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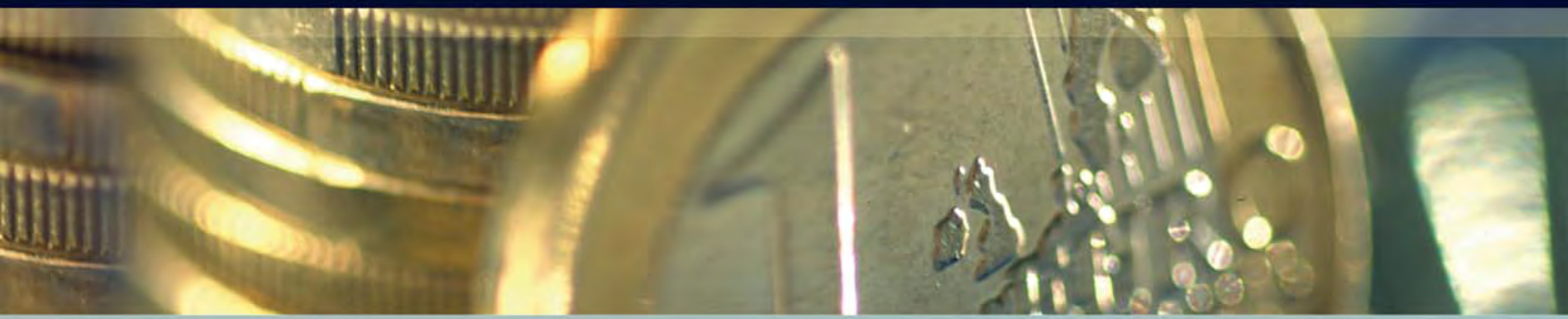

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Options for International Financing of Climate Change Mitigation in Developing Countries

Mark Hayden[*], Paul J.J. Veenendaal[†], Ziga Zarnic[‡ §]

Abstract

This paper provides a model-based analysis of the potential macro-economic impacts of different options for international financing of climate change mitigation in developing countries. The model used is the climate change version of WorldScan, which is a multi-region and multi-sector applied general equilibrium model. The adopted framework implements existing carbon market mechanisms and considers alternative options of financing in the post-2012 period. The paper assesses the theoretical potential of sectoral crediting mechanisms and incentives for participation of developing countries in financing climate change actions. Following the outcome of the UNFCCC conference in Copenhagen, it makes no specific assumptions about the future international climate regime. The analysis suggests that more of a carbon market we have when moving from the project-based CDM to sectoral crediting mechanisms and internationally linked cap-and-trade, the more finance the carbon market will channel to developing countries. Relative to the baseline in 2020, global emissions fall by more than 24% at a cost of 0.3% of world Gross Domestic Product (GDP), while the international financial transfers to developing countries amount to a tentative €32 billion. The improved environmental outcome comes foremost from enhanced participation of developing countries that start to take on targets. A consideration of the current financial crisis in the baseline translates into relatively lower costs of all policy options, because the emission targets are defined in terms of pre-crisis emission levels.

JEL Classification: D58, Q40, Q50, Q51

Keywords: Climate Conference in Copenhagen, climate change mitigation, Clean Development Mechanism, emission trading system, own participation of developing countries, sectoral approaches

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Contents

1. Introduction

This paper gives a model-based analysis evaluating the economic impacts of an international agreement on climate change to succeed the Kyoto Protocol. The paper assesses the theoretical potential of expanding the international carbon market through sectoral crediting mechanisms and active participation of developing countries in financing climate change actions compared to the existing project-based carbon market mechanisms.

The model used is an extended climate change version of the WorldScan model developed by the CPB Netherlands Bureau for Economic Policy Analysis. This is a multi-region and multi-sector applied general equilibrium model, which distinguishes between different manufacturing and non-manufacturing sectors of the economy for individual advanced and emerging countries, such as Brazil, China and India. The objective is to use this model to understand better the issues of Copenhagen and to evaluate particularly the issues related to the role of the global carbon market and the volume of financial flows between developed and developing countries, while bearing in mind environmental effectiveness and cost efficiency. The extended version of WorldScan, developed to meet the purpose of this paper, explicitly considers the existing carbon market mechanisms in the Kyoto period and incorporates new sectoral crediting approaches and participation of developing countries to assess their cost-efficiency and potential environmental benefits.

The simulation results reveal some insights into three post-Kyoto scenarios, which describe a frictionless global carbon market, the role of new sectoral approaches and the role of enhanced participation of developing countries in financing climate change actions. In a nutshell, the first scenario serves as a cost-effective benchmark scenario, which assumes a perfect global carbon market by 2013 and a normal evolution of the Kyoto Protocol until 2012.[5] The second scenario considers enhanced participation of developing countries in financing climate change actions, while the third scenario investigates the role of sectoral mechanisms with sector-specific baseline targets for emissions. The analysis is based on CO_2 emissions and does not account for REDD and LULUCF as abatement options. No use is made of excess Assigned Amount Units (AAUs) from the first commitment period of the Kyoto Protocol to meet the 2020 emission reduction targets.

The results show that the world's largest emission reductions of 24% at 0.3% loss of national income by 2020 are achieved under the global carbon market scenario, while the volume of financial transfers to developing countries amounts to a tentative €32 billion. The analysis suggests that more of a carbon market we have when moving from the project-based CDM to sectoral crediting mechanisms (SCM) and internationally linked cap-and-trade, the more finance the carbon market will channel to developing countries. The improved environmental outcome comes foremost from enhanced participation of developing countries that start to take on targets and hence the carbon price leads to reductions above and beyond the own action. The analysis also shows that the current economic crisis is likely to reduce the costs of climate-policy options, resulting in a lower carbon price and lower volumes of private international financial flows through the global carbon market. This is simply due to the fact that emissions in the baseline adjusted for the crisis fall short of emissions in the pre-crisis baseline, while the emission targets are defined in terms of pre-crisis emission levels. Although rather indicative and economically intuitive, these results have to be interpreted with caution by taking into account the underlying assumptions.

[5]The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. 184 Parties of the Convention have ratified its Protocol to date. The detailed rules for the implementation of the Protocol were adopted at COP 7 in Marrakesh in 2001, and are called the Marrakesh Accords. The Article 12 of the Kyoto Protocol referring to the CDM is outlined in the Annex of our paper.

The remainder of the paper has the following structure. Section 2 provides a conceptual framework to the modelling exercise as it describes the existing carbon market mechanisms under the Kyoto Protocol. It also discusses the role of new sectoral approaches and incentives for participation of developing countries in financing climate change actions. Section 3 gives an overview of the main characteristics of the model and highlights its advantages and shortcomings. This section also explains some technical features of the model that are necessary to understand its operation at the sectoral level and the implementation of the environmental policy instruments. Section 4 details the policy scenarios and outlines the underlying assumptions. Section 5 presents the simulation results and section 6 discusses how these are affected when the impact of the current economic crisis is also taken into account. Section 7 concludes.

2. Conceptual Background

Addressing climate change incurs costs. The costs and the environmental effectiveness of underlying actions depend crucially on the international environmental regulation. At the current stage, different financing options to tackle climate change in developing countries exist. However, the purpose of this paper is not to provide an extensive overview of the existing financing vehicles, but rather to focus on the advantages of new sectoral mechanisms and incentives for actions by developing countries compared to the existing carbon market mechanisms.

