A CGE Analysis of climate policy options after Copenhagen: bottom-up approaches, border tax adjustments, and carbon leakage

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Abstract:

After COP15 in Copenhagen, bottom-up approaches in which countries decide individually on emission reduction targets and climate policies are gaining prominence. Due to a likely partial (i.e. regional) coverage, bottom-up approaches might lead to both carbon leakage and reduced competitiveness of trade exposed, energy intensive sectors. We develop a multi-sectoral multi-regional Computable General Equilibrium model for the European Union and 14 further world regions to assess the carbon and economic impacts of different bottom-up approaches up to 2020: (i) a continuation of EU ETS (but without initially free allocation), (ii) an additional cap for the European non-ETS sectors, (iii) different bottom-up approaches among all Annex I countries, and (iv) a combination of unilateral EU policies with border tax adjustments to level the playing field among domestically affected industries and importers. We find that under EU ETS with auctioning approximately 50% of emission reductions within the EU are offset by emission increases in non regulated countries. Even in a comparatively stringent bottom-up approach among all Annex I countries, the carbon leakage rate is still above 20%. Finally, border tax adjustments to halt competitiveness losses due to unilateral EU policy are only effective when the tax rate is high and trade exposed, energy intensive sectors constitute a comparatively small share of the economy.

Keywords: computable general equilibrium modeling, post 2012 climate policies, competitiveness, carbon leakage, border tax adjustments

JEL Codes: D58; Q56; F42.

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1. Introduction

After COP15 in Copenhagen, bottom-up approaches in which countries decide individually on emission reduction targets and abatement policies are gaining prominence. In contrast to top-down approaches, these policies are designed in accordance with national jurisdiction and hence reduction targets might be seen more credible when they are announced. On the other hand, when policies are chosen by the countries themselves and the reduction targets are not negotiated under the umbrella of the UNFCCC, policies are likely to be limited both in regional scope and stringency. Thus, the first aim of this paper is to discuss the effectiveness of different forms of bottom-up approaches, from a continuation of unilateral EU approaches over an extension towards other Annex I countries as stated both before and after the Copenhagen Conference, and compare them to those of the IPCC reduction requirements stated for Annex I countries.

A serious consequence of bottom-up approaches to climate policy with a limited regional scope is reduced environmental effectiveness which has been termed carbon leakage. This phenomenon refers to a partial offset of domestically reduced GHG emissions in countries with less stringent environmental requirements as a result of a relocation of production to regions not facing mitigation policies. A related, but distinct, consequence of climate policies implemented in some countries only is the claimed reduction of competitiveness of trade exposed, energy intensive sectors. The second purpose of the present paper is thus to identify the effects of different bottom-up approaches differing in regional scope and stringency for carbon emissions and output in the European Union, its main trading partners and major world regions.

Thus, along with the likely emergence of bottom-up policy approaches, both the EU and the US foresee measures to shield themselves from negative consequences for environmental effectiveness and competitiveness. In principal, measures for equalizing carbon prices across countries can utilize several leverages: (i) reducing the level of carbon prices in regulated countries (i.e. grandfathering of emission permits); (ii) increasing the level of carbon prices in unregulated countries (e.g. by sectoral agreements among Annex I and non-Annex I countries); and (iii) tax adjustments at the border (according to the grey carbon in international trade; see e.g. Grubb and Brewer, 2009). After the Copenhagen Conference, however, only the third option of border adjustments seems of political relevance and that is why it is found in both EU and US documents (Kuik and Hofkes, 2010). In the present paper, we focus on the effects of one specific type of border tax adjustments: the imposition of an import tax based on the carbon content of sectoral production in the originating country.

The present analysis seeks to delineate the economic and environmental consequences of different options for bottom-up approaches to climate policy for the period after 2012, both with and without border tax adjustments. For that purpose, we develop a multi-sectoral multi-regional Computable General Equilibrium model for the European Union and 14 further world regions, covering 11 sectors and taking account of carbon emissions embodied in production processes. The model is based on GTAP7 data and a BAU is developed for the year 2020. This model is then used in comparative static analysis to assess the carbon as well as economic impacts of different climate policies: (i) a continuation of the EU's ETS in the energy intensive sectors (-21% reduction target relative to 2005), (ii) an additional cap for the European non-ETS sectors (-10% reduction target relative to 2005), (iii) a global bottom-up approach with differentiated reduction targets across groups of countries (as envisioned by the Copenhagen Accord; e.g. -30% reduction in the EU, USA -4%, Russia -15%, relative to 1990 levels), and (iv) a combination of unilateral EU policies with border tax adjustments to level the playing field among domestically affected industries and imports-thereby addressing competitiveness and carbon leakage issues.

Methodologically, the present paper contributes to the literature on multi-sectoral multi-regional CGE models analyzing climate policies, competitiveness and carbon leakage (e.g. Böhringer, 2000; Burniaux and Martins, 2000; Paltsev, 2001; Kuik and Gerlagh, 2003; Babiker, 2005; Fischer and Fox, 2007; Fæhn and Bruvoll, 2009). The present paper aims to reconcile the trade-off between broad sectoral coverage and detailed country representations, by contrasting the domestic and trade effects of the different climate policies for energy intensive sectors (i.e. the so-called ETS sectors since their emissions are capped by the EU's emissions trading system), as well as energy extensive production and service sectors (all of them summarized as the so-called non-ETS sectors) and private household demand. Apart from energy intensity, theses sectors and agents diverge also in their emission abatement options, since the ETS sectors can comply with their emission reduction requirement by buying permits abroad (at least for EU member states) while non-ETS sectors and households are basically required to undertake abatement domestically. However, a linkage of the two systems is currently introduced in the form of `domestic offsetting'. Moreover, within industrialized countries the economic share of non-ETS sectors in output is considerably higher than that of ETS sectors, leading to significantly higher macroeconomic and trade effects when a policy covers non-ETS sectors and households too.

The structure of this paper is as follows. In the following section, we start by a description of the structure of the CGE model, while data and model calibration as well as the specifications for the different policy scenarios are found in section 3. Section 4 discusses the economic and carbon effects of the scenarios on a global scale. Based on quantifications of carbon leakage and competitiveness, Section 5 investigates the suitability of border tax adjustments to address these problems. Section 6 summarizes our results and concludes.

2. The model

We develop a computable general equilibrium (CGE) model to analyze the economic impacts of carbon dioxide emission constraints taken unilaterally or globally, with a focus on the (feedback) effects via international trade and its respective net carbon flows. For that purpose, we construct a CGE model for Europe and 13 other world regions (see Table 1). The regional (dis)aggregation is based on geographical similarity, their common role in climate negotiations as well as the affiliation to certain alliances, like the Commonwealth of Independent States (CIS/GUS).

Table 1: Overview of regions

Aggregated Region	Model code	Aggregated Region	Model code
European Union	EU	South Asia	SASI
Rest of Europe	ROE	United States of America	USA
Russian Federation	RUS	Rest of North America	NAM
Rest of GUS	GUS	Latin America	LAM
China	CHN	Oceania	OCEA
Rest of East Asia (“Asian Tigers”)	EASI	Middle East and North Africa	MENA
Southeast Asia	SEASI	Sub Saharan Africa	SSA

Source: Based on GTAP (2007)

On the sectoral level, we differentiate between 11 sectors according to their energy intensity (see Table 2). Sectors with high energy intensity (i.e. the sectors covered by the European Union’s Emissions Trading Scheme; European Parliament, 2003) are derived energy goods, namely refined oil and coke oven products (P_C) and electricity including its distribution (ELY), and energy intensive sectors (EIS) which according to GTAP7 classification comprise the industries which are responsible for the bulk of a country’s production related GHG emissions. The most prominent industries within EIS are iron and steel, chemicals, cement and paper. Sectors with lower energy intensity (i.e. the non-ETS sectors, NETS) include primary energy extraction coal (COA), oil (OIL) and natural gas (GAS), as well as the non-energy intensive sectors (NEIS), transport (TRNS), food products and agriculture (FOOD), other services and utilities (SERV), and capital goods (CGDS).

The remainder of this chapter gives a detailed description of the CGE model structure, which follows in its basic structure the GTAP-E model, as well as the parameters applied for the evaluation of different policy scenarios (see chapter 3.3).

Table 2: Overview of sectors

Aggregated Sectors	Model Code	GTAP sectors
ETS sectors		
Refined oil products	P_C	Manufacture of coke oven and refined oil products
Electricity	ELY	Production, collection and distribution of electricity
Energy intensive industries	EIS	Chemical industry, non-metallic mineral products, iron and steel, precious and non-ferrous metals, paper products
Non-ETS sectors		
Non energy intensive industries	NEIS	Textiles, wearing apparel, leather, wood products, fabricated metal products, motor vehicles, transport equipment, machinery, communication equipment
Coal	COA	Coal Mining
Crude oil	OIL	Oil extraction
Natural gas	GAS	Natural Gas extraction, manufacture of gas, distribution, steam and hot water supply
Transport	TRN	Water, air, road and rail transport
Food products and agriculture	FOOD	All agriculture and food processing sectors
Other services and utilities	SERV	Water, wholesale, retail sale, hotels, restaurant, construction, financial services, insurance, real estate, public administration, post and telecom
Capital goods	CGDS	Capital Goods

Source: Based on GTAP (2007)

2.1 Basic model structure

Following the structure of agents used in the social accounting matrix generated by GTAP, the so-called regional household $RegHH_r$ represents total final demand in each of the 19 regions (denoted by r and s). This regional household provides the primary factors capital K_r, labor L_r and natural resources R_r (primary energy commodities) for the 11 sectors, and receives total income including various tax revenues. The regional household redistributes this stream of income between the private household PHH_r and the government GOV_r for private and public consumption, respectively. We model capital and labor as mobile between sectors within a region, but immobile among different regions. Moreover, again following the structure of the GTAP social accounting matrix, a specific resource input is used in the production of crude oil, natural gas and coal; therefore those three sectors represent the extraction of primary energy. Thus, there are two different groups of production activities which are represented by slightly different production functions in the model: the production of non-primary energy commodities, and primary energy extraction. The following section provides a description of the production function modeling approach, while the subsequent section deals with modeling international trade, taking the form of bilateral trade relationships rather than an integrated global market.

2.2 Production structure

Nested constant elasticity of substitution (CES) production functions are used to specify the substitution possibilities in domestic production between the primary inputs (capital, labor, and natural resources), intermediate energy and non-energy inputs as well as substitutability between energy commodities (primary and secondary). Since a specific resource input is used in the production of primary energy commodities (coal, oil, gas), we use slightly different production functions for primary energy commodities and all other commodities.

