A CGE Analysis of the Copenhagen Accord from the perspective of less developed countries♠

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Abstract:

While industrialized countries (ICs) are responsible for the bulk of historic anthropogenic greenhouse gas (GHG) emissions, the relative contribution of less developed countries (LDCs) to the atmospheric stock of GHGs is rapidly increasing. Therefore a crucial task – which could not be accomplished at the COP 15 in Copenhagen in 2009 – is to device a fair burden sharing regime among ICs and LDCs to ensure broad cooperation in the mitigation of global warming. We develop a multi-sector, multi-region computable general equilibrium (CGE) model to analyze, whether a climate policy approach limited to ICs will lead to the achievement of the +2°C target. Second, we investigate whether financial transfers to induce energy-efficiency improvements in LDCs, like the envisioned Copenhagen Green Climate Fund, are sufficient to trigger substantial deviations from business-as-usual (BAU) CO_2 emissions in LDCs. We find that climate policy agreements which do not limit emissions in LDCs cannot ensure a global mean temperature increase within +2°C compared to pre-industrial levels. While ICs do achieve partly substantial emission reductions, LDCs' CO_2 emissions tend to grow even stronger until 2020 than under BAU. Moreover, providing financial resources for LDCs, which aim at increasing energy efficiency in the power sector, will not be sufficient unless combined with emission targets for LDCs. From the latter policy, both LDCs and ICs would benefit when taking a combined environmental and economic perspective.

Keywords: burden sharing, post 2012 climate policies, economic development, CGE analysis

JEL Codes: D58; Q56; O13.

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1. Introduction

Today there is a broad scientific and political consensus that greenhouse gas (GHG) emissions need to be reduced significantly to avoid dramatic consequences for the global climate system due to global warming. If global warming is to be limited to a maximum of 2C° above pre-industrial values – a crucial threshold level identified by the IPCC (The Copenhagen Diagnosis, 2009) to protect the climate system from the most severe and irreversible consequences by crossing crucial tipping points – global emissions need to peak between 2015 and 2020 and then to decline rapidly. According to Stern (2006), overshooting the +2C° target might not only become very dangerous but also very costly. He argues that while the costs of immediate action of reducing GHG emissions to avoid the worst effects of climate change can be limited to around 1% of global GDP each year, the costs of non-acting will be in the range of losing 5% to 20% of annual GDP.

At the climate conferences in Kyoto, and more recently in Bali and Copenhagen, a central point of discussion evolved on the shared responsibility for the environmental debt (in terms of accumulated GHG emissions) imposed on future generations. Beyond any doubt, industrialized countries (ICs)[1], most prominently the US, Europe and Japan, are responsible for the bulk of the historical anthropogenic emission responsibility (den Elzen et al., 2005). Consequently, less developed countries (LDCs) have repeatedly argued that they should not be penalized for today's wealthy countries' prodigal treatment of atmospheric commons. But due to rapid industrialization in some emerging economies, notably China and India, the relative contributions to atmospheric GHG concentrations is changing substantially. Botzen et al. (2008) investigate the long-term responsibilities for the causes of warming, and find that – if the current trends continue – China will overtake the USA as the major cumulative contributor to the stock of CO_2 in the atmosphere by the middle of the century. In terms of GHG emissions, China has already surpassed the US as the world's largest emitter in 2006 (Boden et al., 2009).

Thus, any future climate agreement has to consider the fact of common but differentiated responsibilities (UN, 1992) and has to aim at reaching a broad cooperation in order to stabilize the world's climate. Without the active participation of LDCs, the stabilization of the atmospheric GHG

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[1] Many different classifications are used by the United Nations, the World Bank, the IMF and others to differentiate among countries. A very common classification is based on the degree of development, distinguishing for developed countries, which already completed the process of development, and developing countries, which are still on the continuum of development (Perkins *et al.*, 2006). In this paper, we refer to developing countries as less-developed countries (LDCs) and to developed countries as industrialized countries (ICs).

concentration at a tolerable level cannot be achieved (UN-DESA, 2009). This essential participation of LDCs is likely to increase if a global agreement is perceived to be fair (Bohm and Larsen, 1994; Morrisette and Plantinga, 1991). On the one hand, LDCs should commit themselves to actions they are capable of taking on their own, within their financial, institutional as well as technological boundaries and without putting development and poverty reduction on a hold. On the other hand, these autonomous measures in LDCs have to be complemented by adaptation and mitigation support from ICs, as stated by the World Economic and Social Survey 2009 (UN, 2009).

Thus, one important move at the COP 15 in Copenhagen in 2009 was the declaration of intent, contained within the closing document called "Copenhagen Accord", to establish the so called Copenhagen Green Climate Fund (CGCF; UNFCCC, 2009a) in addition to the already existing, though not satisfactorily operating (Boyd et al., 2007; Ellis and Kamel, 2007), flexible mechanisms under the Kyoto Protocol. This new fund aims at channeling financial resources for mitigation and adaptation efforts from ICs to LDCs. The accord pledges USD 30 billion from ICs' budgets for the period of 2010 to 2012 as start-up finance to LDCs, and by 2020 ICs should mobilize USD 100 billion a year (UNFCCC, 2009a).

Another important outcome of COP 15 was the change in methodology to achieve GHG emissions reductions. While earlier UNFCCC negotiations ultimately try to reach a fair and efficient distribution of a certain disposable CO_2 budget (as e.g. set out in the Kyoto Protocol) thus representing a top-down approach, the US proposed a bottom-up approach, in which countries should set for themselves realistic reduction targets binding under their respective national law. The proponents of such a latter approach argue that targets set under national law are much more likely to be enforceable than the UN top-down approach, which faces difficulties in applying sanctions against non-achieving nations (Carraro, 2006, Lutsey and Sperling, 2007). The EU for example, which still inclines to the top-down approach, pledged in the forefront of the COP 15 a 20% GHG reduction target compared to 1990 until 2020, and offered a 30% reduction objective, if a comprehensive, global agreement could have been established (European Commission, 2009). The US instead was offering a GHG emissions reduction commitment in Copenhagen similar to the nationally adopted reduction goal set in the *American Clean Energy Security Act* (ACES), the *Waxman-Markey* bill, reflecting a 4% decrease of annual GHG emissions until 2020 compared to the base year 1990 (US Congress, 2009).

The present paper sets out to answer three main questions of crucial relevance in a post-Copenhagen climate change framework. The first is whether a bottom-up approach scenario (*BUS*) will lead to an environmentally effective outcome. Since under such a setting LDCs are unlikely to set any reduction targets at all and ICs are unlikely to set sufficiently stringent reduction targets, carbon leakage is likely to occur, jeopardizing environmental effectiveness on a global scale. The second question addresses the effectiveness of the CGCF by asking whether financial transfers from ICs to increase energy efficiency in a certain LDC sector (in our case power generation), are sufficient to trigger a substantial deviation from LDC's business-as-usual emissions, or if in addition explicit emission targets for LDCs are necessary. Finally, we will analyze whether providing financial resources for LDCs under the CGCF is also beneficial for ICs, both in terms of direct environmental as well as economic benefits.

To answer these questions, we develop a static multi-regional, multi-sectoral computable general equilibrium (CGE) model. The CGE approach was chosen, since the problem at hand is characterized by the fact that many sectors are involved and directly or indirectly influenced by climate policy measures and that national markets are highly interconnected through international trade – so they react to changes in international prices due to unilateral climate policies. A multi-regional multi-sectoral CGE framework is appropriate to illustrate repercussions of different policy options triggered by changes in relative prices on the domestic market and to represent interconnections between various national economies.

Numerous studies have been conducted with the focus on the effects of the implementation of climate policies. To the best of our knowledge, the present paper is however one of the first to focus explicitly on the impacts of the proposed CGCF on global climate change mitigation as well as on welfare of ICs and LDCs (one exemption is Carraro and Massetti, 2010). Some studies however analyze the options for encouraging LDCs' early action (e.g. Bosetti et al., 2009; Richels et al., 2009, Böhringer and Welsch, 2004). Regarding existing policies of ICs, Böhringer et al. (2009a and 2009 b) utilize CGE models for an economic impact assessment of the EU 20/20 targets. They identify excess costs by up to 100-125% due to a segmentation of the EU's CO_2 permit market in ETS and non-ETS sectors respectively, and due to overlapping regulations.

With respect to the LDC's role in climate policy, Philibert (2000) investigates the effects of non-binding, no-loose targets for LDCs as a complementary policy to the Clean Development Mechanism (CDM). Zhang (2003) investigates the implications of broadening the scope of emissions trading to full global trading, with a special focus on LDCs, especially China. Both find the provision of non-Annex I countries with substantial capital inflows to increase, in addition Annex-I countries can more easily achieve their Kyoto commitments at lowest possible costs. Babiker et al. (2000) concentrates on the impacts of the Kyoto Protocol on LDCs, and finds that it's adverse effects fall mainly on energy-exporting LDCs. Viguier (2004) argues that the optimal provision of the public good "GHG abatement" requires creating incentives for international cooperation. He proposes the "rent-sharing" approach as a meaningful guarantee for LDCs' participation.

Concerning the environmental effectiveness of bottom-up approaches on behalf of some but not all, some studies find that carbon leakage is very small and in some cases even negative because of technological spillover (e.g. Barker et al., 2007; Reinaud, 2005; Sijm et al., 2004; Paltsev, 2001; Mani, 2007). However, most of these studies argue that the absence of a strong evidence for carbon leakage is mainly triggered by the relatively small magnitudes of the employed energy taxes (e.g. Mani, 2007). In this paper however, we will employ much stricter carbon abatement targets in accordance with the IPCC's +2C° target as a first policy scenario. Due to this higher stringency, we expect the carbon leakage rates to be of more considerable magnitude than in previous studies.

Also to avoid carbon leakage, it is crucial to bring LDCs on board of post-2012 climate policies. A necessary aim is therefore, as argued by Winkler (2008), to raise the bar for LDCs by moving from qualitative targets under Article 4.1 of the UNFCCC to measurable, reportable and verifiable mitigation actions, as outlined in paragraph 1b of the Bali Action Plan (UNFCCC, 2007). Thus as an additional policy scenario, we consider this ideal global burden sharing based on the IPCC outline of a 25% emissions reduction in Annex I countries in combination with a 15% deviation from BAU for non-Annex I regions (IPCC, 2007). Unfortunately, such a top-down approach is unlikely to be politically feasible, given the current circumstances in the climate policy debate. To overcome this problem, we introduce the CGCF in a subsequent scenario, channeling the postulated USD 100 billion up to 2020 from ICs to LDCs. As a final scenario, we combine the financial support under the CGCF with the creation of quantitative and verifiable emission objectives, e.g. referring to a (substantial) deviation under BAU.

A main finding of our analysis is that climate policy agreements which do not tackle emissions in LDCs cannot ensure environmental effectiveness. While Annex I countries do achieve partly substantial emission reductions, non-Annex I countries' CO_2 emissions tend to grow even stronger until 2020 than under business-as-usual assumptions. Moreover, by analyzing different specifications of LDC involvement, we find that it will not be sufficient to provide financial resources for LDCs, which aim at increasing energy efficiency in a specific sector or on a project-by-project basis. The resulting efficiency gains within the sector in question – in our case power generation – are likely to be counterbalanced by rising output in the sector itself (known as the rebound effect) and especially by substantial increases in CO_2 emissions in sectors which do not receive support in any means to achieve a decarbonization. Finally, we find that ICs might even slightly benefit economically from providing financial assistance for LDCs' mitigation and adaptation efforts. This is due to the fact that efficiency gains in the LDCs' power generation sectors stimulate overall economic performance, in turn increasing also final demand for imports from ICs.

The structure of this paper is as follows. We start by a description of the structure of the CGE model, while the data source used for the modeling and the results for the BAU 2020 are presented in section 3. Section 4 outlines the assumptions for the policy scenarios. Section 5 describes the model findings of the different policy scenarios, namely their impacts on economic performance in ICs and LDCs as well as on global carbon emissions; addressing also the problem of carbon leakage due to unilateral policies. Sections 6 and 7 discuss and summarize our results and give policy conclusions.