In particular, the financing options need not come only from the carbon market and international public finance, but also from developing countries' own contributions. While the scale of domestic policy action in developing countries is not yet fully clarified, it is clear that significantly increased international flows of public and private finance will be necessary to support a global abatement policy. Sectoral crediting mechanisms could further improve the functioning of the existing project-based mechanism by defining sector-specific baseline targets for emissions. In other words, an environmentally effective climate change action will have to meet emission targets by reducing emissions beyond business as usual levels (BAUs) taking into account the characteristics of manufacturing and utility sectors in developing countries.

Additional financial support by developed countries is needed to help tackle the economic costs of climate change actions, namely the mitigation and adaptation costs. Mitigation costs arise from altering patterns of investment and spending to reduce greenhouse gas emissions as the carbon-intensive technologies will gradually be replaced by low-carbon technologies. Adaptation costs arise from changes in the behaviour of individuals, firms and societies to adapt to climate change. These costs represent a significant financial burden for developing and least developed countries. Aimed at supporting climate change actions in developing countries, financial transfers from developed to developing countries are justified on efficiency and equity grounds. In line with the economic efficiency principle, a global reduction of greenhouse gas emissions at least cost requires a reduction in emissions in regions with low-cost abatement possibilities, such as developing countries. Equity considerations also argue for financial support towards developing countries, notably for adaptation actions in the least developed countries.[6] The volume of financial transfers that developing countries will receive from the EU and other developed countries for tackling climate change will thus be at the heart of comprehensive international action.

At present, funding is channelled through both multilateral and bilateral sources and this is unlikely to change. Maintaining a variety of funding sources and instruments seems preferable to a more highly centralized system of financing, because it addresses a wide range of funding needs. It ensures that donors have adequate control over funding streams and stimulates competition between different funding mechanisms towards greater performance. However, the existing financing mechanisms allegedly do not deliver satisfactory environmental benefits at the

[6]Their societies and economies are among those most exposed to the risks of climate change, they are poorly placed to adapt to its effects, but they have contributed little to the build-up of greenhouse gases in the atmosphere.

lowest possible costs. As addressed further in this paper, it is therefore relevant to assess whether alternative mechanisms could reduce the shortcomings of existing financing mechanisms.

2.1. International Carbon Market Mechanisms

The Kyoto Protocol has created three carbon market mechanisms. The CDM and Joint Implementation (JI) are project-based mechanisms, while the international emissions trading mechanism is based on targets expressed in assigned amount units (AAUs). The transfer of JI credits and AAUs occurs between Annex I countries, whereas the CDM leads to financial transfers to developing countries and it is therefore relevant for the debate on financing options in developing countries.[7]

In the context of EU climate policy, the CDM operates either through government purchase programmes by Member States or through the EU-wide Emissions Trading Scheme (EU ETS). On the one hand, the government purchase programmes include the procurement of CDM credits as a contribution to compliance with the Kyoto target for the period 2008 to 2012. On the other hand, the CDM credits are recognized as a compliance currency in the EU ETS. The CDM allows a country with an emission reduction commitment under the Kyoto Protocol to reduce emissions through the implementation of projects in developing countries.[8] Such projects generate Certified Emission Reduction (CER) credits equivalent to one tonne of CO_2, which can be traded within the EU ETS. At present, the project-based segment of the international carbon market is dominated by trade in Certified Emission Reductions (CERs).[9] The international carbon market including project-based transactions, secondary CDM and allowances markets reached almost 5 billion tCO_2eq worth €86 billion, of which the EU ETS accounted for the lion's share of 3 billion tCO_2eq worth €63 billion (Ambrosi and Capoor, 2009).

Although the CDM is an important element of the international carbon market because it reduces the costs by providing access to offsetting mechanisms, it is loose on efficiency grounds and allegedly does not deliver the expected environmental benefits. With regard to the CDM scale, it is questionable whether the current project-based format delivers a sufficient amount of offsets from those sectors where most emissions occur. With regard to the environmental effectiveness, a continued use of pure offsetting mechanisms may undermine incentives for developing countries to implement own mitigation actions that do not generate credits. In sum, the new international agreement should envisage crediting mechanisms that go beyond mere offsetting and instead stimulate appropriate own actions in developing countries. Moreover, it would be more efficient if the crediting mechanism were to target specific sectors with large abatement potential at lowest costs.[10]

[7]The Clean Development Mechanism (CDM) is an offsetting mechanism under the Kyoto Protocol through which developed countries may finance greenhouse-gas emission reduction in developing countries and receive credits for doing so, which they may apply towards meeting mandatory limits on their own emissions in developed countries.

[8]The Kyoto Protocol included enabling language in Article 12 laying down the main architecture for the mechanism in 1997 (see Annex B). A few years later, decisions 3 and 4 of the first COP/MOP within the so-called Marrakech Accords have activated the CDM. In the meantime further COP/MOP decisions have extended the CDM regulation.

[9]According to the World Bank's report State and Trends of the Carbon Market 2009, forward primary CDM transactions accounted for the largest share of activity in the primary market, with overall confirmed transaction volumes of 389 $MtCO_2e$, which is nearly 30% lower than in 2007 (552 $MtCO_2e$). Primary CER prices in 2008 were an average of 16% higher at €11.46, but the value of transactions decreased by 12% from 2007 levels to €4.5 billion. The 2008 average price reflects higher prices paid before the financial crisis, compared to much lower prices in low volume of transactions in 2008. Most of the CERs were generated by projects in China, which accounts for about three quarters of the total transactions (Ambrosi and Capoor, 2009).

[10]Apart from that, there are other shortcomings of the CDM. Notably, the approval procedures for CDM projects are currently lengthy and complex. This increases transaction costs and represents an obstacle to the large-scale expansion of the CDM. Partly because of its complexity, CDM projects are in practice concentrated in a small number of more advanced developing countries.

2.2. Sectoral Mechanisms and Enhanced Participation of Developing Countries

A possible next step that would go towards solving the problems with the existing carbon market mechanisms is to move gradually to a new sectoral crediting mechanism. A baseline target for emissions would be agreed for a sector. Sectoral credits would only be issued for reductions in emissions that go beyond an agreed ambitious goal that is, defined in a "do something" baseline.[11] If such a new mechanism were to cover the energy-intensive sectors, it would also help to reduce concerns in developed countries about carbon leakage.[12] A sectoral crediting mechanism would allow an easier transition for advanced developing countries to start introducing mitigation policies for their highly competitive economic sectors. Progress needs to be made on a number of issues related to their design and implementation, if sectoral approaches are to contribute to reducing greenhouse gas emissions.[13] In any such approach, practical questions will need to be agreed, such as the definition of the participating sectors and the baseline against which emission reductions should be credited. A more difficult set of issues may be those relating to the differing interests and incentives in developed and developing countries for negotiating and taking part in the sectoral arrangement.

For example, developed countries see sectoral mechanisms as a way to limit concerns about carbon leakage and adverse effects on competitiveness that may result from ambitious climate change policies. However, many low-cost emission abatement opportunities in developing countries are in the electricity sector. The power sector is thus a prime candidate for a future sectoral crediting mechanism. Developing countries may see sectoral arrangements as a way of enabling technology transfer. However, proprietary technology may be a source of competitive advantage for firms in developed countries. Developing countries will need to devise ways to ensure that firms and investors receive a clear carbon price signal, if the sectoral arrangement is to deliver emission reductions cost-effectively. Provided that environmentally effective solutions to these challenges can be found, sectoral approaches have the potential to scale up financial flows through the international carbon market, and give incentives to developing countries to implement domestic climate change mitigation policies. At the same time a well-designed sectoral crediting mechanism would also facilitate the subsequent transition to cap-and-trade. Because of the variety in the situations of individual firms, sectors and countries, the characteristics of particular sectoral mechanisms may have to be adjusted to underlying conditions.