Figure 1 illustrates the production of all other commodities (indexed by *esc*), like the aggregate energy intensive industries (EIS). At the top level the Armington aggregation of domestic and imported intermediate inputs – the domestic supply $D_{esc,r}$ – from non-energy sectors are employed in fixed proportions *v* with an aggregate of capital, labor, natural resource and energy ($(KLR)E_r$). At the second nesting level, a CES composite of capital, labor and natural resources (KLR_r) is combined in fixed proportions (*elke*) with an energy-composite. The natural resource input $NatRes_r$ (only relevant for FOOD sector production, i.e. agriculture) is employed in fixed proportion with capital and labor at an elasticity *elk*. The energy-composite E_r consists of three main nesting stages. The first one represents a trade-off at constant elasticity *elc* between the domestic supplied secondary energy commodities electricity (ELY) $D_{ELY,r}$ and petroleum products (P_C) $PC/CO_{2\,r}$ with an aggregate of primary energy commodities ($OIL/GAS/COA_r$). At the subsequent level this primary energy-composite is comprised of a CES function (*elcl*) between the domestic supply of coal and another liquid/gaseous CES composite in which oil and gas are utilized in constant proportions (*elqd*).

The main difference in the production structure of fossil fuel extraction is that natural resources $NatRes_r$ are the crucial input in the production process. Accordingly, an additional substitution between natural resources and non-resource inputs is introduced. Thus, at the top level in the extraction of fossil resources, natural resources and non resource inputs can be exchanged at zero elasticity, which characterizes a Leontief composite.

The elasticities of substitution in the production processes (see Table 13 in the Appendix) are based on Okagawa and Ban (2008) as well as Beckman and Hertel (2009).

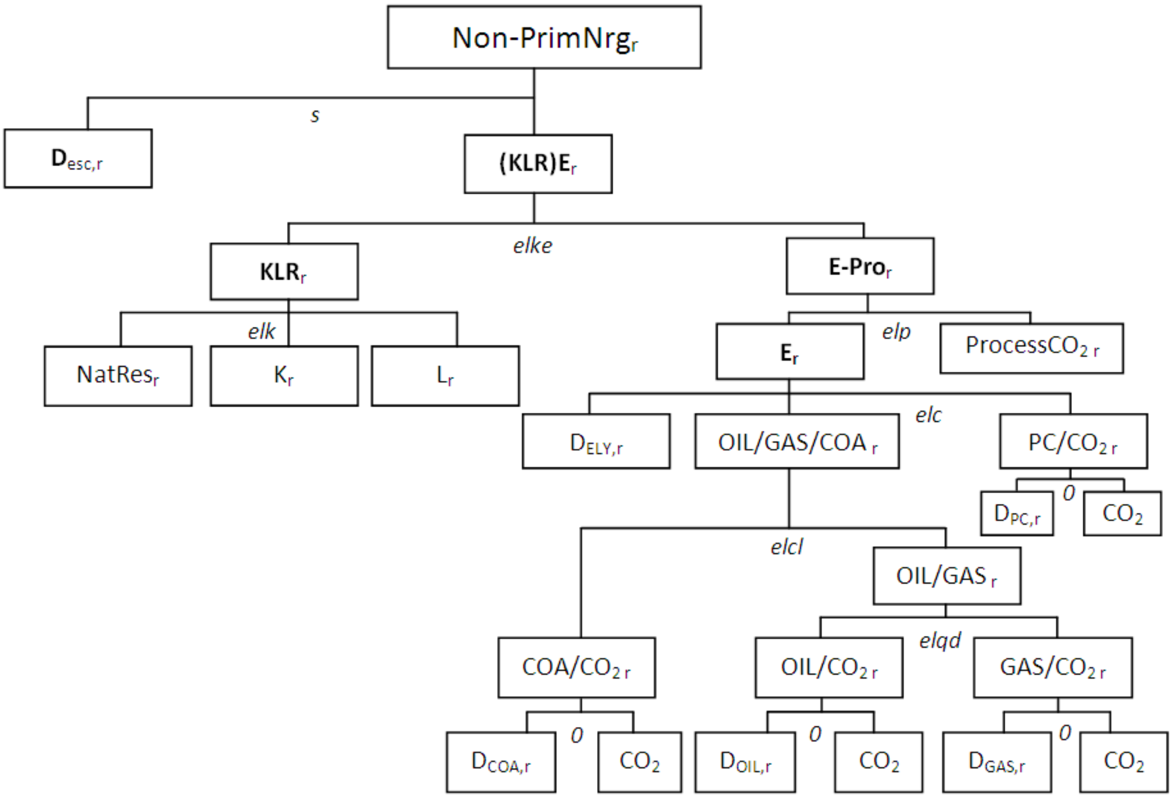

Figure 1: Nesting of production

2.3 International trade

A common assumption within multi-country CGE models which we also employ here is that goods produced in different regions are not perfectly substitutable. Therefore, trade in goods is described by bilateral trade relationships rather than by an integrated global market (Armington, 1969). An Armington aggregation activity $G_{es,r}$, depicted in Figure 2, corresponds to a CES composite (*tela*) of domestic $X_{es,r}$ and imported goods $IM_{es,s,r}$ as imperfect substitutes. The resulting Armington supply $G_{es,r}$ either enters the domestic supply $D_{es,r}$, satisfying final demand and intermediate demand in production activities, or is exported to other regions $EX_{es,s}$, entering again as an imperfect substitute into the formation of the trading partner's Armington supply. The associated *Armington elasticities (tela$_{es}$)*, different in each sector, are presented in Table 13 in the Appendix.

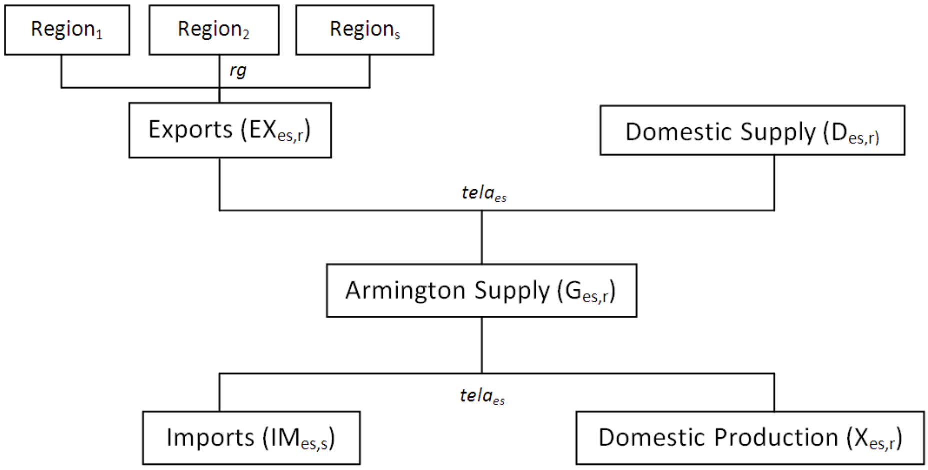

Figure 2: Armington aggregation for country *r*

The imports of any particular region $IM_{es,s}$ consist of imports from either the European Union or the Rest of the World (ROW). At the top level of the import production block, imports from EU regions and from ROW are traded off amongst each other at a constant proportion (*elim*). Imports among EU (ROW) regions are exchanged with a constant elasticity of substitution *m* (*n*). Every bilateral trade flow is linked to a distance dependent amount of transport service *TRANS* by means of a Leontief production function. A global transport market delivers the transport services required for imports to the individual regions. Each international transport service activity is assumed to be a Cobb-Douglas composite of transport goods $TRANS_r$ (provided as an aggregate of water, air and land transport) and domestic market activities (TRN) by each region, which are traded off among regions at elasticity *rg*. Values for the elasticities applied in the modeling of imports are presented in Table 14 in the Appendix.

2.4 Final demand

Final Demand in each region is determined by consumption of the private household and the government. Both the private household and the government maximize utility subject to their disposable income received from the regional household. Disposable income is composed of all factor income and tax revenues. Following the GTAP structure, we differentiate for a broad range of direct taxes (on capital, labor and resource inputs), indirect taxes (intermediate taxes, production taxes or subsidies, consumption taxes, export taxes or subsidies and import tariffs), and we add environmental levies in the form of CO_2 permits.

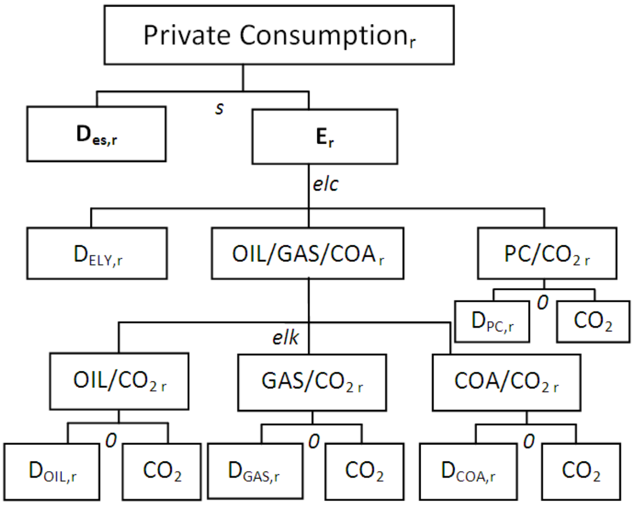

Figure 3: Final demand of private households for country *r*

Consumption of private households in each region, depicted in Figure 3, is characterized by a constant elasticity aggregate of a non-energy intermediate consumption bundle $D_{es,r}$ and an energy aggregate E_r (elasticity: *s*). The energy composite itself consists again of two nesting levels – a CES function with an elasticity *elc*, trading off secondary energy (ELY and P_C) with a primary energy fixed proportion composite (*elk*).

