collins bills (van Asselt and Brewer, 2010; Monjon and Quirion, 2010). And they are also mentioned, albeit cautiously, in the revised directive of the European Union Emissions Trading Scheme (EU ETS) as “carbon equalisation system [... which] could apply requirements to importers” (Directive 2009/29/EC).

While there seems to be no new national climate policy without provisions for a form of carbon tariff (at least in the USA), considerable doubt can be raised whether a comprehensive global climate deal would be possible with the forms of carbon tariffs proposed so far. In particular China has reacted harshly when confronted with the possibility of facing carbon tariffs on its exports. It perceives carbon tariffs as trade sanctions and even threatened with trade war should carbon tariffs be adopted (Laihui and Ying, 2010; Voituriez and Wang, 2011). More broadly, the potentially detrimental economic impacts of carbon tariffs on developing countries are at odds with industrialized countries' commitments made within the UNFCCC to provide financial and technological support for climate change adaptation and mitigation to those countries (see e.g. the Bali Action Plan, 2007; the Copenhagen Accord, 2009; or the Cancun Agreements, 2010). Carbon tariffs are therefore likely to face considerable opposition internationally should they not include some sort of compensation for developing countries.

One idea that has recently been put forward is to recycle the revenues from carbon tariffs back to the exporting developing country with the provision that those revenues be invested in climate change mitigation or adaptation measures (Grubb, 2011; Springmann, 2011). This policy combination of carbon tariffs and clean-development financing addresses the concerns of competitiveness and carbon leakage in the industrialized world and of economic development in the developing world (Springmann, 2011). It could represent a new source for climate finance with mutual incentives which could facilitate broad agreement (Grubb, 2011). More generally, it also includes aspects of a consumption-based approach which highlights the demand for goods in the industrialized world as a driver of emissions needed to produce those goods in the developing world (Peters and Hertwich, 2008; Peters et al., 2011).

Despite the policy's potential as a consensus option, it has not yet been analyzed in detail. So far, it has been raised as a discussion point (Eckersley, 2010; Monjon and Quirion, 2010) or in commentaries (Springmann, 2011); a recent outlook by Michael Grubb (2011) contains indicative revenue estimates and a comprehensive discussion. Böhringer et al. (2011) present aggregate welfare results of revenue recycling and welfare compensation schemes connected to carbon tariffs, but without considering climate financing. The UN Secretary General's High-Level Advisory Group on Climate Change Financing (United Nations, 2010) has estimated total revenues that could be raised through a carbon-tariff-related "carbon exports optimization tax" which would be levied by non-Annex-I countries. However, a comprehensive analysis of coupling carbon tariffs in Annex-I countries to clean-development financing for non-Annex-I countries is still lacking.

This paper fills this gap. It assesses, in detail, the effects of combining carbon tariffs imposed by industrialized Annex-I countries with clean-development financing for the exporting non-Annex-I countries. It estimates region-specific carbon-tariff revenues, analyzes emissions-reduction effects resulting from clean-development financing, and presents impacts of the combined carbon-tariff-clean-development policy on carbon leakage and welfare levels. For this purpose, it utilizes an energy-economic model of the global economy which describes global trade flows and production and consumption activities inclusive of their associated carbon dioxide (CO_2) emissions. It supplements the energy-economic model by detailed marginal-abatement-cost (MAC) curves and bottom-up information on abatement potentials to accurately represent the emission-reduction effects of clean-development financing.

A comprehensive sensitivity analysis takes into account different specifications of the combined carbon-tariff-clean-development policy which is hoped to inform the political debate surrounding this topic.

The analysis is structured as follows. Section 2 describes the energy-economic model, its database, and the modelling of the effects of clean development. Section 3 offers a description of the model scenario and alternative specifications. Section 4 presents the results and Section 5 concludes. Model details are collected in the Appendix for ease of presentation.

2. Model description[1]

2.1. Modelling framework and database

This paper utilizes an energy-economic model of the global economy. It is based on the GTAP7inGAMS package developed by Thomas Rutherford (2010a) and 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 (CO_2).

The energy-economic model is calibrated to the database version 7.1 of the Global Trade Analysis Project (GTAP). This database represents global production and trade for 113 countries/regions, 57 commodities and 5 primary factors for the benchmark year 2004 (Narayanan and Walmsley, 2008). The data include information on bilateral trade, intermediate demand, direct and indirect taxes on imports and exports, as well as CO_2 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 the effects of coupling carbon tariffs to clean-development financing. The broad regional blocks of interest are industrialized Annex-I countries and developing non-Annex-I countries. Annex-I countries have agreed to binding emissions reduction targets under the UNFCCC, so that the implementation of carbon tariffs can be considered a policy option. Developing non-Annex-I countries have not agreed to binding emissions reductions but require clean-development financing to undertake mitigation and adaptation measures. This paper uses an aggregation that explicitly resolves 9 Annex-I and 19 non-Annex-I countries. Table A3 in Appendix 3 lists all those countries, while Table 1 presents a regional aggregation which will often be used for ease of presentation.

Table 1 Aggregated model regions (Table A3 in Appendix 3 contains a full list).

Annex I			
EUR	Europe (EU 27 + EFTA)	JPN	Japan
USA	United States	RA1	Rest of Annex I
non Annex I			
CHN	China and Hong Kong	MES	The Middle East
ASI	Other Asian countries	CSM	Central and South America
AFR	Africa	ROW	Rest of the World

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, 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]

2.2. Modelling the effects of clean development

The effects of clean-development investments in developing countries are modelled as a two-step procedure which separately models emissions abatement and economic impacts. This approach allows for the integration of bottom-up information on abatement potentials without the need to specifically represent clean-development processes in the energy-economic model.

The impact of clean-development investments on emissions in non-Annex-I countries is modelled by incorporating emissions-abatement functions into the energy-economic model. This study derives the emissions-abatement functions from marginal-abatement-cost (MAC) curves that were generated by Morris et al. (2008) using the MIT Emissions Predictions and Policy Analysis (EPPA) model. The EPPA model (Paltsev et al., 2005) contains a detailed representation of the energy sector and emissions control options for CO_2 and other non-CO_2 greenhouse gases. Including EPPA's MAC curves therefore enables a detailed representation of marginal abatement costs of developing countries. For this study, the MAC curves are parameterized by a polynomial of second degree, integrated to obtain total abatement costs, and solved for emissions reductions. The detailed procedure for deriving and calibrating the emissions-abatement functions from MAC curves is described in Appendix 2. A scenario which employs MAC curves for CO_2 emissions which are generated by the basic energy-economic model is considered as a sensitivity analysis.