A future international agreement should ideally set general criteria for sectors and countries that are no longer allowed to participate in the CDM and can therefore only use sectoral approaches. However, an international agreement on clear-cut eligibility rules will be difficult to reach. Should developing countries oppose losing CDM eligibility, it is important to put in place participation incentives for sectoral approaches. Namely, the advantages of sectoral mechanisms for developing countries could come from different sources. For example, the sectoral credits could bring down the transaction costs for installations in a developing country and could further be recognized for the EU ETS compliance at more favourable quantitative conditions than the CDM. An internationally agreed sectoral mechanism could also help address competitiveness concerns as industrialised countries adopt more ambitious mitigation objectives, while providing an opportunity to promote investment in low-carbon technologies (Bosi and Elis, 2005; Baron and Elis, 2006; Burniaux et al., 2009).

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[11] The term "do something" baseline is used to contrast it to the CDM which is based on "do-nothing" baselines, that is, earning credits for any deviation from business-as-usual.

[12] The climate policy can generate spillovers in terms of carbon leakage, where the regions with stringent policy will lower their emissions leading to increasing emissions in regions with looser policy instruments, such as a low carbon tax for the case of carbon dioxide emissions.

[13] For example, a great deal of recent debate evolves around the nature and stringency of the crediting threshold, the scope of sectoral coverage and provisions for eventual governance structure and transitional arrangements for existing CDM projects.

3. The Modelling Framework

3.1. General Structure of the Model

The WorldScan model describes the global economy by considering the interlinkages between different sectors and regions connected by bilateral trade flows. This is a multi-sector, multi-region, applied general equilibrium model developed by the CPB in the Netherlands (Lejour et al., 2006). There are two main characteristics of the extended climate change version that make the model suitable for studying sectoral approaches and participation of individual emerging economies in the context of climate change. First, the model can distinguish as many goods and services markets for individual developed and emerging economies as are accounted for in the database.[14] Second, the model covers carbon dioxide greenhouse gases (GHG) and describes comprehensively climate policy instruments such as the CDM. The recursive dynamics nature of this model makes it more suitable for long-term analysis than for short-term analysis, nesting specific assumptions about the current state and projected values of parameters and policy designs. Therefore, this section not only presents the model structure, but also highlights some of its main advantages and limitations to facilitate the interpretation of results.

In general, WorldScan builds upon the neoclassical heritage of applied general equilibrium models.[15] As such, it explicitly determines simultaneous equilibrium on a large number of markets, including product, labour and capital markets, and it is solved as an equation system that represents a computable general equilibrium (CGE).[16] On the one hand, there is a macro-economic perspective on production, consumption and investment, so that countries can run trade imbalances and investment does not necessarily have to match savings, whereby trade implies changes in the financial position of a country. On the other hand, the model has strong microeconomic foundations concerning producer and consumer behaviour. In particular, all agents are price-takers. Producers minimize the costs of production and consumers maximize utility subject to budget constraints, while trade patterns depend on regional differences in technology, endowments, demand and trading costs.

Taking a brief look at the interplay of different modelling blocks, our focus lies on the sectoral dimension of the model in the climate change context. Each sector is described by a representative firm that supplies a unique variety of a good in each country.[17] All prices are formed endogenously, given the behaviour of producers and consumers. The relative demand for production inputs depends on the characteristics of the sectoral production function. All goods are produced with labour, capital and intermediate inputs and their substitutability is exogenously defined within the system of nested production functions.[18] However, the allocation of inputs is the key to sectoral heterogeneity across countries, because their production shares are derived from the data. In principle, total factor productivity growth is exogenous in the climate change version of the model.

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[14]There is a global coverage of manufacturing and non-manufacturing sectors for individual countries, including emerging economies like China, India, Brazil and South Africa. With respect to climate policies, the model distinguishes between developed Annex I countries and developing countries, referred to as Non-Annex I countries according to the Kyoto Protocol.

[15]The Walrasian general equilibrium prevails when supply and demand are globally equalized across all interconnected markets. Computable general equilibrium models are simulations that combine the theoretical general equilibrium structure with realistic economic data to solve numerically for the levels of supply, demand and price that support equilibrium across a specified set of markets (see Sue Wing, 2009). The mechanisms of the model are founded on empirical analysis wherever this is possible.

[16]In other words, the sectoral inter-linkages in general equilibrium context imply that the impact of climate change policies to, e.g., energy sectors is streamed further down to the rest of economy.

[17]In the current version of the WorldScan climate change model, the intra-sector heterogeneity of firms is not considered so that all firms within one sector share the production technology and exhibit the same total factor productivity. For example, this limitation of the model does not allow a neo-Schumpeterian type of analysis of firm dynamics under different climate change policy scenarios.

[18]For example, capital and labour inputs are mutually substitutable to a much higher degree than, for example, capital and intermediate inputs. The model is flexible in adjustment of sector-specific parameters of production and cost functions by modifying the input share parameters or considering new technologies.

The labour input consists of low-skill and high-skill workers that do not commute between different regions. The labour markets are thus cleared nationally and the wage rates are flexible. Although unemployment can be made endogenous in the model, in the simulations for this paper it was simply kept exogenous.[19] Labour supply is derived from demographic trends and projected rates of labour participation and was also kept exogenous. Workers decide how to spend their income in three stages; first, over consumption and savings,[20] second, by purchasing goods and services and leisure, and finally, by spending on goods and services supplied from abroad.

In doing so, consumers supply the capital that firms demand. Although there is inter-regional capital mobility, capital price equalization is not fully met due to prevailing investment barriers. As for capital markets, international markets for goods and services are linked to each other. Trade in each variety occurs at the sectoral level and depends on its relative price, substitution possibilities, transportation costs, trade and non-trade barriers, and on consumer preferences. The trade dimension makes sector specialization more realistic and inter-regional trade linkages allow the assessment of the spillover effects of climate change policies, i.e. carbon leakage to regions with a less stringent carbon policy.

Although the behaviour of producers and consumers is to a certain degree included in the model, there is no specific behaviour assigned to the government. Tax and tariff rates on production and consumption are determined exogenously and fed-back in the economy through lump-sum transfers to the households characterized in the model.

Regarding the dynamics in the model, value added grows with labour productivity and labour supply. Labour productivity is determined by technological progress and capital growth per unit of labour. Labour supply growth is exogenous and derived from population growth, its age-composition, age-specific participation rates, and unemployment rates. The model lacks rational expectations with longer time horizons, since it is not a fully forward looking inter-temporal optimization model. In other words, the agents in the model cannot anticipate the policy shocks. The model is an excellent tool for impact assessments of alternative policies, but neither intended for forecasting nor for monetary analyses as it does not cover asset markets and assumes monetary neutrality.