2.5 CO_2 emissions and carbon policies

As a prerequisite for our climate policy analysis, we model CO_2 emissions as both arising in production and consumption. As depicted in Figure 1, all fossil final energy intermediate inputs in a production process, irrespective at which nesting level, enter as fixed-coefficient composite of an imposed carbon tax linked with an elasticity of substitution equal to zero to the combustion of fossil fuels. This tax – in our case modeled as CO_2 emission permits which prices coincide with the carbon tax – reflects the carbon taxes a GHG emission abating region has to impose on fossil energy consumption in order to achieve an exogenously set reduction target. There is a unique carbon price in all ETS sectors, and within the EU we assume that the permit trading is allowed among all member states such that the carbon price is equalized across member states. Unique in the EIS sector is the inclusion of CO_2 emissions related with industrial processes ProcessCO$_{2\,r}$, which are nested in a Leontief style CES function together with the intermediate energy input composite E_r. The combustion of fossil fuels in the private households in each country is linked in the same way to CO_2 taxes as it is the case in the production of energy and non-energy commodities. Due to the absence of an EU-wide permit market for the non-ETS and household emission allowances, the tax (which in that case can be best described as the carbon shadow price) is not equalized across member states.

The revenues of the permit sales are collected by the regional households and redistributed to private households and the government.

Regarding the two accounting principles for carbon emission inventories, we differentiate between the production based principle (PBP) and the consumption based principle (CBP). The production based emission inventory represents domestic emissions from economic production within a country and the emissions due to the combustion of fossil fuels in the private sector, while the consumption based approach represents the entity of a country's CO_2 emissions occurring from its economic consumption (final demand). This Consumption Based Principle (CBP) can 'be considered a trade-adjusted version of the production based inventory' (Peters and Hertwich, 2008), by adding emissions from imports and subtracting emissions attributed to exports. Emissions from imports in a specific sector are thus calculated by taking the CO_2 intensities (CO_2 per unit of output) of the respective sectors in the respective countries, multiplied by import quantities, and aggregating across countries. Emissions from international transport are also differentiated by country of origin and by sector for all international transport flows.

3. Model calibration, baseline, and scenario specifications

For our analysis we use the GTAP database (GTAP, 2007) which is unique in its sectoral and regional coverage of consistent input output and trade tables (113 countries and 57 commodities for the base year 2004). Moreover, GTAP-E provides an extension on carbon emissions on a sectoral level for all countries included in GTAP. Despite the impressive scope of the database, it has some limitations particularly in regard to accuracy of data (see, e.g., Peters and Hertwich, 2008). In particular, emissions included in GTAP are solely based on combustion processes (Lee, 2008), while process related emissions (which can be substantial for some sectors like refineries) are not part of the emissions data. For our analysis, we had therefore to develop a BAU scenario for the year 2020 as well as to improve carbon emission data.

3.1 Economic and emission data

The underlying data base for the analysis of the carbon content of Austria's international trade is GTAP Version 7 (GTAP, 2007), containing the most recent and consistent input output and foreign trade accounts for 113 countries and 57 commodities for the base year 2004. Furthermore the data base provides information on international energy markets derived from the International Energy Agency's (IEA) energy volume balances, again for the year 2004 (McDougall and Lee, 2006; McDougall and Aguiar, 2007; Rutherford and Paltsev, 2000). GTAP7 relies on updated energy prices for the year 2004 – using price indices and exchange rates – from the year 2000, to add information about the monetary energy input values to the physical energy quantities.

The remaining crucial data prerequisite for our analysis is the detailed knowledge of emissions originating from the production processes of various sectors in various countries and regions. Lee (2008) started a first attempt to generate CO_2 emissions data for the GTAP7 database. Since these CO_2 emissions are derived from the IEA energy balances, included in GTAP7, they only take account of combustion based CO_2 emissions. This data therefore is excluding some 10% of global CO_2 emissions which are triggered by industrial processes. While 10% might seem negligible, it is not in our context of analysis, because it is 10% of global emissions originating from basically three economic sectors (iron and steel, cement, oil refinement) that each are foreign trade intensive and under fierce international competition. Regaring sectoral CO_2 emissions, the misrepresentation is even worse: e.g. for iron and steel process based emissions contribute 50% of total sectoral emissions (cf. UNFCCC, 2009). These GHG emissions from industrial processes mainly occur in the cement, chemicals and metal production and are therefore added to the EIS aggregate's emissions balance, based on UNFCCC data. [1]

3.2 Baseline adjustment and calibration

In our CGE analysis, we examine Austria's international trade and its net carbon flows for the time horizon 2020. The year 2020 was chosen because it reflects the time frame for the EU's proposed 2020 targets – a 20% reduction of GHG emissions below 1990 levels (-30% if there is an international mitigation agreement negotiated with other developed countries) and a 20% share of renewable energies in EU energy consumption until 2020 (European Commission, 2008). Also, many other officially announced reduction strategies by single countries, regions or by the IPCC (IPCC, 2007) refer to the year 2020. Accordingly, we construct a business as usual (BAU) scenario for 2020 and compare the impacts of the different policy scenarios to this BAU scenario.

Since the GTAP7 data base is consistent for the reference year 2004 and we apply a static general equilibrium model calibrated for this base year, we have to factor in the economic developments until the year 2020 by growth rates. In Poncet (2006) a comprehensive study of the long term growth prospects of the world economy was carried out, providing annual average growth rates for the time span 2005 to 2050 for multi-factor-productivity (MFP), the capital stock and the labor force. For the growth rates which were used to calibrate our model for the 2020 Business As Usual (BAU) scenario,

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[1] Another flaw of Lee's CO_2 emissions calculation lies in the misinterpreted treatment – at least for Austria – of fuels used as feedstock in the chemical and petrochemical industry (P_C). This leads to an underestimation of these industries' CO_2 emissions compared to more detailed data for Austria (Umweltbundesamt, 2008). Based on this additional information and on our own work in this field (Steininger et al., 2009), a reconciliation of the Austrian CO_2 data is possible in principle. However, to keep global consistency within the GTAP7 data set and to avoid implausible model results at the expense of Austrian industrial sectors, we thus stick to the initial CO_2 data base by Lee, but augmented by industrial process related emissions, yet without correction for feedstock use in these sectors.

see Table 15 in the Appendix. To account for improvements in energy efficiency over time, we introduce an exogenous autonomous energy efficiency improvement parameter AEEI. The AEEI is a heuristic measure for all non-price driven improvements in technology, which in turn reduces energy intensity. Following Böhringer (1999) or Burniaux et al. (1992) we assume a constant AEEI parameter and set it to 1% per annum. Considering the current economic downturn, we decided to apply the annual growth rates by Poncet (2006), which were calculated prior to the advent of the financial crises, not for the whole 16 year time differential between 2004 and 2020, but only for a reduced ten year time span. This procedure should counterbalance the setbacks in growth prevailing in 2008 and 2009 and which will not – again based on the most recent information by EUROSTAT and others – come to a halt earlier than 2011.

For our analysis of the different bottom-up climate policies, the CGE model is programmed and solved in GAMS/MPSGE (Rutherford, 1999) utilizing the solver PATH.

3.3 Definition of policy scenarios

Having described the structure of the CGE model, and before using the model to analyze different climate policy scenarios, we outline the settings of our three different scenario families – a unilateral EU scenario group, a post-Kyoto agreement with a voluntary commitment by other countries in addition to the EU, as well as the spectrum of the IPCC's recommendation on GHG emission reductions for Annex I countries to the Kyoto Protocol. The unilateral EU policies are differentiated into targets for the ETS sectors only (as the current EU ETS) and with additional targets for non-ETS sectors and households, reflecting the EU 20-20 targets (European Commission, 2008). For both the post-Kyoto and the IPCC scenarios, we distinguish between a 'high' and a 'low' scenario, since reduction targets have been stated in ranges instead of a single number.

The first two scenarios in Table 3, ETS_EU and NETS_EU, refer to unilateral EU policies as set up by the EU20-20 objectives: under ETS_EU a 21% reduction target relative to 2005 CO_2 emission levels is implemented in all sectors which are included in the current EU ETS, namely the energy intensive industries (EIS), the power generation sector (ELY), and the petrochemical industry (P_C). In the NETS_EU setting, an additional 10% reduction target is introduced in the non energy intensive industries and for private households, again 2020 emission levels compared to 2005 emission levels. In both scenarios, the policies are implemented EU wide. For the ETS sectors we allow for an emission trading scheme with emission permits traded among all EU countries (leading to a common carbon price across Europe for these sectors). For the non-ETS sectors and the private households we do have national targets implying a national shadow price of carbon emission in these sectors that differs across countries.

Table 3: GHG emission reduction targets for 2020 relative to 2004

Region	ETS_EU	NETS_EU	PK_L	PK_H	IPCC_L	IPCC_H
sectors	ETS/NETS	ETS/NETS	ETS+NETS	ETS+NETS	ETS+NETS	ETS+NETS
EU	-20%/na	-20%/-9%	-21%	-31%	-26%	-41%
RUS			+48%	+39%	+23%	-2%
ROE			+4%	+3%	-44%	-51%
GUS			+22%	+22%	+18%	+9%
USA			-16%	-19%	-37%	-50%
NAM			-16%	-3%	-26%	-34%
LAM						
CHN						
EASI			-30%	-30%	-20%	-28%
SEASI						
SASI						
OCEA			-18%	-11%	-44%	-55%
MENA						
SSA						

Source: own calculation based on European Commission (2008); IPCC (2007); personal communication Andreas Tuerk (2009)

The remaining scenarios cover global policies with other world regions setting reduction objectives as well, albeit at different stringency levels. The two global post-Kyoto scenarios PK_L and PK_H presume that CO_2 emission reduction targets have been set voluntarily by many industrialized countries within a global agreement established at the Copenhagen Conference of the UNFCCC. The reduction targets depicted in Table 3 refer to the most recent, official country specific information (L is the lower and H the higher bound) on envisioned GHG reduction goals prior to the COP15 in Copenhagen.

While the post-Kyoto scenarios are the result of *voluntary* emission reduction targets by Annex I countries, the remaining two IPCC scenarios are based on the recommended -25% to -40% GHG emission cuts in all Annex I countries which are necessary to remain within the crucial +2C° target by 2100 compared to preindustrial periods (IPCC, 2007). While the IPCC acknowledges that a major deviation from baseline emissions will be necessary also within non-Annex I countries, no specific, official reduction targets have been communicated yet. As a consequence, reduction targets of non-Annex I countries will not be considered in the subsequent analysis.