MAC curves represent an economy's optimal response to alternative carbon prices, which is likely to be distinctively different from responses to clean-development investments.[4] This study therefore supplements EPPA's MAC curves in several ways to avoid overestimating emissions reductions and their cost-effectiveness. First, it incorporates transaction costs of 4.5% of the abatement costs. This follows results from detailed assessments of clean-development projects (Wetzelaer et al., 2007). Second, this study constrains emissions reductions in non-Annex-I countries by short-term abatement potentials. The region-specific abatement constraints are inferred from detailed case-level data contained in Wetzelaer et al. (2007) and range from 10% in Africa to 26% in India; the average abatement potential is 16%. Table A4 in Appendix 4 provides a detailed overview. Wetzelaer et al. (2007) note that their coverage of mitigation options is not exhaustive and their results should not be viewed as a complete analysis of national greenhouse gas abatement potentials. However, their results provide an indication of technically feasible short-term abatement options which can be considered more grounded than other scale-back factors that have been assumed in the literature (see e.g. Michaelowa and Jotzo, 2005; Kallbekken, 2007).[5]

The clean-development scenario outlined above can be interpreted as being similar in effect to nationally coordinated mitigation measures, such as Nationally Appropriate Mitigation Actions (NAMAs). Although the scenario's cost effectiveness is reduced by accounting for transaction costs, it might still represent an optimistic scenario in that regard. A sensitivity analysis therefore considers a lower end by adopting the cost-effectiveness of the Clean Development Mechanism (CDM) of the Kyoto Protocol. In particular, it adopts a current carbon price of US$15/t$CO_2$ as (constant) abatement cost.[6] While this cost-effectiveness is in line with current market prices for Certified Emissions Reductions (CERs), it is several magnitudes higher than the abatement costs inferred from EPPA's MAC curves (see Table A2 in the Appendix). The sensitivity analysis therefore captures the low-end of achievable emission reduction at a given cost. The real cost of reducing emissions in non-Annex-I countries via clean-development investments will depend on a variety of factors, such as institutional capacity and market distortions (see e.g. Kesicki and Ekins, 2011), but it is likely to lie between the two cases considered.

This study's economic focus lays on aggregate macroeconomic impacts. The economic effects of clean-development investments are therefore modelled in a generic fashion by changes in general investments which induce further changes in demand and production. Although this modelling approach lacks consistency on the sector level, it has the advantage of accounting for aggregate macroeconomic impacts on GDP and welfare measures without the need to specifically represent clean-development processes in the energy-economic model. In the sectoral aggregation used in this study, the investment good generates demand primarily for the category of All Other Goods. Averaged across non-Annex-I countries, this demand is met to about 80% by domestic production and to about 20% by imports. The sensitivity analysis considers alternative investment compositions and finds little difference for the macroeconomic variables of GDP and the welfare measure of per-capita equivalent variation of income that is used in this study. This supports the choice of the generic modelling approach followed here. With respect to the dual modelling approach pursued, the change in emissions from increasing investments is less than 0.1% for the magnitudes considered in this study. This justifies the approach of modelling emissions abatement and economic effects separately.

3. Model scenarios

This study considers three model scenarios to compare and contrast the effects of combining carbon tariffs with clean-development financing. Those are a reference cap-and-trade scenario, a standard carbon-tariff scenario, and the alternative carbon-tariff scenario in which its revenues are used for clean-development investments in the exporting developing countries.

In the reference cap-and-trade (CAT) scenario Annex-I countries reduce their CO_2 emissions by 11% with respect to the benchmark year of 2004. This magnitude is indicative of possible short to medium-term emissions reductions (Levin and Bradley, 2010) and calibrated to match a current carbon permit price of US\$15/tCO_2. A sensitivity analysis considers a higher carbon price of US\$35/tCO_2 which is representative of post-2012 carbon prices (Sikorski, 2011) – this is done by prescribing Annex-I emissions reductions of 21%. The emissions reductions are implemented as an overall cap, which allows for trading among Annex-I countries. This leads to the formation of a uniform carbon price in Annex-I countries and therefore eases the subsequent analysis of clean-development financing by removing carbon-price heterogeneities.

In the standard carbon tariff (BCA) scenario Annex-I countries adopt the reference cap-and-trade scenario described above and, in addition, impose carbon tariffs on energy-intensive imports coming 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.[7] Its computation follows a recursive diagonalization algorithm described in Rutherford (2010b).

The standard carbon-tariff scenario represents an idealized scenario in political terms.

In particular, it abstracts from the administrative and informational challenges associated with measuring emissions embodied in the global supply chain (see e.g. Izard et al., 2010; Moore, 2011). Second, it brushes over some of the legal hurdles that may challenge the introduction of carbon tariffs (Ismer and Neuhoff, 2007; Sindicio, 2008; Tamiotti, 2011).[8] A sensitivity analysis therefore considers calculating the tariff level in proportion to the carbon intensity of domestic Annex-I industries. In practice, this might ease the information and administrative burden of such a policy because, unlike non-Annex-I countries, Annex-I countries have already put measurement, reporting and verification practices in place. The method might also be less likely challenged under regulations of the World Trade Organization (WTO), since it does not discriminate imported goods vis-à-vis domestically produced ones (Monjon and Quirion, 2010).

The third scenario considers coupling carbon tariffs with clean-development financing. In the combined carbon-tariff-clean-development (BCM) scenario Annex-I countries adopt the reference cap-and-trade scenario and impose carbon tariffs on energy-intensive imports coming from non-Annex-I countries. But in contrast to the standard carbon-tariff scenario, Annex-I countries use the carbon-tariff revenues for clean-development financing in the exporting non-Annex-I countries. This is modelled as a two-step procedure as described in the previous section. First, the carbon-tariff revenues are returned to exporting non-Annex-I countries as general investments. This increases domestic demand and production, which accounts for the general-equilibrium effects of clean-development investments in a generic fashion. Second, non-Annex-I countries' emissions balances are adjusted separately to account for the emission-reduction effects of clean-development investments. This is done by using emissions abatement functions that are derived and calibrated from detailed information on marginal abatement costs, transaction costs, and case-level assessments of emission-reduction projects in developing countries as described in Section 2.