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
Industrialized countries		*Less developed countries*	
European Union	EU	China	CHN
Rest of Europe	ROE	South Asia	SASI
Russian Federation	RUS	Southeast Asia	SEASI
Rest of GUS	GUS		
United States of America	USA	Middle East and North Africa	MENA
Rest of North America	NAM	Sub Saharan Africa	SSA
Rest of East Asia ("Asian Tigers")	EASI	Latin America	LAM
Oceania	OCEA		

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 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 intensities (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).

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)*

The basic model structure follows the construction 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 14 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. Capital and labor is modeled 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 remainder of this chapter gives a detailed description of the CGE model structure, which follows in its basic structure the GTAP-E model[2] (Rutherford and Paltsev, 2000), as well as the parameters applied for the evaluation of different policy scenarios. The following section provides a description of the production function modeling approach, while the subsequent section deals with modeling trade, taking the form of bilateral trade relationships rather than an integrated global market.

2.1 Production structure

Within the modeling framework MPSGE, nested constant elasticity of substitution (CES) production functions are employed, 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) (Rutherford, 1999). Since a specific resource input is used in the production of primary energy commodities (coal, oil, gas), slightly different production functions for primary energy commodities and all other commodities are used.

Figure 1 illustrates the production of all other commodities (indexed by *esc*), like the aggregate energy intensive industries (EIS). At the top level the intermediate inputs – the domestic supply $D_{esc,r}$ – from non-energy sectors trades off, subject to a constant elasticity *s*, 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 under a constant, but sectorally different elasticity (*elke*) with an energy-composite. The natural resource input $NatRes_r$ (only relevant for FOOD sector production, i.e. agriculture) is employed under the sectorally differentiated constant elasticity of substitution *elk* with capital and labor. The energy-composite E_r consists of three main nesting stages. The first one represents a trade off at a 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 under the constant elasticity *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 at the top level. Thus, at the top

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[2] The GTAP-E model is an extension of the standard GTAP model (which itself represents a global CGE model, using the GTAP database), focusing on energy and environmental analysis. For documentations on the GTAP-E model and the standard GTAP model see Rutherford and Paltsev (2000), and McDougall (2003a, b).

level in the extraction of fossil resources, natural resources and non resource inputs can be exchanged at zero elasticity, which characterizes a Leontief composite.

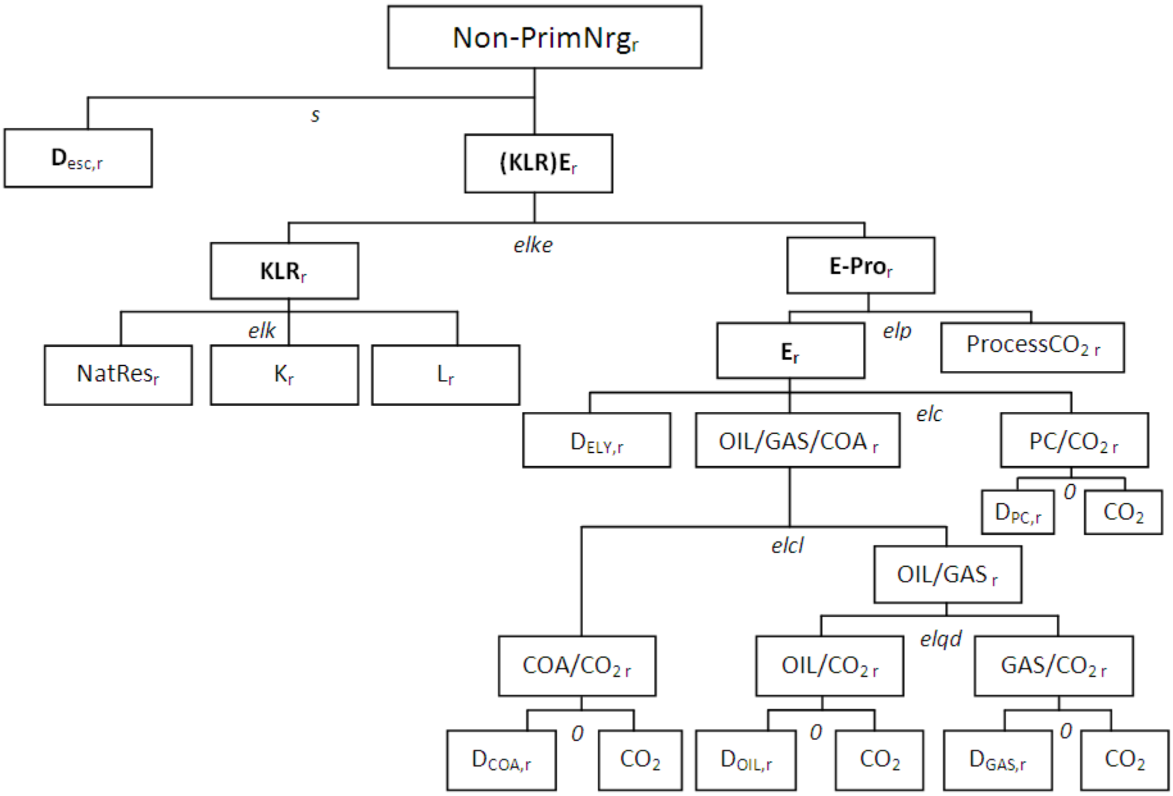


Figure 1: Nesting of production

For our analysis, the elasticities of substitution in the production processes (see Table 24 in the Appendix) are based on Okagawa and Ban (2008) as well as Beckman and Hertel (2009).

2.2 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 25 in the Appendix.

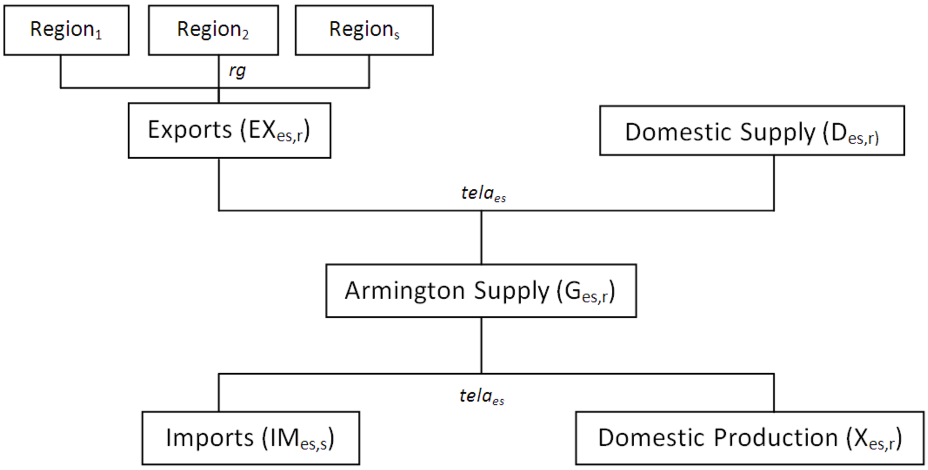


Figure 2: Armington aggregation for country *r*

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 to a constant elasticity (*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 domestic market activities (TRN) by each region and traded off among regions at elasticity *rg*. Values for these elasticities applied in the modeling of imports are presented in Table 25 in the Appendix.

2.3 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.

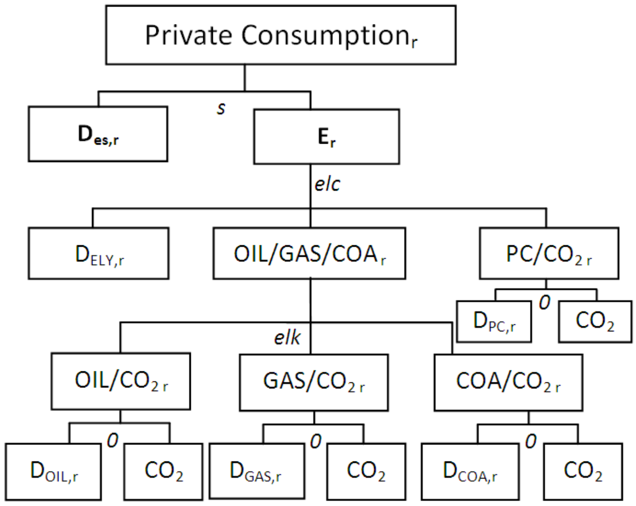


Figure 3: Final demand of private households for country *r*

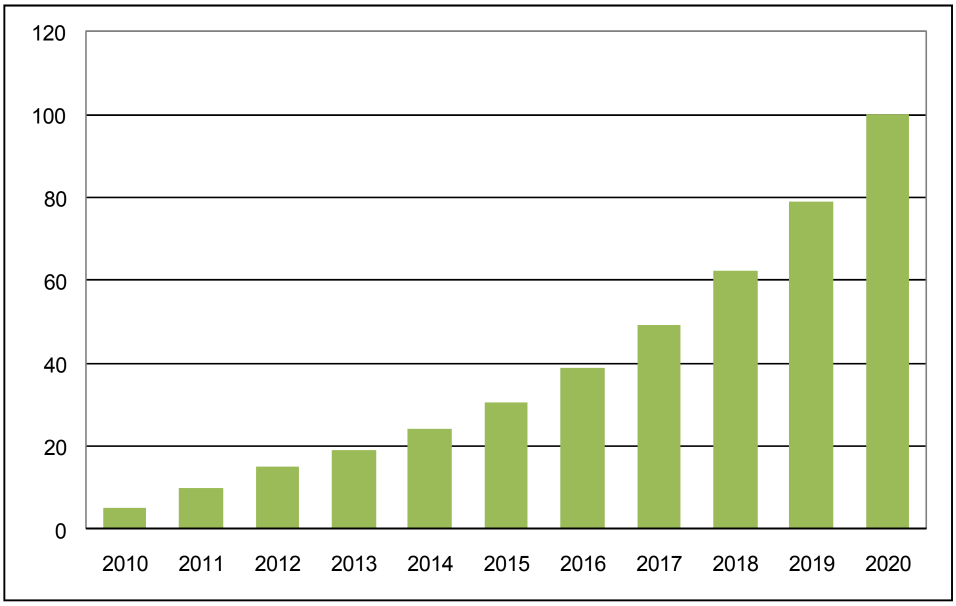
Consumption of private households in each region, depicted in Figure 3, is characterized by a constant elasticity aggregate of a non-energy intermediate consumption bundle $D_{es,r}$ and an energy aggregate E_r (elasticity: *s*). The energy composite itself consists again of two nesting levels – a CES function with an elasticity *elc*, trading off secondary energy (ELY and P_C) with a primary energy constant elasticity composite (*elk*) (see Table 24 in the Appendix for parameter values).

2.4 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 adhered carbon tax linked with an elasticity of substitution equal to zero to the combustion of fossil fuels. These reflect the carbon taxes a GHG emission abating region has to impose on fossil energy consumption in order to achieve an exogenously set reduction target. The taxes – in our case modeled as CO_2 emission permits which prices coincide with the carbon tax – can be differentiated between the sectors included in the EU's emissions trading scheme (ETS) and the non-ETS sectors, including private households. 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. The revenues of the permit sales are collected by the regional households and redistributed to private households and the government.

In addition to carbon taxes/permits we will employ a second type of policy. This policy is the so-called Copenhagen Green Climate Fund (CGCF), which should channel annually USD 100 billion by 2020 from ICs to LDCs, according to the Copenhagen Accord (closing document of COP15). The funds should be employed to foster the decarbonization of the LDCs' economies, and be paid for by ICs.

Figure 4: Annual Financial Flows under the Copenhagen Green Climate Fund (in billion USD)



Source: *Own calculations based on UNFCCC (2009a)*

In our modeling approach we assume that, beginning in 2010, the annual financial transfers gradually increase over time until they reach the postulated USD 100 billion in the year 2020 (see Figure 4). We assume that these financial resources will be drawn from the revenue of auctioning CO_2 emission permits to energy intensive sectors in the ICs. Each nation within the group of ICs therefore channels annually a certain percentage of their permit revenues via the Green Climate Fund to the LDCs' regional households, which in turn use this sum for investment and consumption activities. In the year 2020, 10% of permit auctioning revenues in ICs are thereby redistributed to LDCs, reaching almost the desired USD 100 billion. The distribution of the financial resources among the recipients will be modeled depending on the regions' share of the overall LDC population. Table 3 presents this distribution of the annual financial transfers under the CGCF in the year 2020.