In order to implement the officially announced GHG emission reduction objectives in our model, we recalculate the emission targets relative to the base year 2004. For example the reduction goal in the

ETS_EU scenario, which was a homogenous -21% reduction for all EU member states, slightly changed by country according to the changes in observed CO_2 emissions between 2004 and 2005, resulting in regional diversified targets for the base year 2004. Moreover, since there are no specific reduction targets announced for the specific regional aggregation adopted within this paper, we generated reduction objectives for the respective regions by weighing the reduction targets for Annex I with the base year emissions for both Annex I and non-Annex I countries within the respective regions.[2] Note that Russia's officially announced reduction target in a post-Kyoto agreement would amount to a 15% reduction vis a vis 1990 emissions in a high scenario. By changing the reference year from 1990 to 2004, the target changes from a reduction requirement to an increase in CO_2 emissions since Russia's 1990 CO_2 emissions were substantially higher than in 2004. Only in the strongest IPCC scenario – representing a 40% reduction of GHG in Annex I countries – Russia would be confronted with a minor effective reduction objective of 2% compared to 2004 CO_2 emissions. The same rationale holds for the rest of the GUS region.

4. The economic and carbon effects of the policy scenarios

As apparent from the previous section, one distinctive feature of the different scenarios is the regional scope – reaching from unilateral EU policies to broader ones which cover all Annex I countries. Since our analysis is based on plausible developments, none of the scenarios is of global scope with binding agreements also for developing countries. Another distinctive feature of the scenarios is the sectoral scope of the emission reduction obligations, with EU_ETS being limited to ETS sector emissions while all other scenarios require limitations for non-ETS sectors too. We will thus investigate the economic as well as the environmental ramifications on a global scale and illustrate our findings on the relevance of carbon leakage in this context.

4.1 The effects on GDP

To summarize the global effects of different climate policy scenarios on regional economic performance we utilize the GDP growth rate, which is presented for all regions and all scenarios in Table 4. The first column represents the regions' average annual GDP growth rates over the period 1999 to 2008, while the second column shows the growth rate under BAU assumptions. Compared to the 1999-2008 average growth rates, these 2020 GDP growth rates are in most cases lower, particularly for China, Latin America and Africa.

[2] For instance, the -8% CO_2 reduction goal for the rest of GUS results since only Belarus and the Ukraine have officially announced CO_2 objectives of -5% and -20%, respectively in a low reduction scenario (-10% and -20% for a high abatement scenario) prior to the Copenhagen climate talks, while emissions in all other GUS countries are allowed to grow without restrictions.

The impacts of climate policies on GDP growth rates per region are depicted in columns 3 to 8. In the ETS_EU and NETS_EU scenarios, only the EU is faced by binding emission constraints. In the ETS_EU scenario, almost no consequences on GDP growth rates arise for all other countries (reducing only the EU's annual average GDP growth rate by 0.2 percentage points due to EU wide emissions trading). In the NETS_EU scenario, where the EU restricts GHG emissions to a level of in total -14% below 2005 levels, stronger consequences for worldwide economic growth arise. These reduced growth rates are mostly triggered by high carbon prices in the NETS sectors. Moreover, while the ETS sector is responsible for approximately 13% of output and 40% of carbon emissions in the EU, the inclusion of the NETS sectors and households implies a much stronger reduction of final demand. Despite the negative economic consequences within the EU, the non-abating regions outside Europe are hardly negatively affected by an international multiplier of these slowdown of economic growth within the EU, some may even benefit by means of increasing exports to EU ETS sectors.

Table 4: Annual GDP growth rates for 2020 for the scenarios (2004-2020 average)

	1999-2008*	BAU 2020	ETS_EU	NETS_EU	PK_L	PK_H	IPCC_L	IPCC_H
EU	2.44	2.38	2.36	2.28	2.22	2.13	2.17	1.97
RUS	6.85	2.52	2.50	2.44	2.35	2.33	2.34	2.22
ROE	3.94	2.57	2.57	2.58	2.45	2.43	1.67	1.37
GUS	7.72	3.09	3.08	3.06	2.97	2.93	2.90	2.63
USA	2.62	2.57	2.57	2.57	2.46	2.44	2.28	2.02
NAM	2.95	2.91	2.91	2.92	2.70	2.69	2.58	2.44
LAM	3.50	1.32	1.32	1.32	1.31	1.31	1.31	1.28
CHN	9.76	5.90	5.91	5.90	5.90	5.89	5.89	5.85
EASI	1.89	2.43	2.43	2.43	2.23	2.22	2.30	2.23
SEAS	5.02	5.38	5.39	5.39	5.39	5.37	5.37	5.32
SASI	6.72	4.14	4.15	4.15	4.17	4.17	4.17	4.15
OCEA	3.18	2.99	2.99	2.99	2.84	2.69	2.53	2.22
MENA	5.10	1.78	1.79	1.77	1.69	1.68	1.69	1.65
SSA	4.16	1.16	1.16	1.15	1.12	1.11	1.11	1.07

* Source: IMF (2009)

Only when CO_2 emissions in all Annex I regions are affected by a more comprehensive global climate agreement (PK and IPCC scenarios), countries like the USA, Japan or Ukraine have to face lower GDP growth rates. This is triggered by increased costs of production due to climate policy (in our context carbon permits), but also by a shrinking demand for their exports by the other regulated regions. Even China, which carries no emission reduction obligation within any of our scenarios, looses in the IPCC_H scenario 0.05 percentage points in the annual average GDP growth rate due to global feedbacks of reduced demand even for Chinese exports.

4.2 The effects on sectoral output: competitiveness

To get a better understanding of the economic impacts, we focus now on the sectoral effects and distinguish for policy regions and non-policy regions. In the two unilateral EU scenarios, only the EU constitutes the policy region, while in the post-Kyoto and the IPCC scenarios additional regions become policy regions (ROE, GUS, RUS, NAM, USA, EASI, OCEA).

Starting with the unilateral EU policies, Figure 1 illustrates the effects on sectoral output in policy regions and non-policy regions. In the policy regions, ETS sectors (petro chemicals P_C, electricity ELY and energy intensive sectors EIS) as well as primary energy products are more strongly affected by any policy than most non-ETS sectors. Moreover, the NETS_EU scenario has considerable stronger competitiveness impacts than the ETS_EU scenario, due to the broader regional coverage. Regarding non-policy regions, production in some sectors (namely energy intensive sectors, petrochemicals and transport) increases on account of a shift in production from policy regions which now import carbon intensive products. However, some sectors are also negatively affected in non-policy regions, such as non energy intensive products. In total, global output falls by 0.2% and 0.6% respectively compared to BAU. Therefore, gains in non-policy regions are more than outweighed by losses in policy regions.

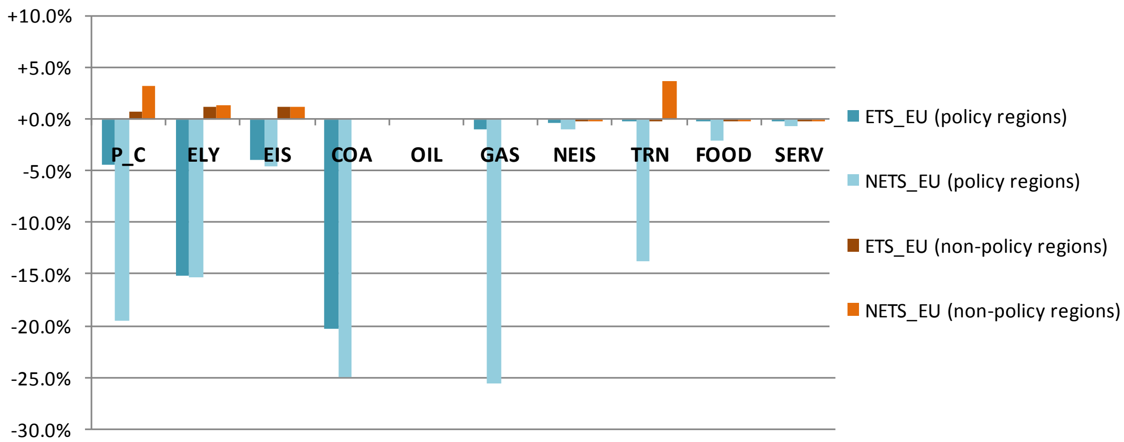

Figure 4: Sectoral output effects of unilateral EU policies

By moving to a regionally broader policy approach (scenarios PK and IPCC), the stronger the impact on output in policy regions become, ranging in total from -3.5% to -8.5% for all policy regions. At the sectoral scale, Figure 5 reveals that the effects are spread more equally across sectors, with particularly strong repercussions on energy intensive sectors. Even though non-policy regions benefit by increased sectoral output in some sectors, other sectors experience negative repercussions due to decreased global demand (non-energy intensive products, services, and food). Thus, disregarding the benefits of reduced carbon emissions, the more stringent the global emission target, the higher are the costs in terms of global output: with -6.5% less global output under the IPCC high scenario compared to BAU.

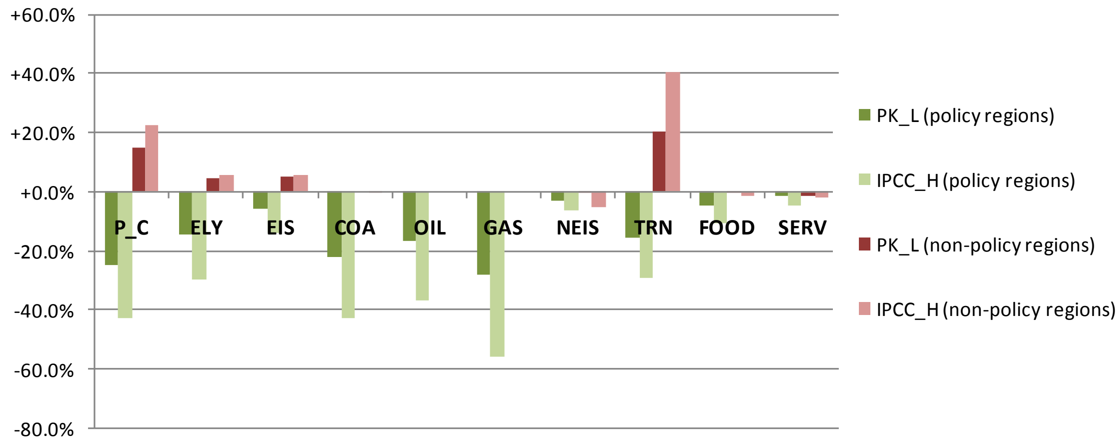

Figure 5: Sectoral output effects of post-Kyoto and IPCC scenarios

4.3 The carbon markets: carbon prices and decarbonization

The carbon prices (i.e. permit prices in ETS sectors) for the different policy scenarios are presented in Table 5. When CO_2 emissions are also limited in non-ETS sectors and for private households (scenario NETS_EU), the EU ETS permit price decreases to 124 USD/tCO_2, due to reduced production triggered by the falling demand by the henceforth constrained NETS sectors and private households. The CO_2 (shadow) prices in non-ETS sectors and for households, depicted in Table 6, are notably higher than the ETS permit prices. This is due to the more difficult reduction of CO_2 emissions found in reality for private households and non-energy intensive sectors – most prominently emissions related to transport.