Clean-development financing that would lead to emissions reductions in excess of case-level abatement constraints could be used for other purposes, such as adaptation financing. However, it should be noted that adaptation financing is not modelled explicitly in this study, so that such interpretation serves indicative purposes only. In the modelling approach followed, carbon-tariff revenues not used for mitigation financing account for general investments which can be interpreted in various ways.

4. Model results

4.1. Emissions embodied in trade and estimates of tariffs and revenues

In the reference cap-and-trade scenario, 638 million metric tons of CO_2 ($MtCO_2$) are embodied in energy-intensive imports into Annex-I countries from outside (Figure 1, left axis). This corresponds to about 4.4% of Annex-I CO_2 emissions or to about 2.5% of emissions globally. The EU and USA import the bulk of those emissions, about 40% and 32% respectively. They are followed by Japan (JPN) with 16% and the Rest of the Annex-I countries (RA1) with 12%.

The main exporters of those emissions to Annex-I countries are China (CHN) and other Asian economies (ASI) (most notably Indonesia, the Asian Tiger economies and India), each with a share of about 30%. They are followed by countries in Central and South America (CSM), the Middle East (MES) and Africa (AFR) with a share of about 10% each. Countries in the Rest of the World (ROW) have a share of about 7%.

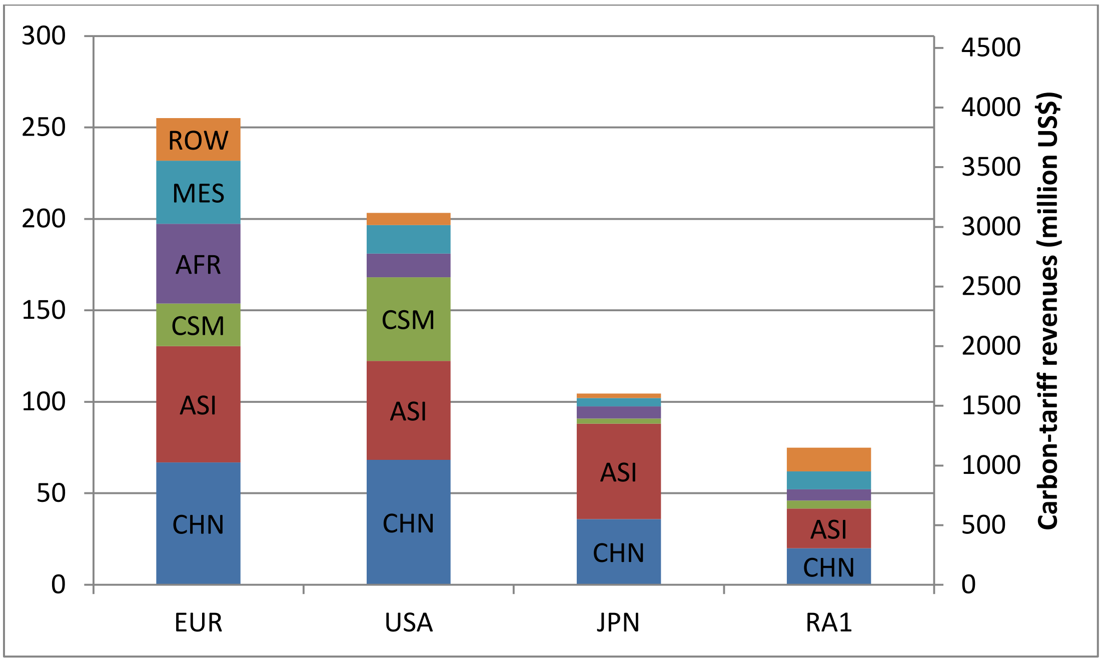

Figure 1. Emissions embodied in energy-intensive (EIT) imports to Annex-I countries (left axis) and revenues from carbon tariffs (right axis). Abbreviations are listed in Table 1.

Levying carbon tariffs on energy-intensive imports in Annex-I countries yields revenues in proportion to the emissions embodied in imports and the price of carbon (Figure 1, right axis). A price of carbon of US$15/t$CO_2$ yields carbon-tariff revenues of about US$9.8 billion.[9] The EU can raise most of this amount, US$3.9 billion, followed by the USA with US$3.1 billion, Japan with US$1.6 billion and the rest of Annex-I countries with US$1.1 billion. The corresponding additional ad-valorem tariff rates range from 1.4% on Mexican imports to 10% on imports from non-Annex-I countries of the former Soviet Union. The average additional tariff rate is 4.3%.

4.2. Clean-development financing and associated emissions reductions

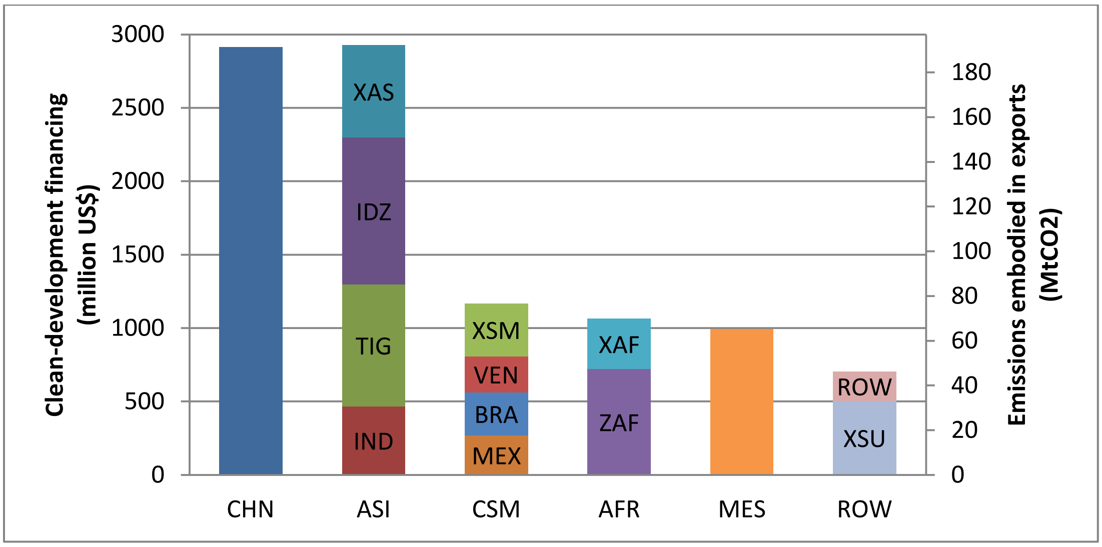

Figure 2. Clean-development financing for non-Annex-I countries (left axis) and emissions embodied in non-Annex-I countries' exports (right axis). [11]