Since we apply a static multi-sectoral, multi-regional general equilibrium model to analyze climate policy options for the time horizon 2020, we have to exogenously account for the financial transfers that occurred during 2010 and 2020 (see Table 3). We do so by summing up the annual financial flows depicted in Figure 4 from 2010 to 2019, and – subject to an assumed internal rate of return of 10% p.a. – introduce a sector specific sort of capital good K_{nrg} (tied to an utilization in the energy sector) as an additional primary factor endowment (which can be exchanged with general capital K, labor L, and natural resources R) of the representative household in LDCs. We assume that in the recipient countries, the financial resources will be used primarily to invest in the improvement of energy efficiency within the power generation sector, since this is the most crucial sector on the way to a low carbon future.

Table 3: Annual financial transfers under the CGCF in the year 2020

	financial flows 2020		transfers 2010-2020 (K_{nrg})	
regions / scenarios	**donors**	**recipients**	**donors**	**recipients**
EU	22,098		7,848	
Eastern Europe	5,350		1,900	
OCEA	3,153		1,120	
NAM	52,216		18,545	
EASI	10,853		3,848	
Industrialized Countries	*93,652*		*33,262*	
LAM		10,355		3,678
CHN		24,417		8,672
SASIA		41,023		14,570
Africa		17,858		6,343
Less Developed Countries		*93,652*		*33,262*

3. Model calibration, baseline adjustment and post-2012 climate policy

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 (see, e.g., Peters and Hertwich, 2008): Since data is contributed by GTAP partners voluntarily, some sources are not the most recent ones; more significant for our analysis, however, is the adjustment necessary to ensure internationally consistent input output and trade tables. Moreover, emissions included 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 in GTAP. In our work we had to correct for these shortcomings in the base data as noted in the subsequent sections.

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 the 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 CO2 emissions data for the GTAP7 database. Since these CO2 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 the 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. Regarding 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, 2009a). 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.

3.2 Model calibration and baseline adjustment

The various climate political targets discussed at the advent of the UNFCCC Copenhagen meeting are all directed towards the achievement period 2020; this CGE analysis therefore focuses also on this commitment period. However, the data is available for 2004. Accordingly, a business as usual (BAU) scenario for 2020 is constructed as a benchmark against which the impacts of the different policy scenarios will be compared.

Since the GTAP7 data base is consistent for the reference year 2004 and a static general equilibrium model is applied, the economic developments until the year 2020 have to be factored in 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. To account for improvements in energy efficiency over time, an exogenous autonomous energy efficiency improvement parameter AEEI is introduced. 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) a constant AEEI parameter is assumed and set at 1% per annum. For the growth rates which were used to calibrate the model for the BAU 2020 scenario, see Table 26 in the Appendix. The values of these growth rates are decisive for generating the BAU case, and differ quite substantially across regions. While ICs' annual growth rates for MFP are assumed to vary between 1.30 and 1.60%, the variance is much higher for LDCs. For Asian regions MFP growth rates above 2% p.a. are assumed, while for LAM, and Africa significantly lower rates (from 0.5 to 0.9%) are projected. With respect to the augmentation of the capital stock in the respective countries, Poncet (2006) predicts the highest growth rates for Asian countries – thereby following the recent historic trend, but slightly alleviated. The worst growth prospects are again predicted for African regions. Considering population growth, we assume by again following Poncet (2006) that most of the global labor force growth will happen in the LDCs. Some ICs will even experience a decrease of their labor force over the next decade.

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, as well as the AEEI parameter, not for the whole 16 year period 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 the analysis of different post-2012 climate policy scenarios, the CGE model is programmed and solved in GAMS/MPSGE (Rutherford, 1999) utilizing the solver PATH, which is calibrated to the previously described GTAP7 data base, representing the year 2004.

3.3 The BAU 2020 scenario

The BAU 2020 scenario is characterized by an average annual GDP growth rate, presented in Table 4, of 2.5% for the group of ICs (over the period 2004 to 2020), resulting in a GDP of 51.3 trillion USD in 2020 (due to the GTAP database, all GDP data is presented in USD, at 2004 real prices). This reflects an increase of rich countries GDP under BAU assumptions by 48.5% until 2020 compared to 2004. During the same period the LDCs' average annual GDP growth performance is 3.74%. This number is substantially lower than the empirical 1999-2004 average annual GDP growth rate of 6.11% for LDCs, which reflects on the one hand the substantial impacts of the current economic crisis on LDCs. On the other hand this result is triggered by the alleviated growth prospects for LDCs until 2020 compared to their growth trajectories in the recent history (see section 3.2), which already imply a certain degree of convergence of ICs and LDCs. The 80% increase of LDC's GDP from 6.4 trillion USD in 2004 to 11.5 trillion USD under BAU 2020 is mainly driven by still high, but significantly lower than the 1999-2008 average, growth rates in big emerging economies like China or India.

Table 4: Average annual GDP growth rates for ICs and LDCs

regions / scenarios	1999-2008*	BAU 2020
EU	2.44	2.38
Eastern Europe	4.33	2.62
OCEA	2.66	2.99
NAM	3.18	2.61
EASI	1.89	2.43
Industrialized Countries	*2.48*	*2.50*
LAM	3.50	1.32
CHN	9.76	5.90
SASIA	5.92	4.78
Africa	4.62	1.59
Less Developed Countries	*6.11*	*3.74*
World	**3.98**	**2.71**

**based on IMF (2009c)*

Turning to CO_2 emissions, global CO_2 emissions under the BAU assumptions are found to increase by 25% compared to 2004. This corresponds to an absolute increase in global production related and private household's emission by 6,429 Mt CO_2 from 27,734 Mt CO_2 in 2004 to 34,163 Mt CO_2 in 2020 (Table 5). LDCs are experiencing a higher increase in their domestic CO_2 emissions by 2020, namely by 29% compared to 2004 levels, than ICs, whose emissions increase corresponds to 19.2%. The high emission growth rate for LDCs is mainly triggered by high CO_2 emission increases in big emerging economies in Southeast Asia – China and India, whose economies are expected to grow stronger over the next years than the ICs', even though they are also affected by the current economic downturn.

Table 5: CO_2 emissions for ICs and LDCs for 2004 and BAU-2020

	2004	BAU 2020	Change
	in Mt CO_2		2004-2020
EU	4,381	5,156	+17.7%
Eastern Europe	3,051	3,601	+18.0%
NAM (incl. USA)	7,294	8,894	+21.9%
OCEA	434	528	+21.6%
EASI	1,956	2,230	+14.0%
Industrialized Countries	17,116	20,409	+19.2%
LAM	1,087	1,132	+4.1%
CHN	4,853	6,830	+40.7%
SASIA (excl. CHN)	2,104	3,056	+45.2%
AFRICA	2,573	2,736	+6.3%
Less Developed Countries	10,618	13,754	+29.5%
Total	27,734	34,163	+25.3%

4. Post-2012 climate policies

Having described the structure of the CGE model, its calibration as well as its results for the 2020 baseline scenario, and before using the model to analyze different climate policy scenarios, the following section will outline the settings of three different scenarios – a post-2012 bottom-up approach with a voluntary commitment by ICs, the IPCC's recommendation on GHG emission reductions for Annex I and for non-Annex I countries to the Kyoto Protocol, and finally another global scenario which additionally introduces the envisioned Copenhagen Green Climate Fund as a source for financial support for the LDCs' effort to achieve emission reductions in a way not jeopardizing human and economic development.

All policies will be compared to the year 2020 since this year reflects the time frame for the IPCC's crucial GHG emissions reduction necessities (IPCC, 2007). Also, many other officially announced reduction strategies by single countries or regions refer to the year 2020; for example 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 ICs) and a 20% share of renewable energies in EU energy consumption until 2020 (European Commission, 2008). Furthermore the Copenhagen Accord sets a deadline to 2020 to generate annual financial transfers from ICs to LDCs under a Green Climate Fund summing up to USD 100 billion a year. In our policy analysis, we discuss three types of scenarios:

- **BUS**: A *voluntary* Post-2012 agreement of Annex I countries, representing a bottom-up approach scenario as favored by the US, at the reduction targets declared by Annex I countries within Appendix I of the Copenhagen Accord, characterized by quite weak emission targets for Russia and the US.
- **GA:** *Compulsory* global agreement of Annex I countries *and* non-Annex I countries, with reduction targets as identified by the IPCC's 4th Assessment Report to remain within the +2° global temperature target (compared to pre-industrial levels) by 2100.
- **CGCF**: A global agreement *without* explicit emission targets for LDCs in which the envisioned Copenhagen Green Climate Fund is utilized to provide financial resources for LDCs' efforts to reach a substantial deviation relative to their BAU GHG emissions growth paths.
- **CGCF+GA**: A global agreement *with* explicit targets for LDCs in which the envisioned Copenhagen Green Climate Fund is utilized to provide financial resources for LDCs' efforts to reach a substantial deviation relative to their BAU GHG emissions growth paths.

In each scenario the regional emission targets are modeled by restricting CO_2 emissions in all sectors – energy intensive and non-energy intensive sectors alike – as well as of private households. For energy intensive sectors, as for example included in the EU emissions trading scheme, the emerging price for CO_2 can be interpreted as the price for emission allowances, while targets for non-ETS sectors and private households implies a national shadow price of carbon emissions.

The global post-Kyoto, or bottom-up scenario (*BUS*) is based on the lower-bound CO_2 emission reduction targets as stated by many ICs in Appendix I to the Copenhagen Accord, established at the Copenhagen Conference of the UNFCCC. This paper will analyze the lower bound of emissions reduction proposals by ICs, since the upper-bound objectives are contingent to the creation of an ambitious global deal, which is unfortunately not palpable today. The reason for analyzing this scenario is to find out whether a bottom-up approach, as suggested by the US delegation at the Copenhagen negotiations, would satisfy the necessary emissions reduction objectives in order to prevent the climatic system from the most severe negative impacts. The reduction targets depicted in column 1 in Table 6 refer to the most recent, official country specific information on envisioned GHG reduction goals, recalculated relative to emissions in the base year 2004.

Table 6: GHG emission reduction targets for 2020 relative to 2004

Region	BUS	GA	CGCF	CGCF+GA
Countries	**Annex I**	**Non-Annex I**		
EU	-22%	-27%	-27%	-27%
ROE	-41%	-44%	-44%	-44%
RUS	+39%	+23%	+23%	+23%
GUS	+18%	+18%	+18%	+18%
USA	-16%	-37%	-37%	-37%
NAM	-11%	-26%	-26%	-26%
OCEA	-18%	-44%	-44%	-44%
EASI	-20%	-20%	-20%	-20%
CHN		+20%		+20%
SEASI		+37%		+37%
SASI		+17%		+17%
LAM		-11%		-11%
MENA		-7%		-7%
SSA				

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

While the *BUS* scenario is the result of *voluntary* emission reduction targets by Annex I countries, which they proposed to achieve irrespective of whether a global deal can be agreed upon, the IPCC recommends -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). In addition the IPCC proposes substantial deviations from their BAU emissions growth path by -15% to -30% for non-

Annex I countries. From the stated IPCC emissions reduction the global agreement (*GA*) scenario investigates the lower bound only. Since the IPCC defines reduction targets for Annex I relative to 1990, but for non-Annex I regions relative to business as usual, emissions reduction targets for LDCs are based on the BAU scenario as defined in section 3.3.

As an alternative policy setting, scenario *CGCF* introduces financial support flows under the envisioned Copenhagen Green Climate Fund from industrialized regions to LDCs, with the aim of a gradual decarbonization of the recipients' energy sectors. As outlined in section 2.4, we assume that until 2012 LDCs will have received USD 30 billion and in the subsequent years the annual transfers will gradually increase until they reach USD 100 billion as proposed in the Copenhagen Accord. We will analyze first, whether these ear-marked energy efficiency financial transfers are sufficient to trigger the -15% or even the -30% deviations from BAU 2020 GHG emissions in LDCs, since, in contrast to scenario *GA*, non-Annex I countries will not be subject to explicit emission reduction targets in this scenario. In other words, we check their effectiveness to reach the envisaged emission reductions in LDCs, even without setting explicit emission constraints as in *GA*. If this approach turns out to be insufficient, emission constraints as in scenario *GA* will be introduced in addition to the financial transfers, leading to an additional scenario, called CGCF+GA.