WorldScan offers a flexible modelling framework that feeds on sectoral data including input-output tables and trade linkages between sectors of different regions in the world. The main source used is the database of the Global Trade Analysis Project (GTAP). The current version of the model relies upon the 7th version of the GTAP database, which has 2004 as the base-year. The full GTAP Version 7 database covers consistent accounts integrated with bilateral trade flows for 57 sectors and 113 regions of the world. WorldScan simulations will not demonstrate these data in full detail, but they will rather present the results for aggregated sectors and country classifications.[21] From this data set we do not only derive the demand, production and trade patterns, but also the labour and capital intensity of the different sectors. Additional data sources used to calibrate WorldScan are described in more detail in Annex A of this paper.

Nonetheless as discussed above, the model is not short of limitations and the assumptions have to be seriously taken into account when interpreting the results, like in any other economic model. However, WorldScan has some very useful properties that make it attractive for our purpose. The next sub-sections explain in more detail its useful consideration of sectoral dimensions and climate change policy instruments. One of the model's advantages therefore is that the heterogeneity of sectors with region-specific energy intensities and modelling of the carbon market leads to asymmetric impacts from climate change policies.[22] The modelling framework

[19]Labour supply and unemployment can be treated endogenously, since there is a wage bargaining model to derive the wage curve and equilibrium unemployment. However, in the simulations of this paper, endogenous labour market responses were switched off.

[20]Savings lead investments and depend on the demographic composition of the population and the growth rate of per capita income.

[21]Main countries and country groups of interest are EU15, EU12, EU27, USA, China, India, Brazil, Annex I and non-Annex I countries.

[22]The energy sector is explained in great detail and the model distinguishes between seven primary energy carriers, as

presented below is derived entirely from the WorldScan climate change model and supported by the description provided by Lejour et al. (2006), which includes a more detailed description of the general model.

3.2. Sectoral Disaggregation of Supply and Demand

3.2.1. The System of Nested Production Functions

In WorldScan, all sectors *s* are heterogeneous within and across regions *r* with respect to allocation of production factors *f*. The aggregate output of an economy is thus an aggregation of the value added of individual sectors, so that gross domestic product in market prices (Y_r) sums the value added of all sectors and taxes (T_{sr}):[23]

$$(1) \qquad Y_r = \sum_s Y_{sr} + T_{sr}, \text{ where } Y_{sr} = p_{sr} q_{sr} - \sum_i p_{isr} q_{isr}$$

In the above Eq. (1), the value added Y_{sr} in sector *s* of region *r* equals the value of production net of intermediate products (*i*) used by that sector ($\sum_i p_{isr} q_{isr}$). In fact, in its simplest form each sector is described by a representative firm that delivers a unique variety of good $q_{sr} = (\sum_f \alpha_{fsr}^{\frac{1}{\sigma_s}} p_{fsr}^{\frac{\sigma_s - 1}{\sigma_s}})^{\frac{\sigma_s}{\sigma_s - 1}}$ produced with inputs *f*.[24] Substitution possibilities are captured by the coefficient σ_s by which substitutability of production inputs (*f*) differs across sectors (*s*). However, the sectors have a similar structure across different regions. The model assumes that firms are price-takers under perfect competition. Thus the price for output q_{sr} *equals* minimal unit costs:

$$(2) \qquad p_{sr} = c'_{fsr}(p_{fsr}) = (\alpha'_{fsr} p_{fsr}^{1-\sigma_{fs}})^{\frac{1}{1-\sigma_{fs}}}$$

An important characteristic of the WorldScan model is that the production technology is described by a nested structure of constant elasticity of substitution elasticity (CES). In particular, the sectors are heterogeneous in terms of substitution elasticities and in factor allocation shares in the production nest that is illustrated by Figure 1. The advantage of WorldScan is that it distinguishes between different energy carriers in the energy production nest, i.e. electricity and seven non-electricity carriers which are coal, natural gas, petroleum products, biodiesel, ethanol, biomass, and renewables (geothermal, solar, and wind energy).[25] The production and demand structure of energy carriers follows the functional specification of the other goods and services sectors, defined at the upper levels of the production function.[26]

For presentation purposes consider the upper-level nested structure in Figure 1. In the first level, production is described by the use of fixed resource input and other variable inputs, which cover

further explained in the next sub-section. The carbon dioxide GHG are explicitly modelled, while other non-CO_2 gases like methane and nitrous oxide are currently not considered.

[23] Taxes are sector (*s*) dependent and include the taxes on consumer goods, intermediate goods, investment goods, production, imports and exports in region (*r*).

[24] In the current version of the WorldScan climate change model, the intra-sector heterogeneity of firms is not considered. In other words, the firms within each sector (*s*) of region (*r*) have the same nested production technology and are homogeneous with respect to input allocation and productive efficiency.

[25] The nuclear generation of electricity is included in the electricity nest (ELY). There is no overlapping between electricity nest (ELY) and the non-coal nest (TNC), as long as the electricity output shares for each individual economy are consistently reported in the data. Since the GTAP dataset does not allow any further disaggregation of energy carriers, the information on the shares of each individual carrier for each economy is provided by the Netherlands Environmental Assessment Agency (PBL).

[26] The distinguishing feature of the energy sector is resource availability. Two developments in energy technology are important, i.e. the efficiency of energy use and the availability of new energy carriers. WorldScan defines non-fossil renewable fuels (nuclear, geothermal, solar and wind energy) as a backstop technology. The demand for energy carriers derives mostly from the production sectors (70-85%) for intermediate use while the remainder is used directly by the households.

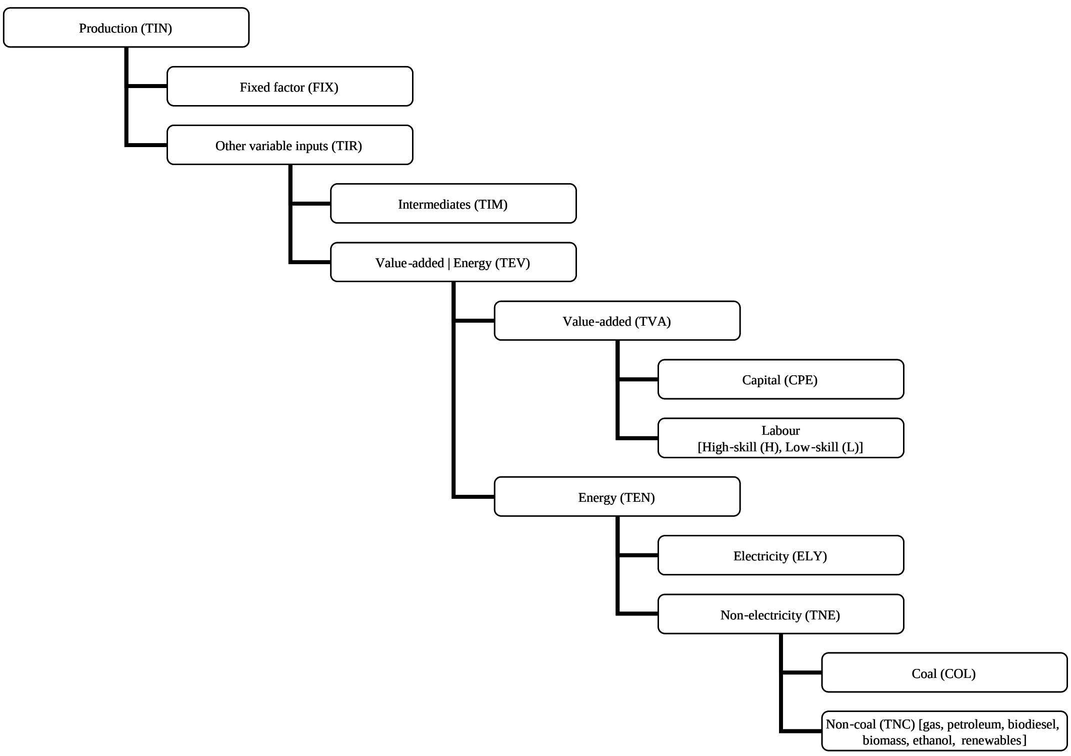
on the one hand intermediate inputs and on the other hand the nested structure of value added and energy inputs. The nested linkages have the form of nested CES production functions, which can be expressed in functional form as:

(3)
$$q_{TIN,sr} = F(q_{FIX,sr}, q_{FIX,sr}; \sigma_{TIN,s})$$
$$= (\alpha_{FIX,sr}^{\frac{1}{\sigma_{fs}}} q_{FIX,sr}^{\frac{\sigma_{TIN,s}-1}{\sigma_{TIN,s}}} + \alpha_{TIR,sr}^{\frac{1}{\sigma_{TIN,s}}} q_{TIR,sr}^{\frac{\sigma_{TIN,s}-1}{\sigma_{TIN,s}}})^{\frac{\sigma_{TIN,s}}{\sigma_{TIN,s}-1}}, \text{ with } \sigma_{TIN,s} \in (0;1) \cup (1;\infty)$$

(4)
$$q_{TIR,sr} = H(q_{TIM,sr}, q_{TEV,sr}; \sigma_{TIR,s})$$
$$= (\sum_h \alpha_{hsr}^{\frac{1}{\sigma_{TIR,s}}} q_{hsr}^{\frac{\sigma_{TIR,s}-1}{\sigma_{TIR,s}}})^{\frac{\sigma_{TIR,s}}{\sigma_{TIR,s}-1}}, \text{ with } \sigma_{TIN,s} \neq \sigma_{TIR,s} \in (0;1) \cup (1;\infty) \text{ and } h = TIM, TEV$$

For each of the production nests in Figure 1, the substitution parameters (σ) are sector-specific but identical across regions; however, the production functions differ over regions too because the input share parameters (α) are sector and region specific. These share parameters are derived from cost shares in the input-output data in the base year (Lejour et al., 2006) with the notations in Eq. (3) and (4) corresponding to Figure 1. The nests at the lower levels illustrated by Figure 1 are analogously defined as the top-level production nest in Eq. (3). However, there is an exception. The value-added nest is modelled differently because it includes also the total factor productivity term. The labour-nest is then modelled as a Cobb-Douglas production function combining high-skilled and low-skilled labour.

Figure 1: Production nest in WorldScan



Similarly to the nested production structure above, the cost function is also nested. Total production costs are defined for each firm as:

(5)
$$q_{sr} = \sum_f p_f q_f, \text{ with } f = FIX, CPE, L_l, L_h, S \text{ where } S = s_1, \ldots, s_s$$

Where P_f denotes the price of input f, which denotes either fixed factor (*FIX*), capital (*CPE*), low-skilled labour (L_l), high-skilled labour (L_h) or inputs from all other sectors ($S=s_1,\ldots,s_s$). Equations (6) and (7) below illustrate the nested unit cost structure for the upper levels of the nested function in Figure 1, expressed as:

$$p_{TIN,sr} = F(p_{FIX,sr}, p_{FIX,sr}; \sigma_{fs}) = (\alpha_{FIX,sr}^{\frac{1}{\sigma_{TIN,s}}} p_{FIX,sr}^{\frac{\sigma_{TIN,s}-1}{\sigma_{TIN,s}}} + \alpha_{TIR,sr}^{\frac{1}{\sigma_{TIN,s}}} p_{TIR,sr}^{\frac{\sigma_{TIN,s}-1}{\sigma_{TIN,s}}})^{\frac{\sigma_{TIN,s}}{\sigma_{TIN,s}-1}}, \text{ with } \sigma_{TIN,s} \in (0;1) \cup (1;\infty) \quad (6)$$

$$p_{TIR,sr} = H(p_{TIM,sr}, p_{TEV,sr}; \sigma_{hs}) = (\sum_h \alpha_{hsr}^{\frac{1}{\sigma_{TIR,s}}} p_{hsr}^{\frac{\sigma_{TIR,s}-1}{\sigma_{TIR,s}}})^{\frac{\sigma_{TIR,s}}{\sigma_{TIR,s}-1}}, \text{ with } \sigma_{TIN,s} \neq \sigma_{TIR,s} \in (0;1) \cup (1;\infty) \text{ and } h = TIM, TEV \quad (7)$$

Note that the price of value added is a CES aggregate of the price of labour and the price of capital, while the price of labour is a Cobb-Douglas aggregate of the wages for high- and low-skilled labour. Capital costs are equal to the real return on capital (k), compensation for risk (o) and depreciation (δ) times the investment price (P_I), that is, $p_K = p_I(k + o + \delta)$. The price of the composite intermediate goods is a CES aggregate of the prices of the underlying intermediates. This is also true for the energy input.

3.2.2. Sectoral Consumption Demand System

Sectoral disaggregation is considered also for the demand side in the model. The equations for the demand for goods and services, including energy categories, correspond to the production classification and are described by a sectoral consumption system. Production equals total demand which consists of consumer demand, intermediate demand, investment demand and exports. For illustration purposes, we summarize only the consumer demand below derived from WorldScan as described by Lejour et al. (2006).[27]

The main difference from the production system is that a non-homogeneous demand system is used for the modelling of consumer demand rather than a homogeneous CES system. The main reason is that an income elasticity of one under the CES system is inconsistent with the empirical consumption literature. The established fact is that the budget share spent on necessary goods becomes smaller with rising income, while the share spent on luxury goods becomes large. From the range of different modelling possibilities, WorldScan applies the linear expenditure systems (LES) derived from the Stone-Geary utility function due to its simplicity in modelling and interpretation (see Neary, 1997). Hence, the overall utility of consumer c is defined as $U_c = \prod_j (c_{cj} - \gamma_{cj})^{\beta_j}$, where c_{cj} is consumption of good j by consumer c and (γ_{cj}) is a parameter representing committed consumption of good j. A positive value of γ_{cj} allows the interpretation of a subsistence level or the minimal quantity of consumption of good j needed to survive.[28] If all subsistence levels are satisfied, the remaining budget (Y_c- γ_{cj}) is distributed over the consumption goods according to their marginal budget shares β_j that have unit sum. The utility function gives rise to a linear demand system, in which the individual demand function is expressed as:

$$c_{cj} = \gamma_{cj} + \frac{\beta_j}{p_j}(C_c - \sum_j p_j^c \gamma_{cj}) \quad (8)$$

[27] The documentation by Lejour et al. (2006) provides further insights into intermediate and investment demand systems. Production factor demand is determined by the cost-share parameter, the output at the higher nest level, the price ratio and the substitution parameters.

[28] For $\gamma_{cj} = 0$, the Stone-Geary function reduces to a Cobb-Douglas utility function.

where total consumption of all goods j at the user price p_j^c purchased by consumer c is $C_c = \sum_j p_j^c c_{cj}$. The aggregate demand equation is then defined as $c_j = \sum_{c=1}^{population} c_{cj}$, which sums individual demand equations over the entire population.