Recycling the revenues from carbon tariffs back to the exporting country distributes those revenues in proportion to their export's emissions intensities (Figure 2).[10] This means that in the main scenario, China and other Asian economies receive together about 60% of clean-development financing, or about US$2.9 billion each. Within Asia, about 70% of the US$2.9 billion go to Indonesia (IDZ) and the Asian Tiger Economies (TIG), 24% to India (IND), and 33% to other Asian countries (XAS). Central and South America, Africa, and the Middle East receive about US$1 billion each. Receipts in Central and South America are almost equally divided between Brazil (BRA), Mexico (MEX), Venezuela (VEN), and other countries in the region (XSM); whereas in Africa, 70% of clean-development financing flows to South Africa (ZAF).

Table 2 provides an overview of the potential effects of such clean-development financing. Investing the financing flows in NAMA-type mitigation plans yields total emissions reductions of about 1.7 $GtCO_2$ which corresponds to 15% of total non-Annex-I emissions. Regionally, China achieves 12% emissions reductions, most other Asian economies 22%, countries in Central and South America 15%, African states 10%, the Middle East 13%, and the rest of the world 15%. Those values correspond to the maximum short-term abatement potentials in those regions.

Table 2 Emissions abatement in non-Annex-I countries and associated distribution between mitigation and adaptation financing.

	Climate finance million US$	Emissions reduction		Mitigation finance		Adaptation finance	
		$MtCO_2$	%	million US$	%	million US$	%
CHN	2914	517	12%	158	5%	2756	95%
ASI	2927	654	22%	863	29%	2064	71%
CSM	1169	187	15%	150	13%	1019	87%
AFR	1064	90	10%	4	0%	1060	100%
MES	991	195	13%	991	100%	0	0%
ROW	704	102	15%	2	0%	702	100%
Total	9768	1746	15%	2168	22%	7600	78%

Table 2 indicates that in total 22% of clean-development financing is used for emissions abatement, leaving 78%, i.e. about US$7.6 billion out of the US$9.8 billion, available for other purposes, such as adaptation financing. However, there are large regional differences reflecting the relative costs of mitigation and the incoming financing flows. For example, India and the Middle East need to invest all of their clean-development moneys to exhaust their short-term abatement potential, whereas Mexico and Indonesia need to invest about 50%, and almost all other countries less than 5%. Reasons for those differences are the large sizes of economies and emissions compared to revenue inflows in the case of India and the Middle East, high abatement costs for Indonesia and Mexico (see Table A2 in the Appendix), and the relatively low emissions compared to revenue inflows in most other countries.

4.3. Carbon leakage

Figure 3 illustrates the impact of clean-development financing on carbon leakage, i.e. the change in carbon emissions in non-Annex-I countries with respect to the total emissions abatement in Annex-I countries (Felder and Rutherford, 1993). It compares the leakage rates in the carbon-tariff-clean-development scenario (BCM) with those obtained in the reference cap-and-trade (CAT) and standard carbon-tariff scenarios (BCA). Total carbon leakage in the CAT scenario amounts to 14%, i.e. for a 100 $MtCO_2$ reduction in Annex-I countries, non-Annex-I countries increase their emissions by 14 $MtCO_2$. China and other Asian economies exhibit the highest individual leakage rates of 3% and 4% respectively. Levying carbon tariffs on energy-intensive imports from non-Annex-I countries in the BCA scenario reduces regional leakage rates by 0.6% on average. Total leakage reduces from 14% to 11%.

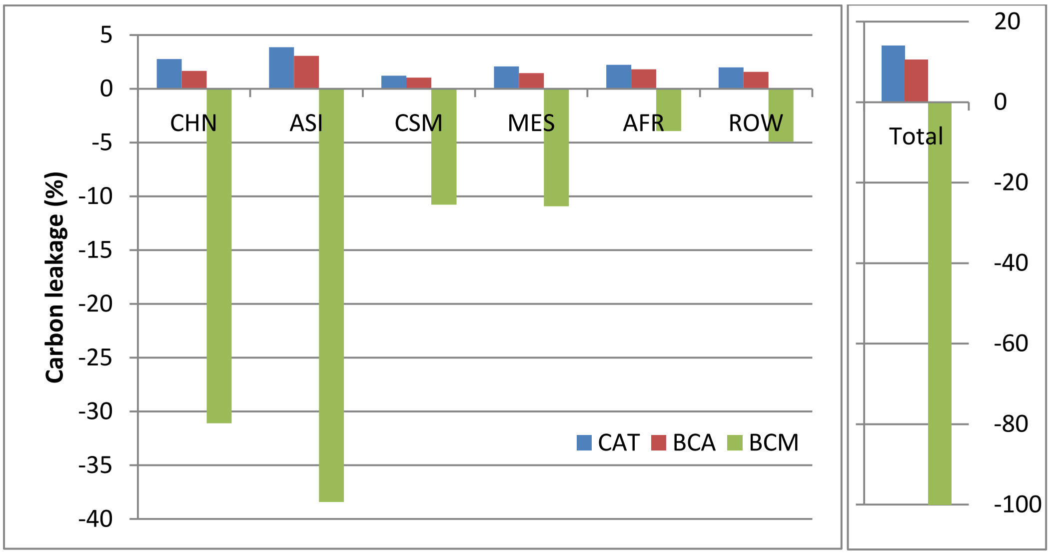

Figure 3. Regional and total carbon leakage in the cap-and-trade (CAT), carbon-tariff (BCA), and coupled carbon-tariff-clean-development (BCM) scenarios.