Table 5: CO_2 prices in ETS sectors per policy implementing region

	ETS_EU	NETS_EU	PK_L	PK_H	IPCC_L	IPCC_H
ETS sectors						
EU	130	124	100	166	135	282
RUS	-	-	-	-	13	35
ROE	-	-	36	38	245	310
GUS	-	-	-	-	4	12
USA	-	-	84	95	229	410
NAM	-	-	120	119	184	251
EASI	-	-	195	188	112	162
OCEA	-	-	63	130	209	338

When moving from scenarios in which emission constraints are introduced only within the EU, to the more comprehensive post-Kyoto scenarios, the EU ETS permit prices experience another drop from the above mentioned 124 USD/tCO_2 to 100 USD/tCO_2. This effect is triggered on the one hand by more efficient production processes as a response to stricter emission constraints and on the other hand by a shrinking foreign demand from countries which were previously not affected by climate policies. As more ambitious reduction targets are introduced in the scenarios, emission permits become more expensive – both in ETS and non-ETS sectors.

Table 6: CO_2 (shadow) prices in non-ETS sectors and for households per policy implementing region

	NETS_EU	PK_L	PK_H	IPCC_L	IPCC_H
Non-ETS sectors					
EU	345	646	951	801	1,446
RUS	-	226	239	1,381	1,760
ROE	-	-	-	12	58
GUS	-	25	23	40	56
USA	-	329	366	808	1,439
NAM	-	250	245	345	437
EASI	-	756	744	502	688
OCEA	-	480	872	1,351	2,136

Eastern European regions (ROE and GUS) and Russia can be identified as the cheapest destination for emission reduction, since these countries are characterized by highly carbon intensive production processes in the base year 2004, leaving enough space for efficiency improvements for 2020. This conjecture can be confirmed by an analysis of CO_2 intensities in the different regions and sectors and leads to the question whether the introduction of climate policies accelerates the decarbonization of societies. Figure 6 compares the carbon intensities, or the CO_2 coefficients, per country and sector for the year 2020 under BAU, which were calculated as the total carbon input in the various production processes divided by total value of output of the respective sector. These CO_2 coefficients differ quite substantially across regions, with the highest differences in the electricity, and energy intensive sectors. It is striking that CO_2 intensities in these sectors are by far highest in China, followed by Southeast Europe, Russia and the developing countries in Asia and Africa, reflecting the disproportionally high CO_2 intensities in these countries' production methods. While the EU's EIS sector for example emits 248 tCO_2 per MUSD output, the GUS region emits 30 times as much CO_2 for the same amount of output.

The imposition of the different climate policy targets trigger a more efficient use of fossil fuels in production relative to BAU 2020. By pricing carbon, industries as well as private households have an incentive to reduce their carbon emissions either by directly reducing the fossil fuel consumption or by raising energy efficiency. In our model, this decarbonization effect is visible by a drop in region and sector specific CO_2 coefficients, as illustrated for the petro-chemical sector in Figure 7. Both the

PK and IPCC scenarios lead to improvements in energy efficiency in all Annex I countries, namely USA, the remaining North America, Oceania (i.e. Australia, New Zealand), East Asia (i.e. Japan), and all EU countries. In contrast, all other regions, namely Russia, China and the remaining American, Asian and African regions, do not experience any considerably improvements compared to BAU 2020. The effect of the NETS_EU scenario (and similarly for the ETS_EU scenario, not depicted in Figure 7) on improved energy efficiency is only apparent for the EU countries, showing the limited scope of solving a global problem unilaterally.

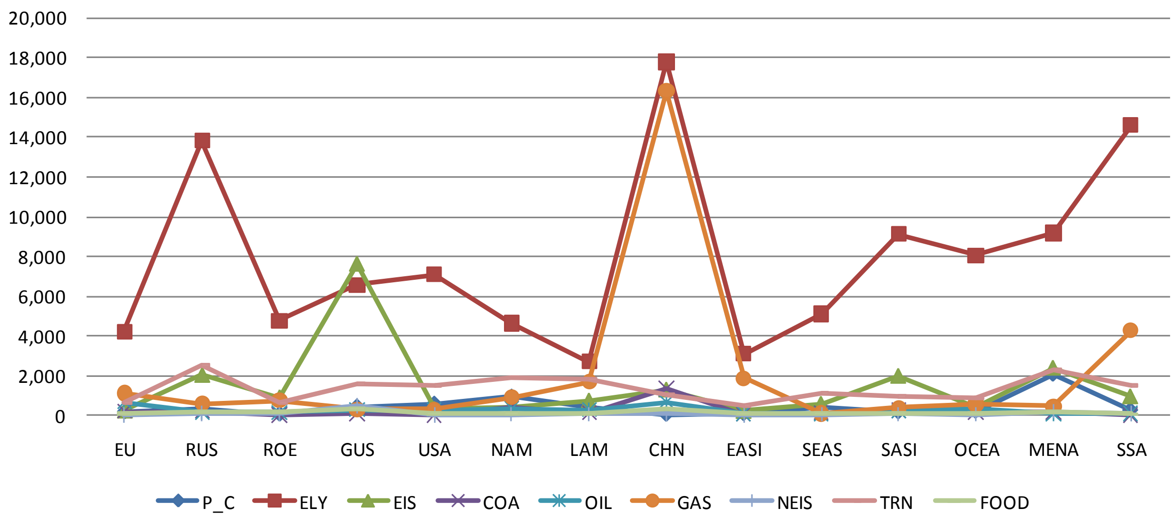

Figure 6: CO_2 intensities for BAU 2020 across countries and sectors (t CO_2/MUSD)

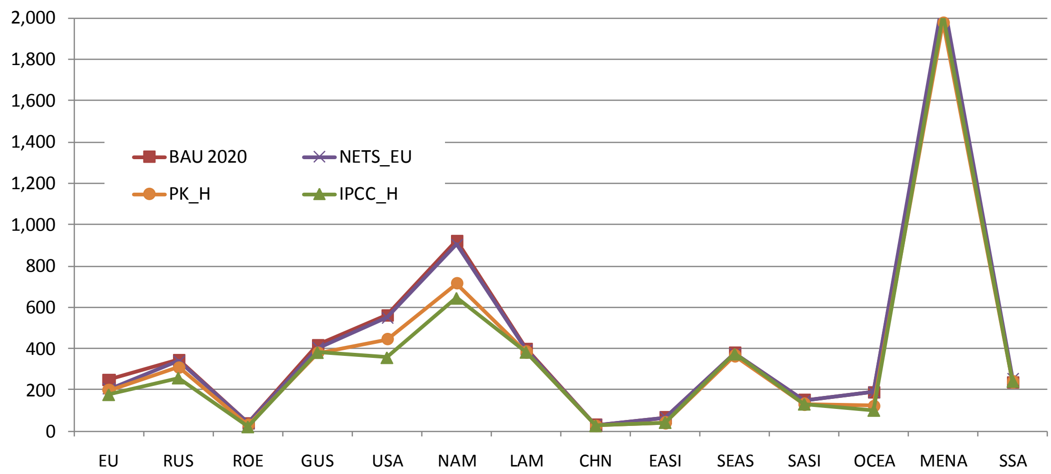

Figure 7: CO_2 intensities for P_C sectors across countries and scenarios (t CO_2/MUSD)

4.4 Global carbon emissions: the question of environmental effectiveness

The resulting development of global CO_2 emissions under the different scenario assumptions is presented in Table 7 (relative to BAU 2020).

Table 7: Change in emissions (in %) relative to BAU

	BAU 2020	ETS_EU	NETS_EU	PK_L	PK_H	IPCC_L	IPCC_H
EU	5,156	-12.6%	-28.7%	-32.2%	-40.6%	-36.5%	-49.0%
Eastern Europe	3,601	+3.3%	+5.5%	+6.1%	+6.8%	-3.6%	-18.7%
NAM (incl. USA)	8,893	+0.6%	+1.9%	-31.1%	-33.2%	-47.0%	-57.1%
LAM	1,132	+0.8%	+3.1%	+15.1%	+16.6%	+17.3%	+21.9%
CHN	6,830	+0.8%	+1.1%	+6.0%	+6.2%	+5.9%	+6.4%
ASIA (excl. CHN)	5,286	+1.0%	+2.6%	-8.8%	-8.4%	-4.9%	-6.3%
OCEA	528	+1.5%	+2.6%	-32.6%	-45.7%	-53.9%	-63.0%
AFRICA	2,736	+3.0%	+6.0%	+18.0%	+19.8%	+20.8%	+28.0%
Total	34,163	-0.8%	-2.0%	-11.0%	-12.7%	-16.3%	-21.9%

As revealed by Table 7, emissions in the presence of climate policies compared to BAU fall quite significantly in most regions. The EU's CO_2 emissions reduction would increase from 12.6% in the ETS_EU scenario to 49.0% compared to 2020 BAU assumptions. Even in North America (including USA), where emissions would rise in the two EU scenarios due to carbon leakage even more than under BAU, CO_2 emissions would fall by 57.1% in the strict IPCC_H setting compared to BAU. However, the development of emissions in China, Latin America and Africa is quite different: For China, CO_2 emissions would be subject to an even more accelerated growth than under BAU premise, fostering emission growth by 6.4% in the IPCC_H scenario relative to BAU. For Africa and Latin America these carbon leakage induced CO_2 effects are even stronger, though these regions are starting from substantially lower CO_2 emissions in the base year 2004 – 1,087 Mt CO_2 for LAM and 2,573 Mt CO_2 for Africa compared to 4,853 for China (Table 7).