3.3. Climate Change Policy

3.3.1. Emission Price

The model distinguishes between exogenous and endogenous changes in emissions. On the one hand, the exogenous changes are not influenced by a climate policy, but are rather associated with other considerations, such as technological improvements. These are captured in the model by technical coefficients that are called autonomous energy efficiency improvements (AEEIs), which reflect the rate of change in energy intensity holding energy prices constant.[29] On the other hand, the endogenous changes are related to climate policy instruments and energy prices. An important instrument is the emission price charged to emitters for their emissions. The economic rationale behind this concept is to shift demand from more to less polluting sources of energy.[30]

Consider the carbon tax rate t_f^E in terms of the revenues of emitting (R_f^E) and the value of fuel use (R_f), which is defined as an *ad valorem* tax rate in the form of a mark-up on the market price of fossil fuels:

(9) $$t_f^E = \frac{R_f^E}{R_f} = E_f \frac{p^E}{p_f^m}, \text{ where } R_f = p_f^m q_f$$

where the amount of fuels q_f is sold at the market (m) price of fuels p_f^m. The carbon tax rate (t_f^E) depends on the magnitude of the fuel-specific emission factor (E_f), which differs according to the carbon content of the fuels e.g. making coal more expensive than natural gas.[31] Producers and consumers pay an emission price (p^E) in US$ per tons of carbon equivalents (US$/tCeq) for the emissions (q_f^E) resulting from the fossil fuel use, i.e. the production inputs (f) in this case include coal, natural gas and petroleum products. The revenues (R_f^E) are returned to the regional households in a lump-sum fashion:

(10) $$R_f^E = p^E q_f^E, \text{ where } q_f^E = E_f q_f \text{ and } f = coal, gas, petroleum$$

The actual user prices, which producers (p) and consumers (p^c) pay for the use of economic goods are then defined as:

(11) $$p_f = p_f^m (1 + t_f^E + t_f)$$

(12) $$p_f^c = p_f^m (1 + t_f^E + t_f^c)$$

[29]The AEEIs are calibrated to the energy usage projected by an exogenous baseline. In adopting efficiency improvements in the WorldScan baseline an elasticity of substitution between fuel use and capital inputs is assumed of 0.5.

[30]For example, the carbon price raises the user price of fossil fuels and lowers the amount of emissions for the case of carbon dioxide related emissions. For the case of other GHG, the emission price raises the output price for the emission sectors and consequently lowers their demand and results in lower levels of GHG.

[31]The revenues R^E are nil for the alternative fuels that do not emit carbon dioxide.

where the market (m) price for fossil fuels (p_f^m) is equal for producers and consumers, a tax on carbon emissions is t_f^E , a tax on fuel inputs for production process is t_f and a fuel consumption tax is t_f^c . The emission price itself does not depend on the specific fuel, but the tax rate does. The modelling of the carbon emissions price as a carbon tax increasing the user fuel price generates the following economic effects. First, the demand for energy by producers falls, resulting in a lower energy intensity for a region with a higher carbon tax. Second, the energy use switches from fossil fuel to less carbon intensive energy carriers. Third, the sector specialization shifts towards lower energy intensity. Finally, the climate policy may generate spillovers in terms of carbon leakage towards non-participating or low-tax regions.

3.3.2. Emission Targets and Trading of Permits

The following two cases demonstrate how the emission volume targets are modelled in WorldScan. Building upon the previous sub-section, consider that a climate policy uses the price instrument for achieving the emissions-level target either domestically or internationally by permit trading.

In the first case without trade, the regions have to meet their individual targets ($\overline{q}_r^E$) domestically. Equation (13) below total emissions from the relevant sectors s in country r will meet the target via adjustment of the emissions price (p_r^E)[32]:

$$(13) \qquad \overline{q}_r^E = \sum_s q_{rs}^E \perp p_r^E \geq 0$$

In the second case with trade, regions can purchase and sell emission permits on the international permit market. Hence, the individual regions can adjust their abatement efforts by trading emission permits. The implicit equation for the emissions price of coalition is:

$$(14) \qquad \overline{q}^E = \sum_r \overline{q}_r^E \geq \sum_r \sum_s \mathrm{q}_{\mathrm{rs}}^{\mathrm{E}} \perp \mathrm{p}^{\mathrm{E}} \geq 0$$

All regions within the abatement coalition share a joint emissions-volume target ($\overline{q}^E$) and a uniform emissions price (p^E). The joint target is the sum of emission target allocations at the country level. The regions may differ in their reduction efforts because of production technology differences, for example, due to differences in sectoral energy efficiency. Their income from emissions trading (Y_r^E) can be expressed as:

$$(15) \qquad Y_r^E = p^E[\overline{q}_r^E - \sum_r \sum_s \mathrm{q}_{\mathrm{rs}}^{\mathrm{E}}]$$

For the exporters of emissions permits, this income Y_r^E will be positive and it will be negative for the importers of emissions permits. Trade is beneficial for the welfare of all participating regions due to marginal abatement costs (MAC) differentials. The regions with higher MAC will purchase emission rights, while regions with lower MAC will sell them until the price meets marginal abatement costs.

[32]The symbol $\perp$ denotes orthogonality, $x \geq 0 \perp y \geq 0$ implying $x \geq 0$, $y \geq 0$ and $xy = 0$.

3.3.3. The Clean Development Mechanism

Recall from the previous sub-section that each sector is represented by a profit maximizing firm, which - in a simplified one-level CES representation - supplies the output $q_{sr} = (\sum_f \alpha_{fsr}^{\frac{1}{\sigma_s}} p_{fsr}^{\frac{\sigma_s - 1}{\sigma_s}})^{\frac{\sigma_s}{\sigma_s - 1}}$ produced with inputs (*f*). The subscripts denoting sectors (*s*) and regions (*r*) are henceforth omitted for clarity reasons. Consider now that a firm has the opportunity to contribute to the CDM at a given CDM-price π and that the volume contribution at unit output is represented by *z*. The unit cost minimization problem therefore includes an additional term *z* denoting certificate sales to the CDM system, and can be expressed as:

$$(16) \qquad c(w,\pi) = \min \sum_f w_f q_f - \pi z$$
$$s.t.$$
$$q_f \geq 0, z \geq 0, s \geq 0$$
$$(\sum_f \alpha_f^{\frac{1}{\sigma}} q_f^{\frac{\sigma-1}{\sigma}}) \geq 1$$
$$z - s \leq z^* - \sum_f \beta_f q_f$$
$$zs = 0$$

Here w_f denotes the price of input *f* and q_f the volume of the input used per unit of output. The variable *z* measures the excess of a benchmark for per-unit emissions z^* over and above emissions $\sum_f \beta_f q_f$ at unit output. When the CDM price π falls short of generating a positive CDM supply, a slack variable *s* is used to set CDM supply *z* to zero. There are two alternative solutions, that is, one with $z = 0$ and the other with $s = 0$. Assuming the solutions are strictly internal at these two points, the CDM supply (*z*) will be strictly positive, if the slack (*s*) is nil. By contrast, if the CDM supply (*z*) is nil, then the slack (*s*) will be strictly positive so that the solution becomes identical to cost minimization without the CDM constraint. When the optimal solution of (16) yields a positive *z* one may derive that in equilibrium:

$$(17) \qquad p = -\pi(z + \sum_f \beta_f q_f) + (\sum_f \alpha_f (w_f + \pi\beta_f)^{1-\sigma})^{\frac{1}{1-\sigma}}$$

Equation (17) says that in the optimum of a CDM-supplying firm the inputs *f* are 'virtually' taxed with $\pi\beta_f$ to drive down emissions while the firm receives a subsidy per unit of output that is the sum of the value of the CDM contribution (πz) and the virtual tax burden $\pi \sum_f \beta_f q_f$. Hence, in WorldScan a CDM-supplying firm is fully reimbursed for its abatement costs while the receipts of CDM-sales do not translate into profits (which are absent under perfect competition) but into a lower output price.