Investing the revenues from carbon tariffs in clean-development financing in the exporting country reduces total leakage by 114%; leakage rates in China and other Asian economies are reduced by 34% and 42% respectively. This makes leakage rates become negative, i.e. both Annex-I and non-Annex-I countries reduce their emissions, which essentially means an absence of leakage. In the clean-development scenario, the total leakage rate approaches -100% which indicates that non-Annex-I countries reduce their emissions by the same percentage as Annex-I countries (measured with respect to the 2004 baseline).[12]

4.4 Welfare effects

Figure 4 and Table 3 analyze the production and welfare effects of the carbon-tariff-clean-development scenario in terms of changes in GDP and per-capita equivalent variation of income. It should be mentioned that the economic impacts of changes in CO_2 emissions are not included in those metrics. Figure 4 compares the GDP changes in the carbon-tariff-clean-development scenario (BCM) and in the standard carbon-tariff scenario (BCA); the reference scenario in both cases is the underlying cap-and-trade scenario. Implementing carbon tariffs without recycling the revenue to the exporting countries leads to significant GDP decreases in non-Annex-I countries of 0.32%. At the same time, Annex-I countries only gain 0.08% from a standard carbon-tariff policy.

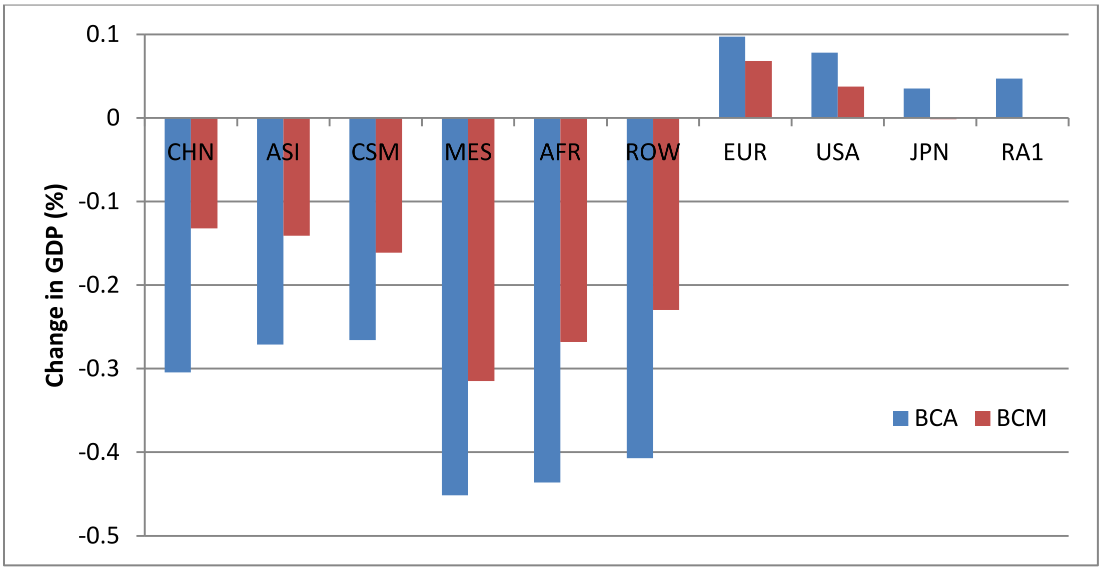

Figure 4. Changes in regional gross domestic product (GDP) in the carbon-tariff (BCA) and combined carbon-tariff-clean-development (BCM) scenarios relative to the reference cap-and-trade scenario.

Combining carbon tariffs with clean-development financing recycles productive capital in terms of carbon-tariff revenues from Annex-I countries to non-Annex-I countries. As a result, GDP levels in Annex-I countries decrease by about 0.04% in the carbon-tariff-clean-development scenario relative to the standard carbon-tariff scenario. However, on aggregate they are still 0.04% higher than in the reference cap-and-trade scenario and remain positive in most countries. In non-Annex-I countries, the inflow of clean-development investment reduces the negative impacts the standard carbon-tariff scenario has on GDP. The GDP levels of non-Annex-I countries are 0.14% higher in the carbon-tariff-clean-development scenario than in the standard carbon-tariff scenario, but still 0.18% lower than in the reference cap-and-trade scenario. Global GDP remains roughly unchanged in both carbon-tariff scenarios.

Table 3 Changes in per-capita equivalent variation of income in the cap-and-trade (CAT), carbon-tariff (BCA), and coupled carbon-tariff-clean-development (BCM) scenarios.

	Per-capita equivalent variation (%)		
	CAT	BCA	BCM
Total	-0.099	-0.156	-0.168
Annex I	-0.143	-0.110	-0.161
Non-Annex I	-0.044	-0.215	-0.176
CHN	-0.024	-0.233	-0.196
ASI	0.123	-0.029	0.012
CSM	-0.473	-0.655	-0.629
MES	-1.742	-2.198	-2.161
AFR	-0.574	-0.890	-0.837
ROW	-0.163	-0.309	-0.288
EUR	0.008	0.068	0.025
USA	-0.023	0.004	-0.032
JPN	0.017	0.054	0.004
RA1	-0.349	-0.324	-0.387

Similar effects can be observed when looking at changes in welfare. Table 3 lists the changes in per-capita equivalent variation of income (EV) in the two carbon-tariff scenarios and in the reference cap-and-trade scenario.[13] Recycling the revenues from carbon tariffs to the exporting non-Annex-I countries alleviates the negative welfare impact of the standard carbon-tariff scenario by 0.04%. At the same time, Annex-I countries experience an aggregate decrease in EV of 0.05%. This leads to a global welfare loss of 0.01% when the total sum of EVs is used as measure. Adopting a Rawlsian view where the welfare level of the poorest region determines global welfare would result in a small global welfare gain of 0.005% in the carbon-tariff-clean-development scenario compared to the standard carbon-tariff scenario.[14]

4.5. Sensitivity analysis

The sensitivity analysis considers the effects of different scenario specifications as listed in Table 4. A post-2012 carbon price of US$35/t$CO_2$ would more than double revenues (and tariff rates) to a total of US$24.5 billion. Most of the additional funds could go towards adaptation financing, since the maximum possible abatement potential is already reached with a lower carbon price in most regions. Reductions in leakage rates are less compared to the main scenario, because of the higher emissions reductions in Annex-I countries (21% compared to 11%). The high tariff rates associated with the higher carbon price more than double the negative welfare impacts but preserve the ratio between the carbon-tariff and clean-development scenarios.

Levying carbon tariffs in proportion to the carbon intensity of domestic Annex-I industries would decrease the revenues from carbon tariffs by a factor of 3 and tariff rates by a factor of 2 on average. Investing this money in clean-development financing would still achieve similar emissions and leakage reductions, but adaptation finance would only be a third compared to the main scenario. The welfare impacts are proportionally lower due to less tariffs being imposed. It should also be noted that this scenario would likely be associated with lower administrative costs, as the emissions intensities of domestic Annex-I industries are more readily available than the emissions intensities of industries in non-Annex-I countries.