As a consequence, total global CO_2 emissions growth can be slowed down by introducing climate policies aiming at a reduction in CO_2 emissions; but only in the most stringent IPCC_H scenario, representing a 40% GHG emission cut in Annex I regions (about 50% of global emissions), emissions in 2020 can be reduced below the base year level of 2004 (see Figure 8). Global CO_2 emissions under BAU 2020 are 23% above CO_2 emissions in 2004.[3] In the least stringent scenario (ETS_EU), 2020 emissions increase in *all* regions compared to 2004, including the abating region (EU). This follows

[3] Compared to the scenario families presented by the IPCC (Fisher et al., 2007) our model's BAU results would blend in among the medium sphere of the IPCC emission scenario range until 2020.

from a relatively stronger increase of CO_2 emissions by not yet regulated non-ETS sectors and private households, which outweigh emission reductions in the ETS sectors. These higher non-ETS emissions in the EU can be overcome by incorporating the non-ETS sectors and the private households into the EU's abatement efforts. When moreover also all other Annex I regions are subject to emission constraints (starting with PK_L) climate policies become more successful in reducing emissions on a global scale. A major contribution originates from the regulation of CO_2 emissions in North America (incl. USA), though these efforts are still outperformed by increasing CO_2 emissions in China. Thus, on a global scale, even in the IPCC_L scenario the decrease of CO_2 emissions in abating regions is still more than counterbalanced by emission increases elsewhere; only in the most stringent scenario analyzed within this paper (IPCC_H) this tendency can be overcome. Thus, with the exception of the strong reduction targets applied under the IPCC_H scenarios, none of the scenarios is sufficient to reduce emissions below 2004 levels.

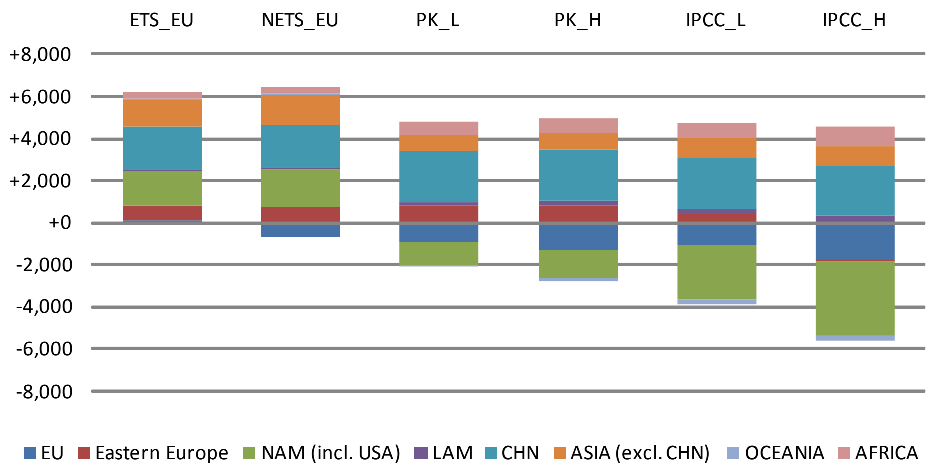

Figure 8: Change in CO_2 emissions (in Mt CO_2) per region and per scenario relative to 2004

5. Carbon leakage and border tax adjustments

One obvious argument why all but one of the scenarios studied fail the goal of reducing global carbon emissions below 2004 levels, is the phenomenon of carbon leakage. Unless carbon emissions are regulated in some but not all countries, a partial offset of GHG emissions reduction in some countries by emission increases elsewhere is argued on account of a relocation of production to regions not facing mitigation policies. In this section, we will address the scope of this problem, and the effectiveness of border tax adjustments to solve it under the presumption of the two unilateral EU policy scenarios.

5.1 Carbon leakage: the macroeconomic scale

We start by comparing the carbon emissions in GHG abating countries – the policy-regions – to those in non-abating or non-policy regions. Table 9 reveals the difference between policy regions' and non-policy regions' 2020 emissions in the respective scenarios and their respective CO_2 emissions in BAU 2020.

Table 1: Climate policies and carbon leakage - Global CO_2 effects relative to 2020 (in Mt CO_2)

	BAU	ETS_EU	NETS_EU	BAU	PK_L	PK_H	IPCC_L	IPCC_H
CO_2 emissions								
policy regions	5,156	4,507	3,679	20,556	15,316	14,649	13,412	11,124
non-policy regions	29,007	29,382	29,805	13,607	15,076	15,178	15,180	15,544
Total	34,163	33,890	33,484	34,163	30,392	29,827	28,593	26,668
Change relative to 2020								
policy regions		-649	-1,478		-5,241	-5,907	-7,144	-9,432
non-policy regions		+375	+799		+1,469	+1,571	+1,574	+1,937
2020 Total		-274	-679		-3,771	-4,336	-5,571	-7,495
Leakage rate 2020		*-58%*	*-54%*		*-28%*	*-27%*	*-22%*	*-21%*

The first salient conclusion from Table 9 is that in the ETS_EU as well as the NETS_EU settings only about one sixth of the world's 2020 CO_2 emissions under BAU assumptions would be regulated by climate policies. Therefore even under the successful implementation of the EU 20-20 targets in the NETS_EU scenario, the EU's CO_2 emissions would be reduced by 14% compared to 2005 emissions, but the total global emissions in 2020 under the NETS_EU scenario would still be only 0.4 Gt CO_2 below BAU. Under a more comprehensive climate policy agreement comprising all Annex I countries of the UNFCCC Kyoto Protocol – represented by the two post-Kyoto and IPCC scenarios – more fundamental reduction achievements could be obtained, since more than 50% of global 2004 CO_2 emissions would be regulated in such a policy framework. But only in the most stringent policy scenario – IPCC_H with a reduction of Annex I regions' emissions by 40% until 2020 compared to 1990 levels – the global net effect would be a decline in emissions compared to 2005 levels.

In addition to the absolute levels of emission effects in policy and non-policy regions, we are interested in the amount of carbon emissions leaking by production shifts to other regions, hence counteracting the emission reductions in the abating countries. Figure 7 compares the abating regions' CO_2 reduction achievements relative to BAU 2020 to the increase of CO_2 emissions in the regions not facing GHG emission constraints. Following the `strong' definition of carbon leakage, the rate of carbon leakage can be calculated as the ratio of the increase of CO_2 emissions beyond BAU in non-abating regions to the emission reductions in the abating regions (see bottom line of Table 1). The derived carbon leakage rates are particularly high in the ETS_EU and the NETS_EU scenario (58% and 54% respectively). Thus, due to the fact that only a small fraction of global CO_2 emissions is under control in these unilateral EU scenarios, more than half of the emission reduction within the EU is counteracted by ancillary emission increases above BAU in non-abating countries. Accordingly, the more stringent and comprehensive the climate policies become, the fraction of abated CO_2 emissions which is offset in non-abating regions declines. But even in the most stringent and comprehensive climate policy scenario IPCC_H, carbon leakage amounts to 21%.

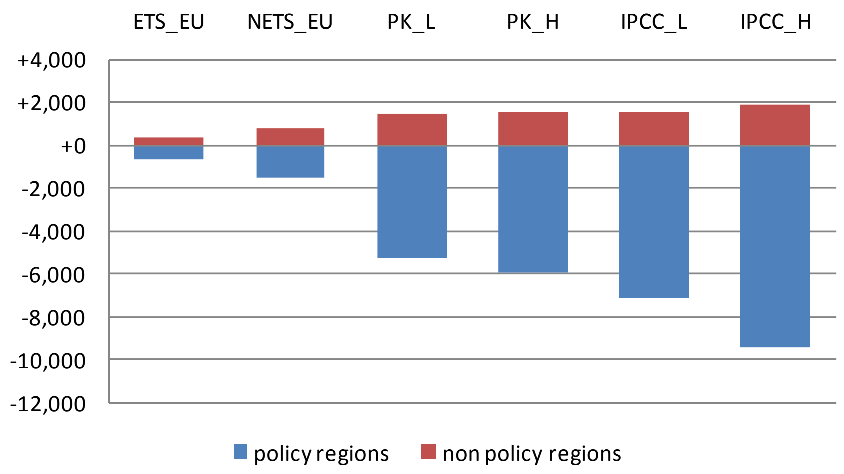

Figure 9: CO_2 effects (in Mt CO_2) in policy and non-policy regions relative to BAU 2020

5.2 Carbon leakage: the sectoral scale

Based on the evidence on the macroeconomic leakage effects, the question arises on the sectoral differences within and between regions. Within the policy regions, the sectors most affected (in absolute terms) by emission constraints are the two ETS sectors ELY and EIS as well as the non-ETS sector TRN and in the more stringent/comprehensive scenarios also the SERV sector (see Figure 10). By analyzing the effects of the ETS_EU scenario we can see that the ETS emissions in the abating region (here the EU) fall quite significantly as well as due to feedback effects of not restricted sectors' emissions growing less strong than under BAU. The non-policy regions' emissions on the other hand react in the exact opposite way. Part of the ETS production relocates to non abating regions, depicted by higher emissions compared to BAU in the P_C, the ELY and the EIS sector. As for sectoral output effects, sectoral CO_2 emission reductions are considerably larger under the regionally more comprehensive scenarios (see Figure 11).

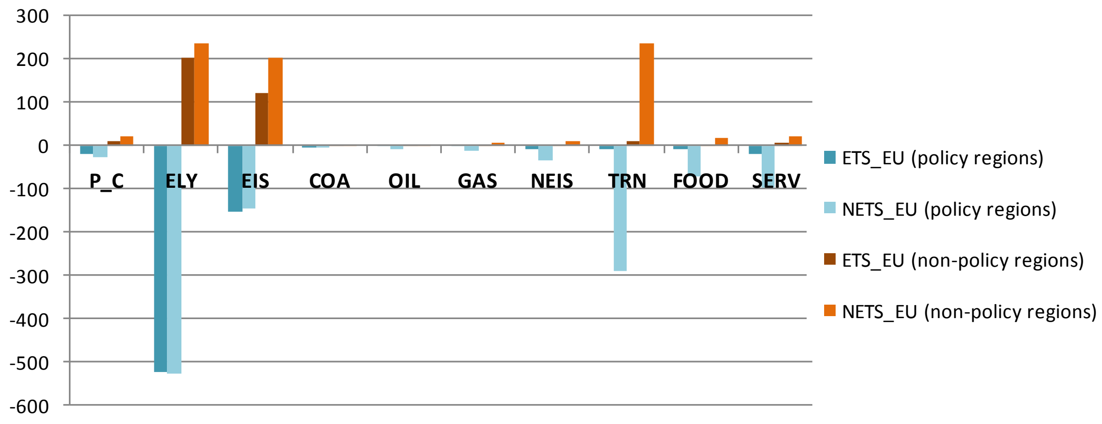

Figure 10: Sectoral CO_2 effects (in Mt CO_2) of unilateral EU policies relative to BAU 2020