4. Model-Based Analysis

4.1. Baseline Specification

Before turning to the simulation results, it is useful to discuss the underlying assumptions because the cost estimates depend on the assumptions about the baseline and climate policy trajectories. The baseline reflects the business-as-usual scenario, which is updated to the latest GTAP-7 data using 2004 as a starting year in the analysis. All counterfactual analyses depart from a so-called middle-course scenario without a climate policy that has been developed by the Netherlands

Environmental Assessment Agency (PBL). This scenario is based on the estimates of trends, and is comparable to the reference scenario used by the International Energy Agency (IEA) and the so-called B2 scenario used by the Intergovernmental Panel on Climate Change (IPCC).

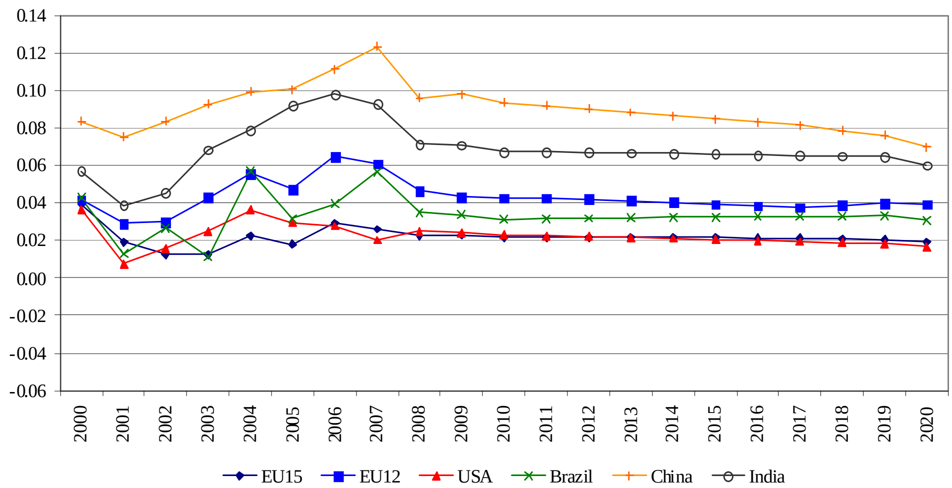
Table 1. Characteristics of baseline scenario, average annual growth, 2004-2020

	CO2 emissions 2004-2020 (%)	GDP volume 2004-2020 (%)	Population 2004-2020 (%)	Real wage 2004-2020 (%)	Energy demand 2004-2020 (%)
Annex I	0.93	2.45	0.38	2.28	1.23
EU27	1.27	2.41	0.05	2.63	1.60
EU15	1.16	2.27	0.11	2.46	1.43
EU12	1.76	4.55	-0.16	4.88	2.47
USA	0.09	2.28	0.93	1.53	0.21
Former Soviet Union	2.51	6.63	-0.26	7.02	3.05
Non-Annex I	4.55	6.37	1.22	5.13	4.95
Brazil	-0.90	3.50	1.13	2.36	0.11
China	4.15	9.41	0.53	9.23	4.43
India	5.83	7.32	1.44	5.23	6.33
World	2.74	3.33	1.06	2.03	3.03

Source: Baseline scenario, the WorldScan climate change model.

Table 1 presents the main characteristics of the baseline scenario for the period 2004-2020. Combined with worldwide economic growth of around 3.3% per year, the global demand for energy will increase significantly by about half in 2020 relative to 2004 with an average annual growth of 3.0%, notably in non-Annex I countries (5.0%). Carbon dioxide emissions are expected to increase more in non-Annex I countries (4.5%) than in Annex I countries (1.0%), except for Brazil (-0.9%). The baseline scenario described in Table 1 considers the evolution of the world's economic growth without the current financial crisis. As shown by Figure 2, this baseline therefore assumes a normal evolution of economic activity after 2007, captured by the series of real GDP growth rates explained in more detail in Annex. This assumption is relaxed further in the paper, where the current financial crisis is explicitly considered in the baseline scenario.

Figure 2. Real GDP growth rate in baseline scenario without crisis, 2000-2020



Source: WorldScan computations based on the European Commission (2009d and 2009e) and IMF (2009) forecast reports until 2008 and own computations afterwards.

The climate change version of WorldScan is calibrated to a climate policy-free energy baseline from the Timer model based on data provided by the Dutch Environmental Assessment Agency (PBL). In particular, the baseline considers exogenous real GDP growth calibrated to the sectoral level by adjusting total factor productivities, exogenous energy use by using energy efficiency adjustments and compensating capital requirements, and exogenous prices of primary energy carriers by using energy resources.[33]

4.2. Policy Scenarios

The objective of different policy scenarios is to demonstrate the limitations of the existing carbon market mechanisms and to assess the cost-efficiency of sectoral approaches and greater participation of developing countries. The following reasoning guides the selection of the policy scenarios. The EU's advocacy of sectoral mechanisms is based on the need (i) to address problems in ensuring the additionality of CDM credits, (ii) to scale up the international carbon market, in line with the need to achieve substantially increased volumes of emission reductions cost-effectively in the post-2012 period, and importantly (iii) to incentivise a transition from pure offsetting to cap-and-trade in major advanced developing countries.[34] A sectoral approach, rather than the project-by-project approach of the CDM, may help to deliver these goals. By establishing a target for sectoral emissions that goes beyond the business-as-usual outcomes, and that should be achieved before emission reductions are eligible for the international carbon market, it should induce action in advanced developing countries while largely ensuring that only genuine emission reductions can be offset against developed country emissions. At the same time, by eliminating the bottleneck of the CDM project approval procedures, it should facilitate the supply of emission reductions to the carbon market.

Table 2. Overview of policy scenarios

S1: GLOBAL CARBON MARKET	
Common emissions trading system (CTS), no CDM	
Intermediate step	
Annex I	Non-Annex I
Common emissions trading system (CTS)	Clean Development Mechanism (CDM) No action No sectoral approaches
S2: ENHANCED PARTICIPATION OF NON-ANNEX I	
Annex I	Non-Annex I
Common emissions trading system (CTS)	Clean Development Mechanism (CDM) Action: Emissions tax at 50% of CTS-price No sectoral approaches
S3: SECTORAL APPROACHES	
Annex I	Non-Annex I
Common emissions trading system (CTS)	Clean Development Mechanism (CDM) Action: Emissions tax at 50% of CTS-price Sectoral approaches: Emissions tax at 90% of the CTS-price in the power sector

In our analysis, it is therefore assumed that a common emissions trading system (CTS) covering all their greenhouse gas emissions is established among Annex I countries. The non-Annex I countries will not altogether abolish the existing CDM, but will instead enhance their own

[33] Energy prices in the baseline differ from current prices, so that the oil price amounts to about 30 $/barrel in 2020, which potentially leads to lower financial flows if the oil price is under-estimated. A future extension of the baseline taking account of a higher oil price of about 60 $/barrel might be appropriate.