Table 4 Sensitivity analysis with respect to carbon price, carbon-tariff basis, and abatement modelling for the carbon-tariff-clean-development (BCM) scenario.

Scenario specification		Carbon-tariff revenues		Emissions reduction		Adaptation finance		Leakage	Welfare (EV%)	
PCO_2 (US$/$tCO_2$)	Tariff basis	billion US$	% of main scn	$MtCO_2$	% of main scn	billion US$	% of main scn	%	BCA	BCM
15	EEI	9.8	100%	1746	100%	7.6	100%	-100	-0.057	-0.069
35	EEI	24.5	250%	1778	102%	21.8	287%	-50	-0.139	-0.157
15	dom. EI	3.5	36%	1586	91%	2.6	34%	-87	-0.036	-0.042
35	dom. EI	8.8	90%	1710	98%	7.1	93%	-45	-0.086	-0.099
CDM scenario:										
15	EEI	9.8	100%	628	36%	0.2	3%	-29	-0.057	-0.069
CO_2-MAC scenario:										
15	EEI	9.8	100%	1629	93%	6.0	79%	-93	-0.057	-0.069

EEI: emissions embodied in imports
dom. EI: domestic emissions intensities

Combining a high carbon price with calculating tariff rates in proportion to domestic emissions intensities smoothes out the effects of the individual scenarios. Tariff revenues, emissions reductions, and adaptation finance are each within 10% of the main scenario. As in the previous high-carbon-price scenario, reductions in leakage rates are reduced, but not due to significantly less emissions reductions in non-Annex-I countries, but due to higher emissions reductions in Annex-I countries. The welfare effects are higher than in the main scenario due to the high carbon price and the higher tariff rates being imposed as a result.

Investing all clean-development financing in market-based CDM projects (with a CER price of US$15/t$CO_2$) would achieve about three times less reductions in emissions and in carbon leakage as the main NAMA-type clean-development scenario. Total emissions reductions would be about 628 MtCO_2 which amounts to 5% of non-Annex-I emissions. Since the regional abatement potentials are higher in most countries (except for Brazil and South Africa), almost all funds can be invested in emissions abatement. This would leave no financing available for adaptation. Revenue and welfare implications of this scenario are equivalent to the main scenario.

Investing climate finance only in CO_2-abatement options modelled by MAC curves of the energy-economic model (instead of using the MAC curves of the MIT EPPA model) achieves 93% of the main scenario's emissions reduction and reduction in carbon leakage. The abatement costs increase by US$1.6 billion, since low-cost non-CO_2 abatement options are not taken into account in this scenario. As a result, 21% less funds are available for adaptation financing. Revenue and welfare implications are equivalent to the main scenario.

Sensitivity analysis with respect to the composition of investment induced by revenue recycling shows no significant changes in the welfare results for a wide range of investment-good compositions. For example, investing all moneys in specific sectors, such as electricity, would result in welfare reductions of about 0.073% in the BCM scenario relative to the reference cap-and-trade scenario. However, this would not change the qualitative interpretation of the results. Larger changes are obtained for investing revenues directly into developing countries' consumption, but this would not be in line with the investment's representation as (clean-)development financing.

5. Conclusion

This study's analysis of combining carbon tariffs with clean-development financing in developing countries rests on a number of assumptions and methodological idealizations. First, clean-development investments in developing countries are modelled as a two-step procedure which separately considers emissions abatement and economic impacts. Second, the economic impacts from clean-development investments are modelled in a generic way as general investments. As a result, the methodology lacks consistency at the sector level. Although this approach is justified when focussing on general macroeconomic indicators as was done in this study, a more integrative bottom-up approach would be needed to analyze the sectoral effects of the policies considered. Another limitation concerns the use of a static energy-economic model. Employing a static analysis is justified when focussing on short-term effects as was done in this study. However, a key challenge in terms of emissions reductions will be the mitigation of potentially large future increases of emissions in developing countries. A dynamic modelling approach would clearly be better suited to analyze such long-term effects. Additional studies are therefore encouraged. Nevertheless, several conclusions can be drawn from this study.

The indicative results of this study shows that combining carbon tariffs with clean-development funding might be an interesting option from several perspectives. It would allow industrialized countries to combat leakage and politically address the concerns of domestic industries by levying carbon tariffs on energy-intensive imports from non-Annex-I countries. Grubb (2011) argues that this would also dispose of the need to distribute emissions allowances for free to trade-exposed industries (as is current practice in the EU ETS). Auctioning those allowances would result in additional revenues and in a potential strengthening of industrialized countries' domestic climate policies.

At the same time, combining carbon tariffs with clean-development investments could address the challenge to provide additional sources of climate finance. This study estimates that US$3.5-24.5 billion (with a central value of US$9.8 billion) could be raised for this purpose from levying carbon tariffs at Annex-I borders. Compared to developed countries' pledges of providing US$10 billion per year of climate finance from 2010-2012 and of mobilizing US$100 billion per year by 2020 (Copenhagen Accord, 2009; Cancun Agreements, 2010), this constitutes a significant amount which warrants to be taken into consideration – also because the cost to industrialized countries is likely to be small. This study indicates a decrease in Annex-I GDP of below 0.04% relative to a standard carbon-tariff scenario and an increase of above 0.04% relative to the reference cap-and-trade scenario (not taking into account the need to raise funds for climate finance in the reference scenario).

With respect to environmental impacts, the clean-development financing supports developing countries' climate change adaptation and mitigation efforts. This study shows that this could reduce developing countries' emissions by 15% if funds are invested in nationally coordinated mitigation plans (similar to NAMAs) and 5% if funds are invested in CDM projects in those countries. Although the former approach is preferable, both results indicate the potential of the combined carbon-tariff-clean-development policy (and of climate finance in general) to enable global emissions reductions in both developing and industrialized countries.

However, there are also some serious drawbacks of the policy analyzed. The welfare analysis suggests that the combined carbon-tariff-clean-development policy might not be preferable over the reference cap-and-trade policy for either developing or developed countries. Recycling carbon-tariff revenues back to the exporting developing countries alleviates some of the negative welfare effects of a standard carbon-tariff policy. However, the welfare gains relative to a standard carbon-tariff scenario without revenue recycling are too small to compensate for the total welfare loss caused by the implementation of carbon tariffs. As a result, global welfare in the carbon-tariff-clean-development scenario is lower than in the reference cap-and-trade scenario and, depending on the measure used, could even be lower than in the standard carbon-tariff scenario.