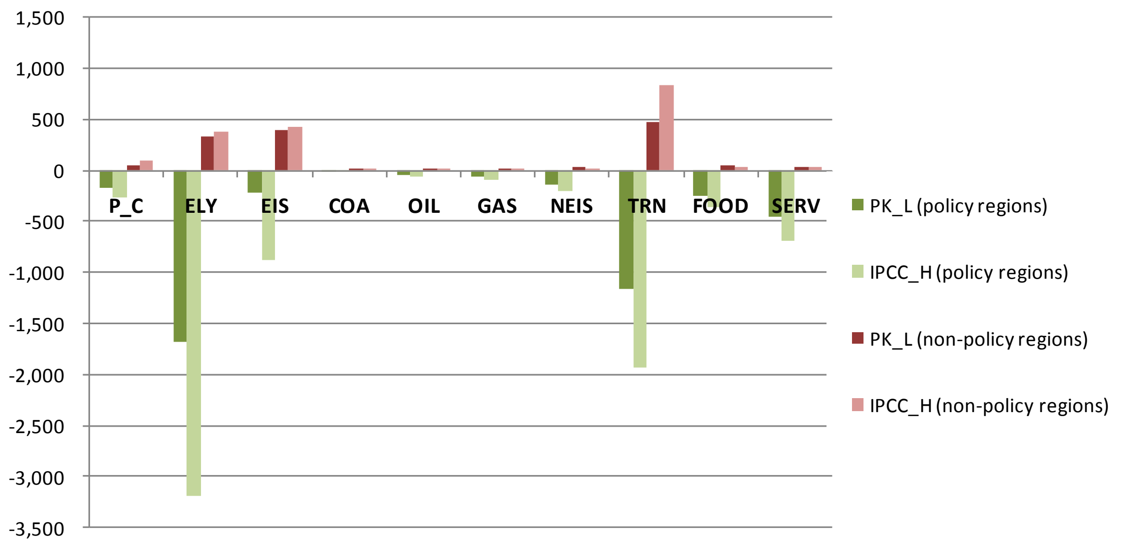

Figure 11: Sectoral CO_2 effects (in Mt CO_2) of post-Kyoto and IPCC policies relative to BAU 2020

These regional and sectoral movements of CO_2 emissions are reflected also in the sectoral leakage rates presented in Table 2. In the ETS_EU case the TRN sector corresponds to a leakage rate of 128%, followed by the EIS sector with 78% and the P_C sector with 50%. The high leakage rates in the TRN sector as well as the primary energy sectors (COA, OIL, GAS) can be traced back to the intermediate input character of theses commodities in the ETS production. Therefore lower ETS production in abating regions triggers lower intermediate inputs, resulting in lower emissions also within these intermediate sectors (and in opposite direction in non-abating regions).

The more stringent and comprehensive emission reduction objectives are obtained in the scenarios, the smaller not only the total leakage rate becomes but also the lower the sectoral leakage rates tend to be. For instance, the leakage rate of the EIS sector in the IPCC_H scenario is only 49%, compared to 141% in the NETS_EU scenario. This is due to the fact that for both PK and IPCC scenarios all Annex I regions are subject to CO_2 emission constraints and that therefore domestically reduced emissions cannot be shifted across borders in such high volumes anymore as with the EU unilateral scenarios.

Table 2: Sectoral carbon leakage rates

	ETS_EU	NETS_EU	PK_L	PK_H	IPCC_L	IPCC_H
	Leakage rate relative to BAU 2020					
Sectors						
ETS sectors						
P_C	-50%	-79%	-29%	-31%	-29%	-36%
ELY	-39%	-45%	-20%	-18%	-14%	-12%
EIS	-78%	-141%	-183%	-132%	-83%	-49%
Non-ETS sectors						
COA	-115%	-45%	-90%	-78%	-63%	-44%
OIL	136%	-47%	-24%	-22%	-20%	-19%
GAS	736%	-46%	-14%	-13%	-12%	-12%
NEIS	-52%	-32%	-28%	-23%	-18%	-8%
TRN	-128%	-81%	-41%	-43%	-38%	-43%
FOOD	-51%	-27%	-19%	-17%	-15%	-12%
SERV	-35%	-21%	-7%	-6%	-6%	-4%
Total	**-58%**	**-54%**	**-28%**	**-27%**	**-22%**	**-21%**

5.3 Border tax adjustments

Having seen that both the macroeconomic and the sectoral leakage rates are highest for the two unilateral EU policy scenarios ETS_EU and NETS_EU, we will discuss the question of compensating policies in case that the EU is left with a unilateral climate policy, such as a continuation of EU ETS or an expansion towards non-ETS sectors and households. One approach discussed is border tax adjustment to reduce carbon leakage and increase competitiveness for European industries. To set up such a measure, we follow the established literature and assume that the EU imposes import taxes which are based on sectoral carbon intensities in the originating countries (Kuik and Hofkes, 2010; Hertel et al., 2009). Thus, the additional import taxes are calculated as the product of sectoral carbon intensities (carbon emission per value of sectoral output in exporting country) and the carbon price in the importing country. To derive import taxes as a rate, this value is then divided by import prices (c.i.f.). Under the ETS_EU scenario, additional import taxes are thus applied on EU imports in P_C, ELY and EIS sectors, while under NETS_EU additional import taxes are applied on imports in all sectors.

Table 3 illustrates that the imposed carbon based import tax, depicted here for the ETS_EU scenario, can be substantial, particularly for imports from China and Eastern Europe. Moreover, some countries are faced for the first time with import taxes.

Table 3: Import tax rates (BTA) for imports to EU (ETS sectors only) under ETS_EU +BTA scenario

	Additional import tax (BTA)			**Original import tax**		
	P_C	ELY	EIS	P_C	ELY	EIS
Eastern Europe						
RUS	0.05	1.77	0.35	0.03	0.00	0.01
ROE	0.01	0.52	0.14	0.00	0.00	0.00
GUS	0.06	0.70	1.18	0.00	0.00	0.02
NAM (incl. USA)						
USA	0.08	0.88	0.05	0.02	0.00	0.02
NAM	0.13	0.58	0.06	0.03	0.00	0.01
LAM	0.05	0.33	0.12	0.00	0.01	0.01
CHN	0.00	2.20	0.23	0.00	0.00	0.04
ASIA (excl. CHN						
EASI	0.01	0.41	0.04	0.02	0.00	0.02
SEAS	0.05	0.68	0.10	0.01	0.00	0.01
SASI	0.02	1.11	0.32	0.00	0.00	0.01
OCEA	0.03	1.04	0.07	0.01	0.02	0.01
AFRICA						
MENA	0.28	1.12	0.37	0.01	0.04	0.01
SSA	0.03	1.84	0.15	0.00	0.00	0.00

In contrast to some earlier studies (e.g. Kuik and Hofkes, 2010; McKibbin and Wilcoxen, 2009), and not astonishing given the high rates of carbon based import taxes, Table 4 and Figure 12 show that the border tax rates according to Table 3 are effective in reducing negative output effects in those sectors most affected by climate policy, e.g. in the petrochemical and energy intensive sectors (i.e. increasing competitiveness in Europe). On the downside, however, output in other EU sectors such as non-energy intensive products and transport falls more than without BTA, since the need for sectoral restructuring is less pronounced compared to BAU (see Figure 12). Another factor causing this more pronounced decline in output can be traced back to the higher import prices leading to cost increases in downstream sectors (see e.g. Houser et al., 2009). As a consequence, total output in the EU falls more than without BTA. This final result is also driven by the fact that decarbonization of the EU economy is reduced by BTA since the ETS sectors are now faced with less severe competition from imports due to the tax.

Table 4: Effects of BTA on output in selected sectors and countries, relative to BAU 2020

Sectors/	Scenario	EU	Eastern Europe	NAM (incl. USA)	LAM	CHN	ASIA (excl. CHN)	OCEA	AFRICA
		change relative to BAU 2020 (in %)							
P_C	ETS_EU	-4.5%	+2.1%	+0.4%	+0.5%	+0.5%	+0.5%	+0.2%	+1.4%
	+ BTA	-3.4%	+0.7%	+0.6%	+0.4%	+0.5%	+0.6%	+0.4%	+0.2%
	NETS_EU	-20.2%	+6.4%	+2.8%	+2.6%	+1.9%	+3.2%	+2.4%	+4.3%
	+ BTA	-23.5%	+5.2%	+2.9%	+2.0%	+2.0%	+3.4%	+2.7%	+2.8%
EIS	ETS_EU	-3.9%	+5.8%	+0.9%	+1.2%	+0.6%	+0.9%	+1.4%	+3.8%
	+ BTA	-2.5%	-0.2%	+0.6%	+0.2%	-0.1%	+0.3%	+1.2%	+1.5%
	NETS_EU	-4.7%	+10.7%	+0.7%	+1.2%	+0.6%	+0.3%	+0.7%	+7.0%
	+ BTA	-3.9%	+6.3%	+0.5%	+1.1%	+0.1%	-0.2%	+0.7%	+5.9%
NEIS	ETS_EU	-0.4%	-0.2%	-0.0%	-0.2%	-0.1%	-0.2%	+0.3%	+0.4%
	+ BTA	-1.4%	+2.5%	+0.0%	+0.4%	+0.4%	+0.1%	+0.6%	+1.8%
	NETS_EU	-1.1%	+0.8%	-0.0%	-0.0%	-0.3%	-0.9%	+0.2%	+3.1%
	+ BTA	-2.5%	+4.5%	+0.2%	+1.4%	+0.4%	-0.4%	+0.6%	+5.4%
TRN	ETS_EU	-0.2%	-0.0%	+0.0%	-0.2%	-0.0%	-0.1%	+0.0%	+0.2%
	+ BTA	-0.8%	+0.7%	+0.1%	+0.1%	+0.0%	-0.1%	+0.1%	+0.6%
	NETS_EU	-13.9%	+5.6%	+2.7%	+5.7%	+2.2%	+3.7%	+2.9%	+7.8%
	+ BTA	-15.2%	+4.4%	+2.0%	+2.7%	+1.7%	+3.1%	+2.4%	+4.8%
total output	ETS_EU	-1.7%	+1.3%	+0.2%	+0.2%	+0.1%	+0.1%	+0.5%	+0.7%
	+ BTA	-1.9%	+0.8%	+0.2%	+0.2%	+0.2%	+0.2%	+0.5%	+0.7%
	NETS_EU	-4.6%	+3.5%	+0.6%	+0.8%	+0.2%	+0.2%	+0.7%	+2.6%
	+ BTA	-5.1%	+3.2%	+0.6%	+1.0%	+0.4%	+0.3%	+0.8%	+2.6%