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 (see Table 6). For example the EU reduction goal in the BUS scenario, which was a homogenous -20% reduction for all EU member states compared to 1990, changed according to the EU's observed CO_2 emission variation between 1990 and 2004, resulting in a -22% target compared to 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.[3]

[3] For instance, a -11% CO_2 reduction goal relative to 1990 (or +18% relative to 2004) under *BUS* for the rest of GUS results since only Belarus and the Ukraine as Annex I countries have officially announced CO_2 objectives of -5% and -20% relative to 1990, respectively in a low abatement scenario within the Copenhagen Accord, while emissions in all non-Annex I GUS countries are allowed to grow without restrictions.

5. The economic and carbon effects of the post-2012 climate policy scenarios

5.1 Can Annex I countries alone tackle climate change? – The bottom-up (BUS) scenario

By applying the CGE model, we calculate the global effects on carbon emissions when many ICs set themselves emission restrictions, which they consider achievable. Such a setting would reflect a bottom-up scenario (*BUS*) as favored e.g. by the US. As pointed out earlier, the lower bound of the emission reduction targets postulated by some ICs within Appendix I to the Copenhagen Accord (UNFCCC, 2010) are applied within the model.

Table 7 summarizes the effects of the bottom-up climate policy scenario *BUS* on CO_2 emissions in 2020, and compares these to the 2004 as well as to the BAU values. It can be seen that under such a climate policy regime with emission reduction objectives set on a voluntary basis, global CO_2 emissions are unlikely to fall until 2020, even under consideration of the current economic crises. Global emissions are found to increase from 27.7 Gt CO_2 in 2004 to 30.4 Gt CO_2 by 2020, only 11% less than under BAU. Although ICs are able to reduce their cumulative emissions by 10.9% under 2004 levels, they are still far away from the necessary emission reductions in the range of -25% to -40% compared to 1990 (as proposed for Annex I countries by the IPCC to limit global mean temperature increase to at most +2°C).

Table 7 Carbon effects by country group of a bottom-up climate policy scenario (BUS)

	2004	BAU 2020	BUS	BUS	BUS
		in Mt CO_2		relative to 2004	relative to BAU 2020
EU	4,381	5,156	3,494	-20.2%	-32.2%
Eastern Europe	3,051	3,601	3,666	+20.2%	+1.8%
NAM (incl. USA)	7,294	8,894	6,179	-15.3%	-30.5%
OCEA	434	528	356	-18.0%	-32.6%
EASI	1,956	2,230	1,565	-20.0%	-29.8%
Total for Industrialized Countries	17,116	20,409	15,260	-10.9%	-25.2%
LAM	1,087	1,132	1,300	+19.6%	+14.9%
CHN	4,853	6,830	7,214	+48.6%	+5.6%
SASIA (excl. CHN)	2,104	3,056	3,426	+62.8%	+12.1%
AFRICA	2,573	2,736	3,222	+25.2%	+17.8%
Total for Less Developed Countries	10,618	13,754	15,162	+42.8	+10.2%
Total	27,734	34,163	30,422	+9.7%	-11.0%

A substantially different picture arises when we take a closer look at the carbon effects on LDCs of such a climate policy scenario. In the poorer parts of the world emissions grow even stronger than under BAU, namely by 10.2%. This represents an increase in CO_2 emissions from 13.8 Gt CO_2 under BAU 2020 to 15.2 Gt CO_2. Compared to 2004, emissions increase by 42.8%. This massive increase of CO_2 emissions in LDCs is mainly caused by considerable emission increases in South and Southeast Asia, most prominently China (+49% compared to 2004).

To some extent these CO_2 emission increases are likely to be triggered by the relocation of carbon intensive production from ICs to LDCs. In the literature the phenomenon of carbon leakage predicts the "leaking" of carbon emissions across borders by a relocation of carbon-intensive industries to poorer countries due to local differences in the stringency of climate change policy measures, which in turn impose different levels of costs on competing firms (Barker et al., 2007).

Following a 'strong' definition of carbon leakage, the increase of CO_2 emissions beyond BAU in non-abating regions is divided by the emission reduction relative to BAU in the abating regions to get a measure for the amount of carbon emissions which is leaking by production shifts to other regions and hence counteract the emission reductions in the abating countries (Peters and Hertwich, 2008). We find the carbon leakage rate under such a bottom-up scenario amounting to 28%. This number is substantially higher than the literature on carbon leakage would suggest.

Other studies (e.g. Sijm *et al*., 2004; Reinaud, 2005) found that under quite moderate climate policy frameworks, such as the Kyoto Protocol, carbon leakage is unlikely to be substantial, since carbon costs associated with the EU-ETS only reflect a minor part of a firm's overall costs. However they agree that in the future, if more ambitious climate policy frameworks are implemented unilaterally by ICs, carbon leakage may indeed become an issue. Hence, if our *BUS* leakage rate is compared to the findings of these other studies, we find these researchers' reasoning confirmed that the more stringent and the more partial climate change policy is implemented, the higher is carbon leakage.

Table 8 depicts the economic effects of a bottom-up climate policy scenario, by comparing output of the different sectors and regions in the presence of unilateral climate policies for Annex I regions with BAU 2020 results. It can be seen that overall output in ICs is reduced by 2.7% (Eastern Europe) to 3.6% (OCEANIA) compared to BAU, depending on the stringency of the country (group) specific emission reduction objectives. By taking a look at the sectoral level, it can be concluded that especially the output of IC's energy intensive ETS sectors as well as primary energy sectors, which provide the fossil fuels for the ETS sectors, are subject to diminishing output levels.

Table 8: Sectoral output effects by country group of the bottom-up scenario (BUS) (relative to BAU 2020, in %)

	Industrialized countries					Less developed countries			
	EU	Eastern Europe	NAM (incl. USA)	OCEA	EASI	LAM	CHN	SASI (excl. CHN)	AFRICA
P_C	-26.0%	+0.6%	-29.3%	-29.4%	-23.0%	+13.5%	+9.0%	+17.8%	+18.7%
ELY	-13.4%	-0.1%	-16.0%	-17.8%	-16.4%	+4.8%	+3.6%	+4.4%	+6.0%
EIS	-4.4%	+9.1%	-6.0%	-6.1%	-7.7%	+4.6%	+2.4%	+2.9%	+22.5%
ETS total	-7.1%	+4.8%	-10.7%	-10.0%	-10.3%	+6.3%	+3.2%	+6.0%	+18.6%
COA	-33.7%	-10.0%	-28.9%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%
OIL	-5.0%	-3.7%	-33.0%	-5.2%	-0.0%	-0.0%	-0.0%	-0.0%	+0.0%
GAS	-35.9%	-0.8%	-34.9%	-33.3%	-99.6%	-0.0%	+0.0%	+0.0%	-0.0%
NEIS	-2.0%	-0.0%	-1.8%	-1.7%	-5.5%	+0.9%	-1.2%	-2.3%	+12.4%
TRN	-17.7%	-3.7%	-17.0%	-14.6%	-9.8%	+22.6%	+7.8%	+21.7%	+36.8%
FOOD	-4.3%	-3.7%	-4.3%	-4.8%	-4.2%	-1.0%	+0.5%	+0.1%	-2.3%
SERV	-1.2%	-4.8%	-1.1%	-1.7%	-0.6%	-1.1%	+0.2%	-0.3%	-5.3%
CGDS	-1.9%	-8.6%	-2.0%	-2.5%	+0.1%	-1.3%	+0.6%	+0.5%	-14.0%
NETS total	-2.7%	-4.4%	-2.4%	-2.9%	-2.3%	+0.4%	+0.1%	+0.7%	-0.9%
TOTAL	-3.2%	-2.7%	-3.1%	-3.6%	-3.3%	+1.3%	+0.6%	+1.5%	+1.5%

For the LDCs, the picture looks quite different. Since they are not subject to any carbon constraints they are even able to increase their output levels – especially in the ETS sectors – above BAU 2020 output quantities. Part of this additional output is intended for exports to the mitigating ICs, which eventually outsource part of their domestic production to non regulated regions. Table 9 visualizes that these increasing output levels in the LDCs go hand in hand with increasing CO_2 intensities, since these regions are not sufficiently encouraged to reduce inefficiencies in their production processes. ICs' CO_2 intensities on the other hand do decrease, thus representing efficiency gains within the production processes.

Summing up, a bottom-up approach as proposed by some countries is unlikely to achieve the necessary emission reductions to protect the global climatic system from the most severe negative consequences, since no turning point in global emissions is likely to be reached within the next decade. The relatively weak individual voluntary targets declared by some ICs in Appendix I to the Copenhagen Accord (UNFCCC, 2010) – especially by the US as well as Russia, play one fundamental role for this unsatisfying outcome. Another reason can be found in the relatively incomprehensive nature of this scenario, which does not include non-Annex I countries and generates therefore potential *pollution havens* for carbon emissions.

Table 9: Change of CO_2 intensities by country region and sectors - BUS vs. BAU 2020

	P_C	ELY	EIS	COA	OIL	GAS	NEIS	TRN	FOOD	SERV
	Change relative to BAU 2020 (in %)									
Industrialized Countries										
AUT	-29.6%	-17.3%	-15.2%	-	-76.6%	-71.6%	-54.7%	-34.2%	-56.6%	-50.3%
GER	-27.5%	-19.0%	-10.2%	-34.3%	-62.9%	-22.3%	-33.9%	-14.2%	-32.2%	-34.4%
ITA	-28.4%	-15.3%	-9.2%	-41.5%	-71.6%	-46.2%	-46.8%	-27.4%	-46.1%	-45.8%
WEU	-28.5%	-18.2%	-6.0%	-45.3%	-57.9%	-49.6%	-57.2%	-29.7%	-57.8%	-51.9%
SEEU	-29.9%	-19.4%	-19.6%	-44.7%	-43.5%	-40.8%	-38.3%	-18.1%	-35.9%	-37.4%
NEU	-28.1%	-19.5%	-9.8%	-44.5%	-69.6%	-57.7%	-41.0%	-20.3%	-42.6%	-41.6%
RUS	-9.7%	+0.2%	+2.8%	+8.2%	+5.1%	+2.7%	+5.4%	+4.6%	+9.7%	+10.3%
ROE	-39.8%	-22.1%	-23.8%	-56.0%	-71.1%	-66.7%	-60.8%	-30.3%	-55.7%	-62.6%
GUS	-8.1%	+3.4%	+3.1%	-14.3%	-16.3%	-5.2%	-7.8%	-3.3%	-2.9%	-9.7%
USA	-19.2%	-14.5%	-11.2%	-49.2%	-49.6%	-41.1%	-40.8%	-21.1%	-43.5%	-39.1%
NAM	-20.3%	-12.4%	-14.4%	-55.9%	-43.9%	-38.6%	-35.9%	-17.8%	-34.4%	-36.0%
OCEA	-25.4%	-16.3%	-14.9%	-50.1%	-68.5%	-52.4%	-48.6%	-25.5%	-46.6%	-42.9%
EASI	-29.6%	-16.1%	-10.4%	-62.2%	-69.3%	-51.4%	-40.8%	-27.3%	-42.0%	-40.8%
Less Developed Countries										
LAM	-4.3%	+5.8%	+6.1%	+13.5%	+12.7%	+11.0%	+9.2%	+6.9%	+11.0%	+7.9%
CHN	-7.9%	+0.2%	+4.1%	+3.0%	+11.5%	-0.1%	+5.4%	+7.4%	+8.1%	+8.5%
SEAS	-3.0%	+3.0%	+9.1%	+25.9%	+19.0%	+17.2%	+14.2%	+7.2%	+15.4%	+13.2%
SASI	-12.9%	+3.0%	+4.4%	+23.5%	-6.1%	-5.7%	+7.8%	+9.6%	+11.4%	+5.9%
MENA	-3.7%	+1.0%	+6.4%	+11.9%	+9.9%	+8.5%	+12.0%	+5.7%	+10.3%	+10.1%
SSA	+0.9%	+7.7%	+8.7%	+9.4%	+26.9%	+25.3%	+14.5%	+8.1%	+14.7%	+13.8%

5.2 A global agreement in the fight against global warming – the global IPCC scenario

The previous section argued that a bottom-up approach for a post-2012 climate policy framework is unlikely to deliver the mitigation efforts needed to tackle the problem of climate change. Carbon leakage may even jeopardize the environmental effectiveness of such a unilateral, voluntary climate policy framework. Considering the high risks associated with overshooting a global mean temperature increase above +2°C compared to pre-industrial levels, there exists an urgent need for much stricter, more comprehensive mitigation efforts. One such set of mitigation trajectories is represented by the IPCC’s proposal to reduce GHG emissions in Annex I countries to the UNFCCC Kyoto Protocol by -25% to -40% compared to 1990 emission levels until 2020. In addition, non-Annex I countries are required to reduce their emissions by 15% below BAU, as can be seen in the last column of Table 10[4]. These diverse emissions reduction objectives reflect the fact of substantially different historic emission obligations by ICs in contrast to LDCs, and smoothes therefore the way for a convergence to a more equitable per capita distribution of the resulting anthropogenic carbon emissions budget (Böhringer and Welsch, 2004).