On the political level, this calls into question whether combining carbon tariffs with clean-development financing would be enough to make China and other developing countries reconsider their general opposition to carbon tariffs. US$100 billion per year of climate finance by 2020 has already been pledged by Annex-I countries with no concession that developing countries might accept new tariff barriers in return. Indeed, developing countries might argue that climate finance raised from carbon tariffs is not additional as it comes at the expensive of worsened terms of trade for those countries.

An additional problem of coupling carbon tariffs to clean-development financing is that funds are distributed in proportion to non-Annex-I countries' emissions intensities and terms of trade with Annex-I countries. This could encourage exporting countries to raise the emissions intensity of traded goods in order to receive more funds (see Winchester, 2011, for a discussion on differentiating production lines), while precluding especially least-developed countries with little exports from receiving any. The latter effect was indeed observed in this study (see Figure 2). The problems could be addressed by using alternative tariff bases, such as domestic emissions intensities or best available technologies (Ismer and Neuhoff, 2007), and by channelling the revenues from carbon tariffs into a global climate fund (such as the Green Climate Fund established in the Cancun Agreements) with disbursements made according to greatest needs.

In any case, the negative welfare effects on developing and developed countries might disqualify the policy combination of carbon tariffs with clean-development financing as a global consensus option. However, as the policy addresses the issues of carbon leakage and the need to raise revenue for climate finance, it might continue to play a role in sub-global policy approaches of Annex-I countries until further (possibly collaborative) alternatives for addressing those issues emerge.

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Notes

1. The model is formulated as GAMS/MPSGE code which can be obtained from the author upon request.
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.
3. Energy-intensive goods include iron and steel; chemicals, including plastics and petrochemical products; non-ferrous metals, including copper and aluminium; and non-metallic minerals, including cement.

4. Responses to carbon prices include substitution away from coal towards gas in electricity production, improving energy efficiency, the use of non-fossil energy, and reducing energy demand. Clean-development investments can promote some of those activities, but not all unless the policy is highly prescriptive.
5. Previous studies that have aimed at estimating the availability of emissions reductions in developing countries have scaled back the emissions-reduction potential derived from MAC curves in various ways, e.g. by assuming practical abatement that is one-tenth of the economy-wide MAC estimate (Jotzo and Michaelowa, 2002; Michaelowa and Jotzo, 2005) or by limiting the implementation of abatement measures via a participation rate of less than one (Kallbekken, 2007).
6. Adopting constant abatement costs assumes that all CDM credits (CERs) can be supplied at current prices. This assumption is justified for the volume of CERs that is associated with the magnitude of emissions abatement considered in this study (see e.g. World Bank, 2011).
7. Indirect emissions include the carbon contents of all imported and domestic intermediate inputs.
8. As a further idealization, this study's main scenarios do not consider possible tariff exemptions for least-developed countries as included in several US proposals (van Asselt and Brewer, 2010). Such exemptions would also preclude those countries from receiving moneys for clean-development investment in the carbon-tariff-clean-development scenario considered.
9. Monetary values are given in 2004-US$. Because the model is calibrated to match current carbon prices and short-term emission reductions, the

monetary values can be seen as indicative of the possible short-term (e.g. annual) effects of the climate policies modelled.

10. This practice might create wrong incentives which are discussed in Section 5.

11. In comparison to Table A3, the aggregation has been reduced for ease of presentation. KOR and SIT have been summarized as TIG; THA and MYS have been included in XAS; XNF has been included in XAF; and XAM has been included in ROW.

12. Table 2 lists emissions reductions in non-Annex-I countries that are higher than the 11% emissions reductions prescribed for Annex-I countries. This is calculated with respect to the cap-and-trade scenario and therefore includes the compensation of leakage-related emissions increases from that scenario.

13. Introducing a price of carbon in the cap-and-trade scenario reduces the welfare of the affected Annex-I countries. In addition, non-Annex-I countries are affected, primarily due to reductions in fossil-fuel exports to Annex-I countries. Thus, the reference against which the carbon-tariff scenarios are evaluated includes aggregate welfare losses for both regional blocks.

14. The poorest region in the aggregation used is the Rest of Africa (XAF). In Table 3, XAF is further aggregated to AFR which, when looking at regional aggregates, is still the poorest region listed in the table.

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Appendix 1

Description of the basic computable-general-equilibrium model

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 constant-elasticity-of-substitution (CES) production functions. They are arranged in three levels to describe the input composition and substitution possibilities between inputs (Figure A1). The top-level nest combines capital, labour, and material inputs (KLM) with energy inputs (E) and with resource inputs (RES) (except for secondary energy inputs); the second-level nest combines non-energy material inputs (M) with capital and labour inputs (VA) in the KLM-nest, and electricity inputs (P(ELE)) with final-energy inputs (FE) in the energy nest; and the third-level nest captures substitution possibilities between capital (PK) and labour (PL) in the VA-nest and between different final energy inputs (coal, refined oil, gas) (P(FE)) and their associated CO_2 emissions (PCARB) in the FE-nest. Elasticities of substitution are adopted from the GTAP database version 7.1 and from Böhringer et al. (2011) – they are listed in

Table A1.

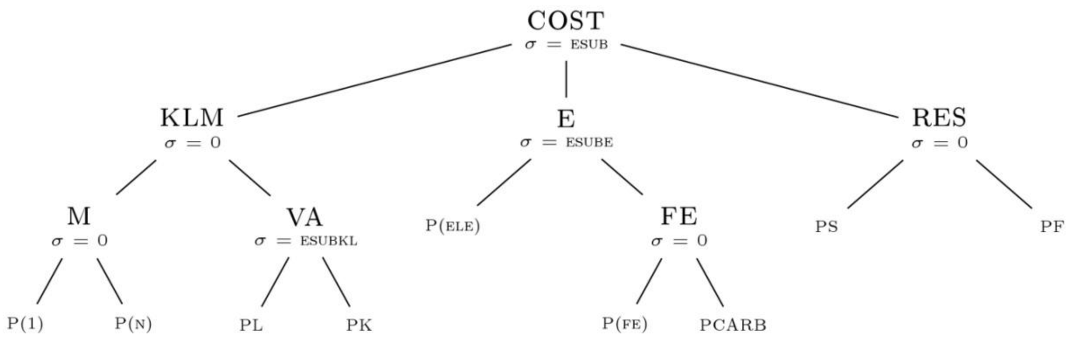

Figure A1. Nesting structure of CES production functions.