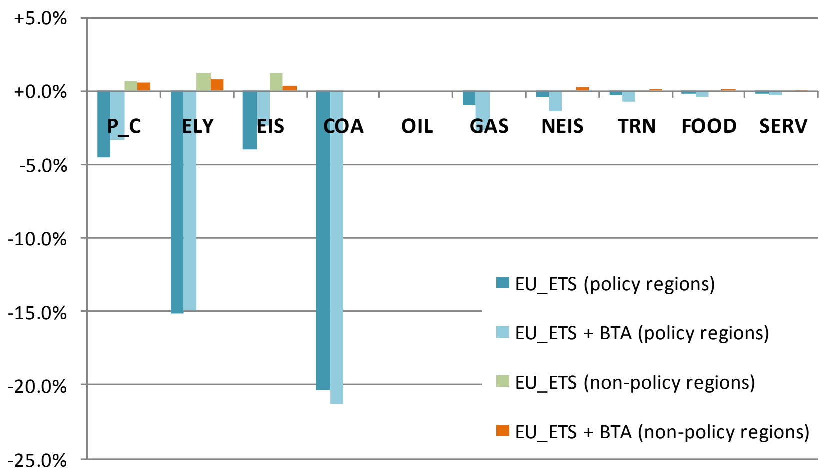

Figure 12: Sectoral output effects (in Mt CO_2) of unilateral EU policies with BTA relative to BAU 2020

Regarding the claimed effectiveness in reducing carbon leakage, we find that this is in fact the case at the macroeconomic scale, and particularly so for the ETS_EU scenario (see Table 5). Leakage is also reduced in ETS sectors, but increased in most non-ETS sectors including primary energy products, which is also evident from Figure 13. This counter-acting effect is particularly strong under the

NETS_EU scenario where all sectors and households are faced by emission constraints in the EU. Thus, border tax adjustments can be effective when a small number of countries implements emission reduction targets *and* only some sectors are regulated while others are not. Moreover, the carbon based import tax rates applied in our model are substantial, and with smaller rates e.g. based on domestic (i.e. EU) or best available technology, the effectiveness to reduce both competitiveness effects and carbon leakage are considerably smaller.

Table 5: Sectoral carbon leakage rates (relative to BAU 2020)

	ETS_EU	NETS_EU	ETS_EU + BTA	NETS_EU + BTA
Sectors				
P_C	-50%	-79%	-42%	-65%
ELY	-39%	-45%	-33%	-39%
EIS	-78%	-141%	-25%	-111%
COA	-115%	-45%	-179%	-71%
OIL	136%	-47%	183%	-66%
GAS	736%	-46%	-1000%	-62%
NEIS	-52%	-32%	-148%	-60%
TRN	-128%	-81%	-198%	-73%
FOOD	-51%	-27%	-101%	-35%
SERV	-35%	-21%	-63%	-28%
Total	**-58%**	**-54%**	**-47%**	**-49%**

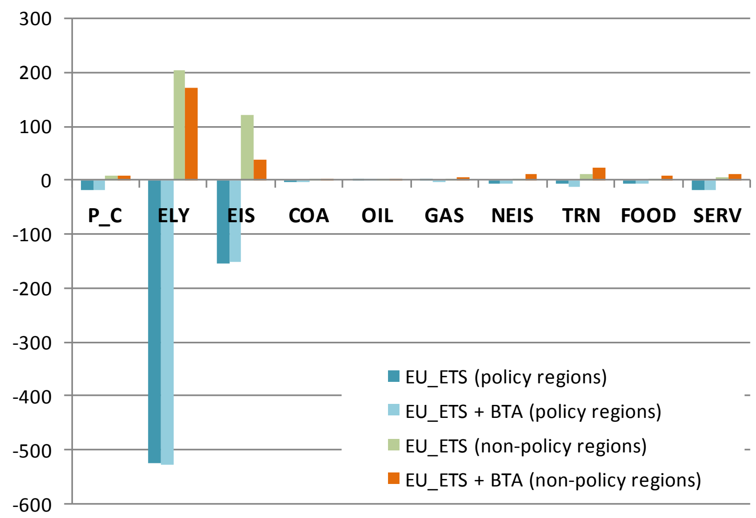

Figure 13: Sectoral CO_2 effects (in Mt CO_2) of unilateral EU policies with BTA relative to BAU 2020

6. Conclusions

Within our CGE model of the EU economy and its main trading partners, we analyzed the consequences of three types of climate policy scenarios relative to a business as usual (BAU) scenario for 2020, namely two unilateral EU climate policies, analytically separating a policy for the ETS sectors only (ETS_EU) or also for non-ETS sectors and households (NETS_EU); a voluntary post Kyoto agreement of Annex I countries (PK_L, PK_H); and a compulsory global agreement for Annex I countries, with reduction targets as identified by the IPCC's 4th Assessment Report to reach the +2° temperature target by 2100 (IPCC_L, IPCC_H). Our main findings can be summarized as follows.

In scenario ETS_EU, the European Union implements an emissions trading scheme in the energy intensive sectors (ETS sectors, namely P_C, ELY, EIS) only, but the other countries do not limit their emissions. This leads to a reduction in EU's GDP by 0.2% relative to BAU. When the European Union extends its climate policy also to the non-ETS sectors and households but the other Annex I countries still do not reduce their emissions, effects on GDP are more than doubled. The post Kyoto scenarios PK_L and PK_H with voluntary reduction commitments also by other Annex I countries, further intensify the economic consequences for GDP, exports, and imports. Finally, under the IPCC scenarios which constitute, according to the IPCC Fourth Assessment Report, the necessary reduction targets for Annex I countries to remain within the +2° temperature target (compared to pre-industrial levels) by 2100, GDP is up to 8.0% lower than under BAU and exports and imports fall by up to 12.5% and 8.6% respectively. Thus, under all scenarios Austrian international trade is affected more strongly than its domestic production.

At the global scale, effects on GDP depend on how universal emission targets are set, both in terms of sectoral and regional coverage. In both unilateral EU policy scenarios, hardly any GDP effects arise for regions and countries outside the EU. When all Annex I regions face constraints, also GDP growth rates of the US and Oceania decline. Regarding worldwide CO_2 emissions, the BAU scenario is characterized by 34.2 Gt CO_2, already adjusted for economic slowdown due to the current economic crisis, compared to 27.7 Gt CO_2 in 2004.

When the EU introduces binding targets for ETS and non-ETS sectors and households but all other countries do not commit themselves, only 1/6th of global emissions are regulated (= EU 20-20 target) and global emissions still rise by 5.8Gt CO_2 above 2004 levels. Even under the more stringent post Kyoto (PK_L and PK_H) and the IPCC_L scenarios global emissions cannot be reduced under 2004 levels: emissions increase by 0.9 Gt CO_2 to 2.7 Gt CO_2 compared to 2004, since Annex I countries only comprise slightly more than 50% of global emissions (according to the PBP). Only in the most stringent policy scenario that we analyzed within this paper – IPCC_H, where Annex I countries are constrained to reduce their CO_2 emissions by 40% compared to 1990 levels by 2020 – global CO_2 emissions can be mitigated strong enough to fall by 1 Gt CO_2 under 2004 levels.

Regarding carbon leakage, we find that for the unilateral EU policies almost half of the emission reductions realized in the EU are offset by emission increases elsewhere. When also all other Annex I countries restrict their emissions, carbon leakage is still above 20%. Thus, for achieving a stabilization of GHG emissions, a global solution, top down or not, is still an essential prerequisite which was also acknowledged by the Copenhagen Accord.

At the sectoral level, both competitiveness and carbon leakage can pose a problem for sectors which are energy intensive and trade exposed. Measures to protect these industries such as the fiercely discussed border tax adjustments might reduce the risks of both within these sectors, but trigger counteracting effects in other sectors. Furthermore, raising the costs of imports in the respective sectors reduces the incentive to improve energy efficiency within these sectors and increases the costs to other sectors downstream. In addition to that, the transaction costs associated with identifying the suitable import tax rates in practice are likely to further reduce the benefits of border tax adjustments.

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Appendix

Table 13: Elasticities in production

Sector	*s*	*int*	*elke*	*elk*	*elc*	*elcl*	*elqd*	***tela**$_{es}$*
COA	0.73	0.31	0.55	0.14	0.16	0.07	0.25	3.05
OIL	0.73	0.31	0.55	0.14	0.16	0.07	0.25	5.20
GAS	0.73	0.31	0.55	0.14	0.16	0.07	0.25	10.76
P_C	0.00	0.39	0.26	0.46	0.16	0.07	0.25	2.10
ELY	0.00	0.39	0.26	0.46	0.16	0.07	0.25	2.80
EIS	0.63	0.00	0.30	0.32	0.16	0.07	0.25	3.21
NEIS	0.56	0.49	0.49	0.15	0.16	0.07	0.25	3.71
TRN	0.35	0.33	0.28	0.31	0.16	0.07	0.25	1.90
FOOD	0.36	0.00	0.46	0.2	0.16	0.07	0.25	2.39
SERV	0.58	0.00	0.48	0.29	0.16	0.07	0.25	1.91
Final Demand	0.20	1.00	-	-	0.50	1.00	-	

*Source: * Okagawa and Ban (2008), Beckman and Hertel (2009); ** GTAP (2007)*

Table 14: Elasticities in import structure

Elasticity	value	Elasticity	value
elim	8	*n*	4
m	4	*rg*	4

Source: Rutherford and Paltsev (2000)

Table 15: Annual Growth rates 2004 – 2020

Regions	MFP*	Capital stock*	labor force*
AUT	1.30	1.40	-0.20
GER	1.50	1.60	-0.10
ITA	1.30	1.10	-0.50
WEU	1.40	1.60	-0.03
SEEU	1.40	2.00	-0.40
NEU	1.40	2.50	0.20
ROE	1.50	1.80	0.30
RUS	1.50	1.80	0.30
GUS	1.50	1.80	0.30
CHN	2.60	5.70	0.10
EASI	1.50	2.20	-0.30
SEAS	2.70	5.20	0.60
SASI	2.10	4.40	0.80
USA	1.50	2.60	0.70
NAM	1.60	2.60	0.50
LAM	0.50	1.40	0.70
OCEA	1.60	3.00	0.50
MENA	0.90	1.10	1.00
SSA	0.50	0.90	0.50

**based on Poncet (2006)*