Table 10: Carbon effects by country group of a global IPCC scenario (GA)

	2004	BAU 2020	GA	GA	GA
		in Mt CO_2		relative to 2004	relative to BAU 2020
EU	4,381	5,156	3,276	-25.2%	-36.5%
Eastern Europe	3,051	3,601	3,470	+13.7%	-3.6%
NAM (incl. USA)	7,294	8,894	4,710	-35.4%	-47.0%
OCEA	434	528	243	-44.0%	-53.9%
EASI	1,956	2,230	1,564	-20.0%	-29.8%
Industrialized Countries	17,116	20,409	13,263	-22.5%	-35.0%
LAM	1,087	1,132	967	-11.0%	-15.0%
CHN	4,853	6,830	5,824	+20.0%	-15.0%
SASIA (excl. CHN)	2,104	3,056	2,595	+23.3%	-15.0%
AFRICA	2,573	2,736	2,584	+0.4%	-5.5%
Less Developed Countries	10,618	13,754	11,970	+12.7%	-13.0%
Total	27,734	34,163	25,233	-9.1%	-26.1%

This global agreement (GA) scenario, limiting total global CO_2 emissions, results in a 9.1% reduction of global emissions by 2020 compared to 2004. Thus, the necessary peak of global anthropogenic CO_2 emissions between 2015 and 2020 (The Copenhagen Diagnosis, 2009) can be accomplished within this scenario setting and can be seen as the first step to a substantial reduction of global annual GHG emissions until midst of the century as demanded by the IPCC to stay within a 450 to 500ppm CO_2e concentration of GHGs in the atmosphere (IPCC, 2007).

Especially the effect on LDC's CO_2 emissions is highly important, since it reflects a big step forward to achieve a decoupling of economic growth (at an annual GDP growth rate of 3.59% p.a. between 2012 and 2020) from energy consumption and in turn a reduction in CO_2 emission intensity. While LDCs achieve an important deviation from the BAU emissions growth path, ICs as a whole can reduce their CO_2 emissions by 22.5% under the 2004 level – from 17,116 Mt CO_2 to 13,263 Mt CO_2. Only the

[4] Note that the reduction target for the region AFRICA is lower than for other LDCs. We assume a less stringent emission constraint compared to BAU for this region, since emissions under BAU are predicted to rise only marginally compared to 2004 levels, due to a very low level of economic and human development. Setting too high reduction objectives already until 2020 might jeopardize development in some African regions.

Eastern European countries, above all Russia among the GUS countries, still generate more CO_2 emissions under this scenario setting as in 2004, namely by 13.7%. This is due to the considerable emission reductions which took place after the collapse of the former Soviet Union and the resulting economic downturn, even allowing these countries to increase emissions when targets are set on the basis of 1990 levels.

Taking a look at the economic effects of an internationally coordinated climate policy regime, Table 11 shows that in this global scenario also LDCs experience a decrease in their output levels. The effects on ICs' output become more severe than under *BUS*. This results not only from stricter mitigation objectives, but also from the circumstance that in addition to the decreasing domestic demand and foreign demand from other Annex I countries as in BUS, now in addition LDCs begin to reduce their demand for goods from Annex I countries.

Table 11: Sectoral output effects by country group of the global IPCC scenario (GA) (relative to BAU 2020, in %)

	Industrialized countries					Less developed countries			
	EU	Eastern Europe	NAM (incl. USA)	OCEA	EASI	LAM	CHN	SASI (excl. CHN)	AFRICA
P_C	-29.8%	-2.7%	-47.2%	-55.3%	-21.6%	-12.0%	-5.5%	-10.8%	-2.9%
ELY	-16.2%	-3.2%	-31.0%	-37.7%	-16.8%	-3.0%	-10.8%	-7.7%	-6.8%
EIS	-4.3%	+2.9%	-14.1%	-16.8%	-7.3%	+0.9%	-3.2%	-5.9%	+16.3%
ETS total	-7.7%	+0.1%	-21.2%	-23.6%	-9.8%	-2.0%	-4.3%	-7.1%	+6.6%
COA	-42.8%	-14.8%	-48.4%	-45.1%	-29.8%	-14.2%	-15.1%	-2.8%	-0.1%
OIL	-28.9%	-9.2%	-66.4%	-69.7%	-70.2%	-24.5%	-0.0%	-13.0%	-4.2%
GAS	-62.0%	-5.0%	-53.1%	-68.2%	-100.0%	-32.6%	-31.4%	-9.5%	-22.1%
NEIS	-3.2%	-1.5%	-3.3%	-3.5%	-8.6%	+0.4%	-5.8%	-6.5%	+13.5%
TRN	-17.9%	-0.3%	-31.1%	-32.6%	-7.1%	+1.4%	+4.5%	-4.9%	+29.1%
FOOD	-5.7%	-4.4%	-10.1%	-10.9%	-4.2%	-1.2%	-0.6%	-0.1%	-3.4%
SERV	-1.9%	-6.0%	-3.2%	-4.8%	-0.5%	-1.3%	-1.1%	-0.7%	-7.4%
CGDS	-2.7%	-10.9%	-4.3%	-6.6%	+1.2%	-3.2%	-0.3%	-1.5%	-21.1%
NETS total	-3.6%	-5.5%	-5.3%	-7.8%	-2.6%	-1.9%	-2.5%	-2.8%	-4.1%
TOTAL	-4.1%	-4.5%	-6.7%	-9.3%	-3.5%	-1.9%	-2.8%	-3.4%	-2.8%

On a sectoral basis, again the fossil energy intensive, and therefore also carbon intensive sectors, suffer most from the introduction of a CO_2 price mechanism. This fact is true for all countries – industrialized and less developed alike. However output decreases substantially less in LDCs since their emission objectives are by no means as strict as their counterparts in ICs – thus reflecting the vision of shared but differentiated responsibilities.

5.3 An incentive for LDCs to get on board of climate policy – the Copenhagen Green Climate Fund

The negotiations at COP 15 in Copenhagen have pointed out that it will be a crucial, yet a difficult task to get LDCs on board of post-2012 climate policy. Many analysts found that the substantial contraction of GHG emissions necessary to stay within the +2°C frontier will not be manageable without the active participation of LDCs (see e.g. Stern, 2009 and UN, 2009c) and that their essential participation is likely to increase if a global agreement is perceived to be fair (Bohm and Larsen, 1994; Morrisette and Plantinga, 1991). The LDCs' lack of confidence in a top-down climate policy agreement, with respect to a fair and equitable distribution of mitigation efforts, was one of the reasons for the weak outcome of the climate policy negotiations at Copenhagen. Right from the start of the conference, the G77 and China were calling for ICs to go ahead by stating binding and demanding reduction targets as well as by agreeing to provide financial, technological and capacity-building support for the LDCs' mitigation efforts. In order to achieve a closing document which was at least "recognized" by the parties to the UNFCCC, one important move was the declaration of intent to establish the so-called Copenhagen Green Climate Fund (CGCF). This – not yet formally created – fund aims at channeling financial resources for mitigation and adaptation efforts from ICs to LDCs. The following section will analyze a global scenario similar to the just described GA setting, with the difference that ICs mobilize the proposed financial resources to address the needs of LDCs.

5.3.1 The Copenhagen Green Climate Fund (CGCF) scenario without explicit constraints for LDCs

The results for CO_2 emissions of the modeling approach of the CGCF as set out in section 4 are depicted in Table 12. This first scenario, *CGCF,* analyzes, whether the financial support under the CGCF is sufficient to induce the desired -15% deviation from BAU in LDCs or whether a global deal necessitates explicit emissions reduction objectives also for LDCs in addition to financial and technological support. We assume that LDCs receive in total an annual transfer of USD 95 billion in 2020, drawn as 10% from emission allowances sales to energy intensive industries in ICs, which can be utilized by LDCs to foster final demand or investments. In addition, LDCs as a group are modeled as receiving an additional capital stock of USD 33 billion by 2020, which is exclusively utilized in the power generation sector ELY, to improve energy efficiency there.

The crucial finding of Table 12 is that financial support – although it is earmarked to the use in energy improvement measures in the electricity sector –, is unlikely to trigger the desired outcome of reducing CO_2 emissions in LDCs, without setting explicit GHG emission targets for the recipient countries. LDCs do not achieve a deviation from their BAU emission trajectories; en masse they even overshoot the BAU 2020 results by 11.4%.

Table 12: Carbon effects by country group of the Copenhagen Green Climate Fund without constraints for LDCs (CGCF)

	2004	BAU 2020	CGCF	CGCF	CGCF
		in Mt CO_2		relative to 2004	relative to BAU 2020
EU	4,381	5,156	3,276	-25.2%	-36.5%
Eastern Europe	3,051	3,601	3,470	+13.7%	-3.6%
NAM (incl. USA)	7,294	8,894	4,710	-35.4%	-47.0%
OCEA	434	528	243	-44.0%	-53.9%
EASI	1,956	2,230	1,564	-20.0%	-29.8%
Total for Industrialized Countries	17,116	20,409	13,263	-22.5%	-35.0%
LAM	1,087	1,132	1,326	+21.9%	+17.1%
CHN	4,853	6,830	7,247	+49.3%	+6.1%
SASIA (excl. CHN)	2,104	3,056	3,456	+64.2%	+13.1%
AFRICA	2,573	2,736	3,289	+27.8%	+20.2%
Total for Less Developed Countries	10,618	13,754	15,318	+44.3%	+11.4%
Total	27,734	34,163	28,581	+3.1%	-16.4%

Table 13: CO_2 intensities of electricity production in LDCs in tCO_2/MUSD

	2004	BAU 2020	GA	CGCF	GA	CGCF
		tCO_2 / MUSD			relative to 2004	
LAM	3,044	2,696	2,450	2,719	-20%	-11%
CHN	21,464	7,805	17,261	16,341	-20%	-24%
SEAS	5,933	5,107	4,892	4,872	-18%	-18%
SASI	10,757	9,139	8,472	8,735	-21%	-19%
MENA	10,228	9,189	8,901	8,723	-13%	-15%
SSA	16,595	14,618	15,848	14,444	-5%	-13%

The reason for this puzzling result is that, even though most LDCs achieve a reduction of their CO_2 intensity within the power generation sector compared to the *GA* scenario (in which no financial support was granted to LDCs[5], but they were confronted with emission reduction obligations) (see

[5] For LAM and SASIA the financial support is obviously not sufficient to trigger a measurable increase of energy efficiency in the whole power generation sector in the absence of explicit emissions reduction objectives. These regions are even subject to a worsening of their ELY emissions coefficients in scenario CGCF relative to GA – rising electricity output induces a shift to less clean energy production, which could not even be counteracted by investments in energy efficiency improvements under the CGCF.

Table 13), this does not hold true for the other economic sectors, such as EIS, NEIS or P_C (see Table 14). Without financial support under the CGCF and without explicit limits to their CO_2 emissions levels, these sectors face too little incentives to improve energy efficiency of production processes.