The modelling of international trade follows Armington's (1969) approach of differentiating goods by country of origin. Goods within a sector and region are therefore represented as a CES aggregate of domestic goods and imported ones with associated transport services. 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 and the budget constraint is determined by factor and tax incomes with fixed investment and public expenditure.

Table A1 Elasticities of substitution and elasticities of supply.

	OIL	GAS	ELE	COL	CRU	EIT	TRN	AOG
esub	0.50	r	0.50	r	r	0.50	0.50	0.50
etaen	x	0.25	x	1.00	0.50	x	x	x
esubkl	1.26	0.65	0.50	0.20	0.20	1.26	1.68	1.27
esube	0.00	0.00	0.50	0.00	0.00	1.00	1.00	1.00
esubd	2.10	5.00	2.80	3.05	5.00	3.28	1.90	2.54
esubm	4.20	10.00	5.60	6.10	10.00	6.69	3.80	6.54

esub: top-level elasticity of substitution
etaen: elasticity of supply
esubkl: capital-labour elasticity
esube: elasticity of substitution between energy inputs
esubd: elasticity of substitution between domestic goods and imports
esubm: intra-import elasticity of substitution
r: region-specific, concrete value depends on resource rental share and etaen
Sources: GTAP database 7.1 (Narayanan and Walmsley, 2008) and Böhringer et al. (2011).

Appendix 2

Derivation and calibration of emissions reduction functions from MAC curves

MAC curves can be parameterized by polynomial functions (see e.g. Böhringer et al., 2005; Anger, 2008). This study parameterizes EPPA's MAC curves by a polynomial of second degree with positive coefficients:

$$MAC(\Delta E, r) = a(r) \cdot \Delta E^2 + b(r) \cdot \Delta E, \qquad a(r), b(r) > 0,$$

where r denotes the model region, ΔE emissions reductions and a and b are regression coefficients. Constraining the regression coefficients to be positive has the effect of limiting the polynomial to its quadratic term, i.e. $b(r) = 0$ for all r, for the MAC curves considered here. This allows one to find a real-valued solution when solving for emissions abatement.

Emissions reduction functions can be obtained from the MAC parameterization by integration and solving for emissions abatement. Integrating the MAC function with respect to ΔE yields total abatement costs which are identified as clean-development financing in this study and given by carbon-tariff revenues R_{tau}. Solving for emissions abatement then yields:

$$\Delta E(r) = \sqrt[3]{\frac{3R_{tau}}{a(r)}} \ .$$

The emissions reduction function is a concave function which exhibits decreasing emissions reduction to clean-development investment in accordance to the underlying MAC curves.

R_{tau} is discounted by 4.5% to account for transaction costs that can accrue during several phases of project development. This value is inferred from a detailed analysis of clean-development projects in non-Annex-I countries (Wetzelaer et al., 2007).

The regression coefficients $a(r)$ are obtained by an ordinary-least-squares regression of marginal abatement costs on emissions reductions for each model region – they are listed in Table A3. The regressions were made for emissions reductions of up to 20-30% to account for short-term abatement potentials in non-Annex-I countries (Wetzelaer et al., 2007). The corresponding total abatement costs that are needed to reduce emissions by 100 $MtCO_2$ are listed as an illustration for the magnitudes of the regressions coefficients. Finally, the disaggregation of EPPA's 10 non-Annex-I regions to this study's 19 is highlighted.

Table A2 Parameterization and calibration of marginal-abatement-cost (MAC) and total-abatement-cost (TAC) functions.

Country/Region in MIT EPPA model	Disaggregation to this study's model	Quadratic fit a	R^2	TAC(100 $MtCO_2$) [million $]
China	CHN	3.28E-06	0.98	1.09
India	IND	4.54E-05	0.98	15.14
High Income East Asia	KOR, THA, SIT, MYS	1.26E-04	0.98	41.97
Middle East	XWS	3.82E-04	1.00	127.40
Indonesia	IDN	2.83E-03	1.00	944.34
Mexico	MEX	8.94E-04	0.98	297.99
Central and South America	BRA, VEN, XSM	4.90E-05	0.97	16.32
Africa	ZAF, XNF, XAF	1.18E-04	0.99	39.35
ROW	XAS, XAM, ROW	4.22E-05	0.95	14.06
Former Soviet Union	XSU	1.35E-05	1.00	4.49

Appendix 3

Regional aggregation

Table A3 Model regions.

Annex I					
EUR	Europe (EU 27 + EFTA)		RA1	Rest of Annex I	
USA	United States			ANZ	Australia and New Zealand
JPN	Japan			CAN	Canada
				RUS	Russian Federation
				UKR	Ukraine
				TUR	Turkey
				RA1	Rest of Annex I
non Annex I					
CHN	China and Hong Kong		MES	The Middle East	
ASI	Other Asian countries		CSM	Central and South America	
	IND	India		BRA	Brazil
	KOR	South Korea		MEX	Mexico
	IDZ	Indonesia		VEN	Venezuela
	THA	Thailand		XSM	Rest of South America
	SIT	Singapore + Taiwan			
	MYS	Malaysia			
	XAS	Rest of Asia			
AFR	Africa		ROW	Rest of the World	
	ZAF	South Africa		XSU	Rest of Former Soviet Union
	XNF	Rest of North Africa		XAM	Rest of America
	XAF	Rest of Africa		ROW	Rest of the World

Appendix 4

Emissions reduction constraints

Table A4 Annual abatement potentials of non-Annex-I countries.

Country/Region in Wetzelaer et al. (2007)	Disaggregation to this study's model	Annual abatement potential (%)
China	CHN	0.12
India	IND	0.26
Rest of East South Asia	IDZ, THA, MYS	0.22
Rest of High Income Asian economies*	TIG, KOR	0.22
Brazil	BRA	0.05
Rest of Central and South America	MEX, VEN, XSM	0.19
South Africa	ZAF	0.10
Rest of Africa*	XNF, XAF	0.10
Rest of the World*	XSU, XAM, ROW; XAS, MES	0.16

** extrapolated from Wetzelaer et al. (2007) based on regional values or average*

Source: based on data contained in Wetzelaer et al. (2007)