Table 14: Absolute difference of CO_2 intensities in LDCs – CGCF without constraints vs. GA with constraints for LDCs

	P_C	ELY	EIS	COA	OIL	GAS	NEIS	TRN	FOOD	SERV
	tCO$_2$ / MUSD									
LAM	+95.9	+269.4	+116.1	+66.2	+195.3	+999.5	+20.8	+351.0	+35.2	+7.8
CHN	+6.0	-919.7	+166.7	+700.7	+234.8	+1,321.8	+29.3	+177.1	+111.5	+28.2
SEAS	+60.8	-19.7	+112.6	+119.6	+38.1	+40.0	+15.2	+207.6	+41.8	+12.7
SASI	-1.5	+262.5	+160.9	+289.2	+93.4	+157.7	+24.6	+257.1	+30.6	+15.9
MENA	+356.8	-178.7	+378.2	+104.1	+41.3	+250.2	+85.8	+428.5	+58.5	+30.6
SSA	+7.2	-1,403.8	+2.2	+0.1	+1.0	+42.9	-0.4	-22.2	-0.7	-0.1

Table 15: CO_2 emissions increase under CGCF compared to GA

	CHN	SEAS	SASI	LAM	MENA	SSA
	in Mt CO$_2$					
COA	56	1	2	0	0	0
OIL	12	2	2	18	14	1
GAS	27	1	2	14	18	0
P_C	2	19	3	19	126	0
ELY	413	60	142	36	116	-34
EIS	349	67	78	50	130	-10
NEIS	92	17	10	8	23	-1
TRN	95	152	79	135	174	-13
FOOD	110	18	21	17	15	0
SERV	82	13	14	11	30	0
PrivHH	185	31	124	49	112	4
Total	+1424	+382	+478	+358	+758	-53

Moreover, as Table 15 points out, total emissions in LDCs are increasing in scenario CGCF compared to scenario GA. This increase in emissions is on the one hand triggered by the fact that – with the exemption of ELY– no sectors or households are subject to climate policy regulations and on the other hand by a rebound effect[6] in the controlled ELY sector. Since the power sector in LDCs receives

[6] If production costs in a certain sector can be reduced by reducing the amount of energy input per unit of output – by increasing the efficiency of the production process –, the cost savings might be rerouted to an expansion of the production levels (Binswanger, 2000).

financial support from ICs, and is thus substituting capital inputs for energy inputs, which in turn is reflecting efficiency gains, electricity production becomes relatively cheaper. The decreasing emission coefficients for the LDCs' ELY sectors in Table 13 and Table 14 point in the same direction; however this per unit emissions decrease is in the end more than counterbalanced by rising output levels.

Not only electricity production tends to increase in the LDCs, in fact overall output reflects an upward trend (see Table 16). Compared to scenario *GA*, where LDCs were subject to carbon constraints and experienced therefore a decline of output compared to BAU 2020, in *CGCF* without explicit constraints their overall output – predominantly the output of ETS sectors – increases compared to BAU, by 1.1% for CHN to 2.6% for Africa.

Table 16: Sectoral output effects by country group of the Copenhagen Green Climate Fund without constraints for LDCs (relative to BAU 2020, in %)

	Industrialized countries					Less developed countries			
	EU	Eastern Europe	NAM (incl. USA)	OCEA	EASI	LAM	CHN	SASI (excl. CHN)	AFRICA
P_C	-29.3%	-2.3%	-46.7%	-52.7%	-22.8%	+16.7%	+12.1%	+20.9%	+22.6%
ELY	-16.3%	-3.4%	-31.1%	-37.6%	-16.5%	+6.5%	+8.7%	+8.1%	+10.4%
EIS	-4.7%	+1.5%	-14.0%	-18.2%	-7.5%	+4.2%	+3.3%	+3.1%	+21.7%
ETS total	-7.9%	-0.6%	-21.1%	-24.3%	-10.1%	+6.8%	+4.9%	+7.3%	+20.1%
COA	-41.1%	-13.3%	-47.3%	-0.0%	-0.0%	-0.0%	-0.0%	-0.0%	-5.7%
OIL	-5.6%	-5.2%	-54.2%	-34.1%	-0.0%	-0.0%	-0.0%	-0.0%	+0.0%
GAS	-53.5%	-2.0%	-52.5%	-59.7%	-99.8%	-0.0%	+0.0%	+0.0%	-0.0%
NEIS	-2.6%	-1.4%	-2.6%	-4.1%	-6.9%	-2.1%	-3.4%	-5.7%	+9.5%
TRN	-19.6%	-2.8%	-31.7%	-33.8%	-7.9%	+28.7%	+10.8%	+28.4%	+47.4%
FOOD	-5.1%	-4.0%	-9.6%	-10.4%	-4.1%	-2.0%	+1.3%	+1.4%	-2.2%
SERV	-1.8%	-5.6%	-3.2%	-4.9%	-0.7%	-0.4%	+1.4%	+0.4%	-4.7%
CGDS	-2.8%	-10.0%	-4.1%	-6.8%	+0.6%	+1.2%	+3.2%	+1.6%	-10.6%
NETS total	-3.4%	-5.1%	-5.1%	-7.5%	-2.5%	+0.8%	+0.3%	+0.9%	+0.0%
TOTAL	*-3.9%*	*-4.3%*	*-6.5%*	*-9.1%*	*-3.4%*	*+1.7%*	*+1.1%*	*+1.8%*	*+2.6%*

The increasing domestic production is caused by two trends. First, the representative households in LDCs are equipped with more disposable income compared to the global scenario without the CGCF in place, triggering a higher domestic final demand. The model results show an average GDP growth rate for LDCs of 3.76% between 2012 and 2020 compared to 3.59% under *GA* assumptions, resulting in a 2.6% higher 2020 GDP. The LDCs' overall average annual GDP growth would even slightly increase above the BAU 2020 level (see Table 17).

The second driver of production, and therefore CO_2 emissions increases in LDCs, is to be found in rising exports, triggered by foreign demand from ICs, especially for products stemming from energy intensive industries, since this sector is strongly regulated in ICs under climate policy agreements. While in the *GA* scenario LDCs were also subject to environmental regulations concerning CO_2 emissions, their energy intensive industries face now no limitations on their emissions and are therefore able to increase their output to satisfy domestic and foreign demand.

Table 17: Annual average GDP growth rates (2004-2020) for ICs and LDCs for scenarios GA and CGCF

regions / scenarios	BAU 2020	GA	CGCF
EU	2.38	2.17	2.17
Eastern Europe	2.62	2.17	2.20
OCEA	2.99	2.52	2.53
NAM	2.61	2.31	2.32
EASI	2.43	2.30	2.30
Industrialized Countries	*2.50*	*2.25*	*2.26*
LAM	1.32	1.22	1.33
CHN	5.90	5.77	5.92
SASIA	4.78	4.63	4.81
Africa	1.59	1.36	1.56
Less Developed Countries	*3.74*	*3.59*	*3.76*

This leads to the appearance of carbon leakage also under scenario *CGCF*. We find the carbon leakage rate in this scenario amounting to 21%. This percentage is lower than in the BUS scenario which was described before. In *CGCF* ICs are subject to much stricter emission constraints, leading to more substantial CO_2 emission reductions in absolute terms. At the same time the CO_2 emissions increase in unregulated LDCs is in absolute terms not significantly higher than under *BUS*, in which LDCs were not subject to carbon constraints either. The increment of 156 MT CO_2 is again triggered by the even stronger increasing foreign demand from ICs.

Even though ICs provide part of their CO_2 permit sale revenue as financial assistance for energy efficiency improvement measures in the LDCs' electricity sectors, they do profit from doing so. Again, since the LDC's representative households are equipped with more disposable income in this scenario than under the GA setting, they also demand more imported goods stemming from ICs, next to an increased domestic final demand. This leads to a lower decrease of ICs' overall output (compare last lines of Table 16 and Table 11) , as well as to higher average annual GDP growth rates between 2004 and 2020 in *CGCF* than under *GA* (see and Table 17). However, ICs have to accept a lower growth rate in *GA* and *CGCF* than under BAU 2020, in order to achieve an increase in environmental quality, expressed by decreasing CO_2 emissions.

In order that financial transfers under *CGCF* can be utilized in an efficient and effective way it is therefore inevitable to restrict future carbon emissions also in LDCs – at least as proposed by the IPCC by a certain degree under BAU emission levels. Otherwise, LDCs are very likely to become – up to a certain extent – carbon havens, by producing goods which ultimately satisfy not only their domestic demand but also the foreign demand of domestically abating ICs. Furthermore a decarbonization of their economies and the development of a low-carbon high-growth path would be out of reach. Therefore a final policy scenario investigates the combination of explicit emission obligations for LDCs as under *GA*, and the financial support mechanism *CGCF*.

5.3.2 The CGCF with explicit targets for LDCs – the CGCF+GA scenario

The previous section argued that in order to get LDCs on board of post-2012 climate policy, ICs have to take the lead by taking on ambitious, legally binding targets as well as providing financial, technological and capacity-building support for LDCs. Yet we have also seen in the last section that the envisioned CGCF will only be environmentally effective if LDCs are not allowed to let their emissions grow in sectors which are not supported by capital from ICs. Without explicit CO_2 emissions objectives, LDCs do not have a strong incentive to reduce their CO_2 emissions, since they are able to earn profits by producing carbon intensive goods for ICs. Nevertheless, since GHG emissions are global pollutants and due to the fact that it will be the LDCs themselves, who will be hit earliest and hardest by the severe negative impacts of climate change, LDCs would benefit from climate change mitigation efforts, especially if they are supported by ICs.

Table 18: Carbon effects of a global agreement with support for LDCs – CGCF+GA

	2004	**BAU 2020**	**CGCF+GA**	**CGCF+GA**	**CGCF+GA**
		in Mt CO_2		relative to 2004	relative to BAU 2020
EU	4,381	5,156	3,276	-25.2%	-36.5%
Eastern Europe	3,051	3,601	3,470	+13.7%	-3.6%
NAM (incl. USA)	7,294	8,894	4,710	-35.4%	-47.0%
OCEA	434	528	243	-44.0%	-53.9%
EASI	1,956	2,230	1,564	-20.0%	-29.8%
Industrialized Countries	17,116	20,409	13,263	-22.5%	-35.0%
LAM	1,087	1,132	967	-11.0%	-15.0%
CHN	4,853	6,830	5,824	+20.0%	-15.0%
SASIA (excl. CHN)	2,104	3,056	2,595	+23.3%	-15.0%
AFRICA	2,573	2,736	2,561	-6.4%	-6.3%
Less Developed Countries	10,618	13,754	11,947	+12.5%	-13.1%
Total	27,734	34,163	25,210	-9.1%	-26.2%

Table 18 depicts the global carbon effects for the *CGCF+GA* scenario, which is a combination of the *CGCF* scenario and the *GA* setting. The results are almost identical with the *GA* results, since the same reduction targets are applied. Therefore the environmental effectiveness is also given within this scenario.

Regarding environmental effectiveness in the context of achieving the +2°C target, as well as economic impacts of the *CGCF+GA* scenario, we will take a closer look at the sectoral energy efficiency effects in LDCs (see Table 20) as well as on their economic growth performances. This scenario finds an average GDP growth rate of 3.63% for LDCs, with substantial contributions by China and the rest of South and Southeast Asia. Even though this GDP growth rate is slightly lower than under *CGCF* scenario assumptions, in which LDCs were not subject to emission objectives, the effectiveness of the CGCF can be deduced from an increase in the overall GDP of LDCs by USD 64.5 billion in 2020 compared to scenario *GA*, where LDCs had to fulfill the same emission reduction objectives, but without financial transfers from ICs (see Table 19).

Table 19: GDP and annual average GDP growth rates (2004-2020) for industrialized and less developed countries

regions / scenarios	GA	CGCF	CGCF+GA	GA	CGCF	CGCF+GA
		in MUSD 2004			% p.a. 2004-2020	
EU	19,027,704	19,047,213	19,026,996	2.17	2.17	2.17
Eastern Europe	1,605,506	1,611,959	1,605,464	2.17	2.2	2.17
OCEA	1,124,513	1,127,183	1,124,418	2.52	2.53	2.52
NAM	19,227,751	19,250,576	19,236,465	2.31	2.32	2.31
EASI	8,388,867	8,391,210	8,389,803	2.3	2.3	2.3
Industrialized Countries total	*49,374,341*	*49,428,142*	*49,383,145*	*2.25*	*2.26*	*2.26*
LAM	1,791,599	1,824,622	1,799,476	1.22	1.33	1.24
CHN	4,109,352	4,204,571	4,134,573	5.77	5.92	5.81
SASIA	3,324,010	3,420,693	3,339,506	4.63	4.81	4.66
Africa	2,036,700	2,099,926	2,052,636	1.36	1.56	1.41
Less Developed Countries total	*11,261,661*	*11,549,812*	*11,326,190*	*3.59*	*3.76*	*3.63*

Since CO_2 emissions in LDCs are only allowed to increase by 85% compared to BAU assumptions, also the emissions intensity in the different sectors is decreasing compared to a scenario without emission constraints (*CGCF*). The strongest decline of emission intensity happens in the ELY sector, which is the sector directly benefiting from CGCF transfers. Also the emission coefficients of the other sectors are decreasing until the disposable carbon budget is fully deployed. Only in Sub Saharan Africa, where we do not implement any emission restrictions, CO_2 intensities in some sectors are slightly increasing in the *CGCF+GA* scenario compared to *CGCF* (see Table 20).

Table 20: Absolute differences of CO_2 intensities in LDCs – CGCF+GA vs. CGCF

	P_C	ELY	EIS	COA	OIL	GAS	NEIS	TRN	FOOD	SERV
					tCO_2 / MUSD					
LAM	-89.0	-382.5	-102.4	-65.9	-195.7	-1,001.3	-20.5	-350.4	-34.8	-7.5
CHN	-5.8	-591.2	-114.9	-700.6	-233.0	-1,377.6	-28.2	-180.8	-110.4	-27.3
SEAS	-54.8	-367.8	-96.1	-119.8	-38.3	-40.2	-14.8	-207.8	-41.3	-12.1
SASI	+2.3	-866.4	-86.1	-291.0	-97.6	-164.0	-24.6	-264.6	-30.4	-15.7
MENA	-343.9	-405.8	-350.2	-102.4	-41.3	-250.1	-84.1	-425.7	-56.8	-29.3
SSA	-5.7	+11.5	+7.8	+0.2	+0.4	-31.2	+1.9	+32.9	+2.0	+0.8

Output of LDCs still can be expanded under this scenario compared to *GA*, where LDCs do not receive financial support from ICs, even though considerably less than if no emission constraints are levied on LDCs like in scenario *CGCF*. That it nevertheless comes to an increase of economic output is due to the fact that on the one hand the high efficiency gains in the ELY sector lead to a raise in output of this sector itself, but on the other hand, are releasing emission allowances for other sectors, which can be used to increase output, despite explicit investment in energy efficiency improvements. Therefore also exports of energy intensive products to ICs increase, since they become relatively cheaper on the international market (see Table 21).

Table 21: Output effects by country group of a global agreement with support for LDCs – CGCF+GA (relative to scenario GA, in %)

	Industrialized countries					Less developed countries			
	EU	Eastern Europe	NAM (incl. USA)	OCEANIA	EASI	LAM	CHN	SASI (excl. CHN)	AFRICA
P_C	0.0%	0.0%	0.2%	0.2%	-0.1%	-0.9%	0.8%	-0.2%	-0.2%
ELY	-0.1%	-0.2%	-0.1%	-0.1%	0.0%	1.9%	5.8%	5.2%	3.3%
EIS	-0.1%	0.3%	0.4%	0.4%	0.0%	-0.3%	1.3%	0.9%	-0.1%
ETS total	-0.1%	0.1%	0.3%	0.3%	0.0%	-0.1%	1.7%	1.4%	0.4%
COA	0.7%	0.1%	0.2%	2.9%	0.3%	-3.5%	-1.2%	-2.1%	-5.4%
OIL	1.2%	0.2%	3.6%	3.8%	6.7%	-2.1%	0.0%	-1.7%	-0.5%
GAS	0.5%	0.1%	0.3%	0.5%	16.4%	-2.5%	1.6%	-1.0%	-1.3%
NEIS	0.3%	0.6%	0.9%	0.7%	0.5%	-0.9%	-0.8%	-1.4%	-0.4%
TRN	0.2%	0.3%	0.3%	0.2%	0.1%	-0.8%	-0.3%	-0.7%	-1.2%
FOOD	0.1%	0.1%	0.1%	0.8%	0.0%	0.0%	0.6%	1.3%	0.9%
SERV	-0.1%	-0.2%	-0.2%	-0.2%	-0.1%	0.8%	1.3%	1.0%	1.2%
CGDS	-0.2%	-0.2%	0.0%	-0.3%	-0.2%	1.9%	2.3%	1.0%	2.9%
NETS total	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.6%	0.3%	0.7%
TOTAL	*0.0%*	*0.0%*	*0.1%*	*0.0%*	*0.0%*	*0.3%*	*0.8%*	*0.4%*	*0.7%*

Even though the economic effects for ICs are still negative compared to BAU 2020 and *BUS*, which is characterized by quite weak – but unilateral – targets for Annex I countries, also ICs can profit from the financial support they provide to LDCs. Since the financial transfers increase the LDCs' representative households' disposable income, they also increase their demand for foreign products and services originating from ICs. As a result, output and in turn GDP in many ICs sectors increase slightly, due to higher exports to LDCs. Table 19 presents GDP and the annual average GDP growth rates in the different scenarios, while Table 21 provides a sectoral break-down for scenario *CGCF+GA* compare to *GA*.

6. Discussion

Having seen that the different scenarios lead to reduced economic performance but higher environmental effectiveness compared to BAU 2020, the question arises as to how human well-being is affected both on a global scale as well as for ICs and LDCs separately. This question cannot be answered within our static CGE model since we assume there that households derive utility from instantaneous commodity consumption only. To incorporate such a social planner perspective, we therefore proceed by using our quantitative results on economic performance (GDP growth) environmental effectiveness (reduced CO_2 emissions) and assess them together within the following function for human wellbeing[7]:

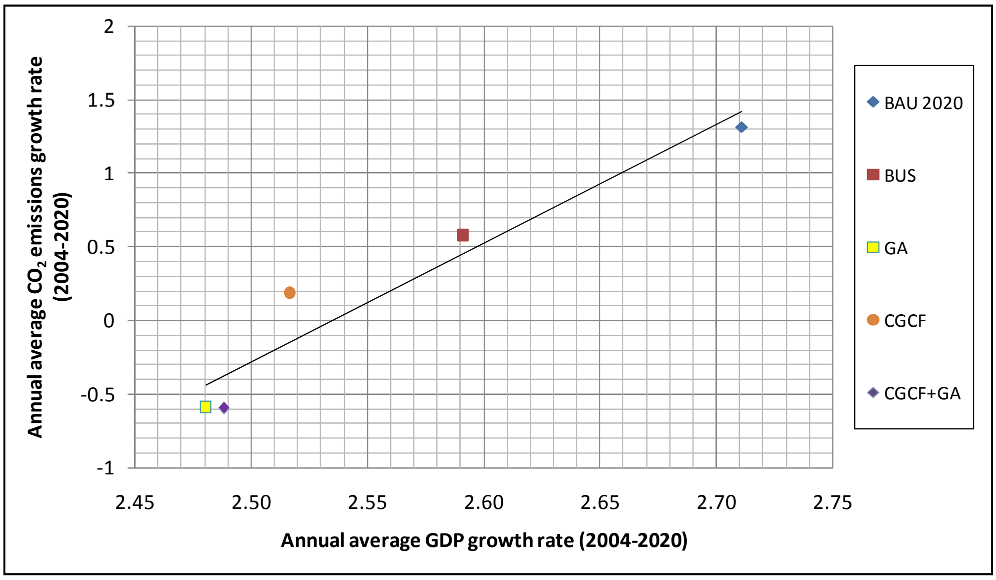
$$HWB(C,E) = C^{\alpha}E^{\beta}$$

with $\alpha + \beta = 1$. α and β represent the relative preferences for consumption *C* (expressed by GDP), and environmental quality *E*, measured by the mitigation level (reduced CO_2 emissions). Similarly as a social welfare function, this approach does not consider a single individual, but the society as a whole. Furthermore, by conditioning human well-being additionally on environmental quality, this approach moves beyond affiliating human well-being exclusively with commodity consumption and/or economic growth as the main driver to achieve higher welfare levels.

Before constructing the indifference curve map for human wellbeing under the different scenarios, we start by comparing global GDP to the global CO_2 emissions growth rates across scenarios on average for the time horizon 2004 to 2020 (see Figure 5). It clearly follows that a somewhat slower economic growth will inevitably have to be accepted, for achieving the +2° C target.

[7] The human well-being function is based on the commonly used Cobb-Douglas utility function. However, it is important to note, that a Cobb-Douglas utility function represents only one possibility to illustrate people's preferences. Other forms of particular utility functions can e.g. be characterized by a constant elasticity of substitution (CES), perfect substitutability or perfect complementarity (Nicholson, 2005).

Figure 5: Global Economic Growth vs. Environmental Effectiveness



For realizing this target, global society has to depart from a situation situated somewhere in the far top-right corner of Figure 5, with an average annual GDP growth rate between 1999 and 2008 of 3.98% and annual global CO_2 emission still growing at high rates, to a point in the lower left corner to guarantee sustainability.

Table 22: Annual average GDP growth rates (2004-2020) for industrialized and less developed countries

regions / scenarios	1999-2008	BAU 2020	BUS	GA	CGCF	CGCF+GA
EU	2.44	2.38	2.22	2.17	2.17	2.17
Eastern Europe	4.33	2.62	2.25	2.17	2.20	2.17
OCEA	2.66	2.99	2.84	2.52	2.53	2.52
NAM	3.18	2.61	2.50	2.31	2.32	2.31
EASI	1.89	2.43	2.31	2.30	2.30	2.30
Industrialized Countries	*2.48*	*2.50*	*2.35*	*2.25*	*2.26*	*2.26*
LAM	3.50	1.32	1.31	1.22	1.33	1.24
CHN	9.76	5.90	5.90	5.77	5.92	5.81
SASIA	5.92	4.78	4.79	4.63	4.81	4.66
Africa	4.62	1.59	1.52	1.36	1.56	1.41
Less Developed Countries	*6.11*	*3.74*	*3.73*	*3.59*	*3.76*	*3.63*
World	**3.98**	**2.71**	**2.59**	**2.48**	**2.52**	**2.49**

Table 22 shows the regional breakdown of GDP effects: while all world regions will have to accept lower GDP growth rates on account of climate policies, especially LDCs will not be able to return to their pre-crisis growth performances, as indicated by the average annual GDP growth rate between 1999 and 2008 (see column 2 in Table 22). Even though the LDCs' GDP growth rates in the presence of climate policy regimes remain above those in ICs, they are subject to substantial decreases compared to the pre-crisis era, and they become particularly low under scenarios *GA* and *CGCF+GA*. This can be traced back on the one hand to the direct impacts of CO_2 mitigation objectives on LDCs' domestic markets, but on the other hand to the even more important factor of decreasing foreign demand by ICs.

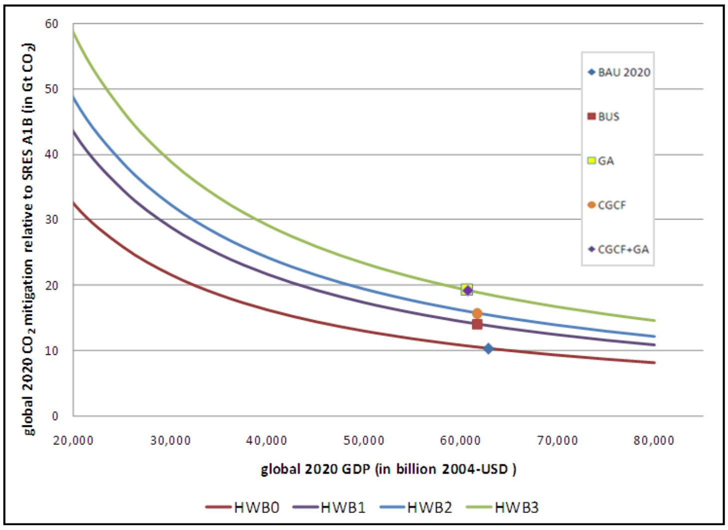
Therefore the economic growth rates of LDCs and ICs experience a convergence until 2020, with the average annual GDP growth rate of LDCs only 1.24 percentage points above the ICs' equivalent, compared to 3.63 percentage points in the period 1999-2008. This convergence is on the one hand triggered by weaker growth rates for multi factor productivity as well as capital accumulation, compared to the recent past and on the other hand by the disproportionately strong impacts of the current economic crisis on the LDCs' economies. Moreover, it can be derived from these results that ICs will be confronted with a higher decrease of their annual average GDP growth rate, namely by 0.24 percentage points compared to BAU 2020, than the LDCs. This country group instead will experience in *CGCF+GA* a decline of their annual average growth rate by 0.11 percentage point, again relative to BAU 2020.Nevertheless, the question arises if a slow-down of economic growth does necessarily trigger a de facto reduction of human well-being, since, in turn, other important factors for human well-being, such as favorable environmental conditions, can be strengthened.

Having discussed effects for economic performance and CO_2 emissions separately, we can now combine both within an indifference curve map for the human well-being. Assuming values for $\alpha = \beta = 0.5$, which means that the global society values economic growth and environmental quality equally strong, Figure 6 relates the model results to this enhanced concept of human well-being[8].The graph depicts global GDP in 2020, measured in billions of 2004-USD, on the X-axes and on the Y-axes the deviation of estimated 2020 annual global CO_2 emissions relative to the A1B CO_2 emissions scenario for fossil fuel combustion from the IPCC's special report on emission scenarios (SRES) (Nakicenovic et al., 2000). We can see that the BAU 2020 scenario already implies a reduction of global annual CO_2 emissions compared to the SRES scenario A1B. This is mainly due to the fact that this paper already included the current economic downturn in its analysis, while the SRES, released in 2000, did not expect such economic developments. The BAU 2020 as well as the *BUS* scenario, which can be identified by relatively high global average annual GDP growth rates in combination with high average annual CO_2 emissions growth rates, are situated on the lower curves of the indifference curve map in Figure 6, namely HWB_0 and HWB_1. As anthropogenic CO_2 emissions cannot be reduced sufficiently, climate change impacts become worse and jeopardize the various constituents of human

[8] The shape of the indifference curves in Figure 6 depends on the scaling of the two axes. In order to not skew the picture, the scale of the two dimensions level of mitigation and GDP should be of equal magnitude.

well-being, such as health, exposure to catastrophic events, nutrition or fresh water supply. Furthermore, as Stern (2006) argues, the potential economic losses associated with future climate change impacts will exceed the costs for the necessary mitigation measures. Therefore overall human well-being will be lower in societies which place too little value on the environment.

Figure 6: Global Human Well-being indifference curve map for 2020



The climate policy scenario *CGCF*, which does not assume explicit carbon emission constraints for LDCs, results in the human well-being level HWB_2. Within this scenario, a fraction of economic growth is abandoned in favor of climate change mitigation. Globally coordinated climate policy frameworks, such as *GA* and *CGCF+GA*, instead eventually result in higher human well-being for the global society. As can be seen in Figure 5 the global annual average GDP growth rate in the period from 2004 to 2020 of these two scenarios is almost identical to the one in *CGCF*, which does not necessitate explicit reduction efforts from LDCs. However, the internationally coordinated scenario experience at the same time CO_2 emissions reductions compared to 2004 emissions levels, while the Annex I scenario *CGCF* cannot achieve such a decrease of global CO_2 emissions. Therefore, scenarios *GA* and *CGCF+GA* are environmentally effective by achieving substantial emissions reduction objectives, while being welfare maximizing at the same time.

Table 23 presents the regional decomposition of these welfare effects on ICs and LDCs. For this breakdown we assume different values for the coefficients α and β in the human well-being function for ICs and LDCs respectively. We adopt one aspect of the discussions concerning the EKC hypothesis (Alstine and Neumayer, 2008), which claims that more developed societies value environmental quality higher ($\alpha<\beta$) than less developed ones ($\alpha>\beta$), which are still more inclined to reach higher levels of economic development. It can be deduced from Table 23 that across all climate policy scenarios analyzed within this paper, the effects on human well-being, relative to 2004, are higher in LDCs than in ICs. This is caused by the fact that due to the relatively high GDP growth rates for LDCs (see Table 22), compared to those from ICs, LDCs experience economic growth at a higher magnitude than global CO_2 emissions reduction can be accelerated over the different scenarios. Since LDCs put more weight on economic growth at their current stage of economic development than ICs, their relative gains regarding the level of human well-being tends to exceed those of ICs. Already in the BAU setting as well as in the *BUS* scenario, LDCs experience major GDP increases compared to 2004, which in turn trigger an increase of human-wellbeing for LDCs in BAU 2020 and *BUS* by 17% and 33% respectively. ICs however, are confronted with an actual decrease of human well-being by -12% in BAU 2020 and only a slightly increase by 4% in *BUS*, resulting from substantial increases in global anthropogenic CO_2 emissions.

Table 23: Regional decomposition of well-being effects for the 2020 climate policy scenarios

	CO2 mitigation rel. SRES A1B (in Gt CO2)	GDP absolute (10^{12} USD)	Well-being change relative to 2004	GDP absolute (10^{12} USD)	Well-being change relative to 2004
Region	**global**	**Industrialized countries**		**Less developed countries**	
values for α and β		**α=0.4 and β=0.6**		**α=0.6 and β=0.4**	
2004	16.71	34.57		6.40	
BAU 2020	10.28	51.33	-12%	11.52	+17%
BUS	14.02	50.19	+4%	11.51	+33%
GA	19.20	49.37	+25%	11.26	+48%
CGCF	15.86	49.43	+12%	11.55	+40%
CGCF+GA	19.23	49.38	+25%	11.33	+49%

LDCs as well as ICs would profit from fully internationally coordinated climate policy scenarios. In scenario *GA*, representing the lower bound of the IPCC's propagated CO_2 target in line with the crucial +2C° target, ICs would experience an increase of their level of human well-being by 25% compared to 2004, LDCs by 48%. However, as argued in section 5.3, only scenario *CGCF+GA* is politically feasible, since LDCs justifiably claim financial support from ICs. *GA* is not equipped with a financial transfer mechanism, such as the CGCF. *CGCF+GA* would therefore deliver the highest benefits for LDCs, represented by an increase of human well-being by 49% compared to 2004, which itself stems from a higher GDP growth rate compared to *GA* (see Table 22 and Table 23). At the same time ICs would not have to loose on their level of human well-being since both, their level of GDP as well as the level of global environmental quality in 2020 under *CGCF+GA*, would be higher compared to *GA*. *CGCF* however, is not feasible either, since solely providing financial support for LDCs will not be enough to ensure environmental effectiveness, reducing both the ICs' and the LDCs' level of human well-being.

7. Conclusions

In this paper we used a multi-regional, multi-sectoral computable general equilibrium model to investigate climate policy options for the post-2012 era. The main focus was thereby on LDCs and their contribution to the mitigation of global warming. By investigating climate policy scenario *BUS* which does not tackle emissions in LDCs, environmental effectiveness cannot be ensured. While Annex I countries do achieve partly substantial emission reductions, depending on the stringency of the respective scenarios, non-Annex I countries' CO_2 emissions tend to grow even stronger until 2020 than under BAU assumptions. In the end, they even have the potential to more than counterbalance the achieved emission reductions on a global scale. Since we found exports of energy intensive goods to the wealthy, abating regions to increase, part of these rising LDCs emissions are due to carbon leakage and – in a broader perspective – would have to be allocated to consumption induced CO_2 emissions from ICs.

To overcome the problem of carbon leakage as well as the possibility of jeopardizing environmental effectiveness on a global scale, LDCs have to be brought on board of post-2012 climate policies. Scenario *GA* investigated such a global climate agreement also taking account of LDCs. This was done by analyzing a global scenario based on the IPCC outline of a 25% emissions reduction in Annex I countries in combination with a 15% reduction from BAU for non-Annex I regions. The results show that such a regime would be environmentally effective in achieving a turning point of global carbon emissions in the year 2020.

Unfortunately, such a top-down approach is unlikely to be politically feasible, given the current circumstances in the climate policy debate. LDCs are – justifiably, when considering the historical obligations for the bulk of anthropogenic GHG released into the atmosphere so far – not (yet) ready to agree to stringent CO_2 emissions reduction objectives. The objective for now is, to provide substantial financial, technological and capacity building support for them, in order to navigate them on a low-carbon high-growth pathway, without putting at risk their efforts to improve overall human wellbeing, apart from pure GDP growth.

Thus, the Copenhagen Green Climate Fund is introduced as a scenario (*CGCF*), channeling the postulated USD 100 billion up to 2020 from ICs to LDCs. A crucial finding is that it will not be sufficient to solely provide financial resources for LDCs, which aim at increasing energy efficiency in a specific sector (like electricity) or on a project-by-project basis. The resulting efficiency gains within the sector in question – in this special case power generation – are likely to be counterbalanced by rising output in the sector itself (known as the rebound effect) and especially by substantial increases in CO_2 emissions in sectors which do not receive support in any means to achieve a decarbonization. A final scenario therefore combined the financial support under the CGCF with the creation of quantitative and verifiable emission objectives, e.g. referring to a (substantial) deviation under BAU. The model results show that only within this policy regime, financial support for LDCs contribute to environmental effectiveness.

Furthermore, this paper evaluated the carbon and economic effects of the different policy scenarios with respect to their implications on human well-being. Instead of defining economic growth as the sole foundation for human well-being, this paper includes environmental quality in a global human well-being function, and weighs it equally strong as economic growth. The results show quite plainly that internationally coordinated scenarios, such as *GA* and *CGCF+GA*, imply the highest levels of global human well-being. Even though the society has to give up some fraction of economic growth, the achievements in increasing environmental quality outweigh these economic effects.

Furthermore we find that climate policy scenarios such as *CGCF+GA* have the potential to reduce ICs' annual average GDP growth rates between 2004 and 2020 compared to BAU by more than LDCs' growth rates. These differences reflect the notion of shared but differentiated responsibilities: LDCs do have to put a stop on an unlimited increase of GHG emissions, but ICs will have to contribute the bulk of the necessary CO_2 emissions mitigation. First, because they reflect a disproportionate historic obligation with respect to the already accumulated CO_2 emissions in the global atmosphere; second, because their actual per capita CO_2 emissions are far higher than those of the LDCs, and third, because LDCs will be hit hardest and earliest by climate change, while having the least adaptive capacity. Hence our model results presuppose a society which does accept a reduction of GDP growth and in turn ever increasing consumption levels.

This paper therefore concludes that an effective, efficient and equitable post-2012 climate policy design has to incorporate three elements. First, all countries – Annex I and non-Annex I alike – have to contribute within their financial, institutional and technological limits to the necessary mitigation efforts. A deal without LDCs might result in an increase of carbon emissions on a global level. Second, in order to get LDCs on board, a clear sign for a fair agreement has to be sent in the direction of LDCs. This means that LDCs should set for themselves realistic targets instead of being subject to unrealistically stringent emission reduction objectives decided top-down. Third, ICs have to provide substantial financial, technological and capacity-building support for LDCs' mitigation efforts. ICs should not only do so out of historical and ethical reasons, but also out of self serving motives. We find that ICs would equally benefit from internationally coordinated climate change policy frameworks – while *GA* leads to higher economic and lower environmental benefits, the opposite is true when *GA* is combined with *CGCF*. Furthermore, total human well-being in ICs is higher for both scenarios than either BAU, BUS, or CGCF without binding emission targets for LDCs.

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Appendix

Table 24: Elasticities in production

Sector	*s*	*v*	*int*	*elke*	*elk*	*elc*	*elcl*	*elqd*	$tela_{es}$
COA	0.00	0.73	0.31	0.55	0.14	0.16	0.07	0.25	3.05
OIL	0.00	0.73	0.31	0.55	0.14	0.16	0.07	0.25	5.20
GAS	0.00	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 25: Elasticities in import structure

Elasticity	value
elim	8
m	4
n	4
rg	4

Source: *Rutherford and Paltsev (2000)*

Table 26: 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)*