[34] The choice of our policy scenarios is motivated also by the previous work of European Commission (see e.g. European Commission, 2009a and 2009b). Large differences in the marginal abatement costs between countries and sectors are the key driver for the creation of market-based mechanisms that eventually lead to cost-efficient reductions of emissions.

participation amounting to about half of the effort of Annex I countries in terms of abatement costs per unit of emissions. In addition, the existing project-based CDM will be augmented by sector-based approaches in non-Annex I countries. The global carbon market (GCM) scenario represents a cost-effective benchmark case against which we compare the counterfactual scenarios entailing different alternatives to the current CDM. All scenarios assume that no use is made of excess Assigned Amount Units issued under the first commitment period of the Kyoto Protocol to meet emission reduction commitments after 2012.

Table 2 summarizes schematically the main modelling assumptions across different counterfactual scenarios. All scenarios consider that the Kyoto Protocol remains in place until 2012, which includes the EU Emissions Trading System. In the post-2012 regime, the Annex I countries form a coalition and agree to similar mitigation efforts within a common emissions trading system (henceforth, we consider the abbreviation CTS for common trading system). A distinguishing point is that we consider different policy options for non-Annex I countries by gradually increasing their abatement effort and introducing the sectoral crediting mechanism for the power sector in the third scenario.

Scenario 1 assumes the creation of a perfect global carbon market by 2013, implying that marginal abatement costs are equalized in all countries so that global abatement costs are minimized. The CDM is no longer in place as all countries can trade freely in emission permits within a common trading system. As shown in Table 2, we consider an intermediate scenario before turning to the assessment of own participation and sectoral approaches in the non-Annex I countries. The intermediate scenario facilitates the assessment of the current CDM as it assumes that non-Annex I countries keep the CDM in its present project-based form.

Scenario 2 assesses the possibility of a developing country's own participation in financing domestic programmes to reduce emissions. The Annex I countries participate in a common trading system, but the non-Annex I countries have to provide a fraction of their own funds from public transfers in order to become eligible for receiving the CDM transfers. This scenario is modelled in a two-step fashion. In the first step, we define a "do-something" baseline in terms of emissions per unit of sectoral outputs in the CDM-supplying countries. In the second step, we take only reductions below this baseline as eligible for the CDM-credit exports. The production sectors in the non-Annex I countries are thus not covered by the CTS but instead supply the credits to the CDM scheme. The non-Annex I countries take half of the effort of the Annex I countries since the second baseline is determined by an emission tax imposed in non-Annex I countries, which is equal to 50% of the common trading system price.

Finally, Scenario 3 assesses the potential of sectoral approaches compared to the existing project-by-project crediting mechanisms. The sectoral credits are only issued for the reductions in emissions that go beyond an agreed threshold represented by this second baseline. As in scenario 2, the non-Annex I countries enhance their participation by taking half as much effort as Annex I countries. In addition to scenario 2, the non-Annex I countries impose a carbon tax in the power sector at 90% of the CTS price, which shifts the second baseline for the power sector downwards relative to other sectors.

The power sector is chosen somewhat arbitrarily to demonstrate the impact of sectoral approaches. However, arguments can be found in favour of this choice. First of all, the electricity sector is a significant and increasingly important contributor to global greenhouse gases (GHG) emissions. Together with the heating sector it accounts for about one quarter of total GHG (Bradley et al., 2007). Besides that, this sector is considerably abundant with financial means in most countries of the world. It is one of the sectors with considerably large technical potential for emissions reductions and thus low-cost abatement opportunities (Baron and Elis, 2006; Burniaux, 2009). Abatement of emissions in the power sector will be crucial in developing countries, as developing countries gradually increase demand for energy and represent almost half of the expected growth in global CO_2 emissions on a business-as-usual basis. For example, China's power sector accounts for about half of this total and India's power sector represents approximately one quarter of it (IEA, 2009). A possible economic intuition underlying the analysis of sectoral approaches in the electricity sector is that sectoral incentives for electricity restructuring towards greater efficiency are needed to achieve environmentally effective outcomes. The sectoral crediting mechanisms could offer one of the vehicles to induce changes in the electricity sector by facilitating targeted public and private investments.

4.3. Assumptions Underlying Policy Scenarios

In all policy scenarios the emission pledge for the EU27 is set at 20% reduction below 1990 emission levels by 2020. This working assumption is in line with the Commission communication to the European Parliament on "20 20 by 2020" (European Commission, 2008), which among others specifies that the EU commits to reduce greenhouse gas emissions by at least 20% by 2020 and to ensure that 20% of final energy consumption is met with renewable sources. For modelling purposes, the pledges are transformed into quantitative emission ceilings compared to 2005. The quantitative ceiling is calculated as the percentage change from 2005 emission reductions by 2020 taking into account the reduction pledges with respect to 1990 emission levels. For example, for the 20% reduction target of the EU with respect to 1990 emissions we arrive at a reduction of 14% compared to 2005 emissions.[35] Comparable to our calculations, Levin and Bradley (2009) consider also a quantitative ceiling for the EU27 at -14% compared to 2005 for the EU27 20% reduction while Wagner and Amman (2009) establish the quantitative ceiling for the EU27 at -13% compared to 2005 for the EU27 20% reduction target. The pledges for the emission reductions by non-EU27 Annex I countries are uniformly set at 20% in 2020 compared to 2005 levels. The target for developing countries is set at a 15% emission reduction below the baseline in 2020.

The renewable targets are specified in the model according to the "20 20 by 2020" initiative (European Commission, 2008) by which 20% of final energy consumption is met with renewable sources by 2020. In the model, we first calculate the 20% renewable target in volume terms assuming that Member States unilaterally commit to a pledge of 20% cut compared to 1990 emission levels, as defined in the "20 20 by 2020" initiative. The renewable targets expressed in volume terms are then applied to all our policy scenarios. The reason for this uniform treatment of renewable targets in all scenarios is that the model assumes progressive marginal costs of renewable energy carriers. Given that mitigation operates by substitution of heavily-polluting energy carriers by less-polluting energy carriers, a consideration of renewable targets endogenously with the energy use in each scenario would generate implausible income losses for the EU.

5. Outcomes of the Analysis

5.1. Simulation Results

The presentation of simulation results follows the objective of this paper and brings into focus the environmental effectiveness, cost-efficiency and macro-economic impacts of different climate policy options. The results are typically expressed as percentages of baseline values in 2020.[36] Table 3 presents the results of counterfactual policy scenarios against the benchmark global carbon market (GCM) scenario.

[35]The ceiling considers a uniform target for the ETS sectors and the country-specific targets for the non-ETS sectors for the pledge of 20% (see Table A2 in Annex for detailed information), which are based on the official document by the European Union (2009a). As stated in this document, the reduction efforts by the EU Members are based on the principle of solidarity between Member States and the need for sustainable economic growth across the EU, so that Members with relatively low per capita GDP and high growth expectations may increase their GHG emissions compared to 2005. The quantitative ceilings are calculated separately for the ETS and non-ETS sectors, by taking into account the pledges and emission volumes, and then summed up together to define an aggregate quantitative.

[36]Alternatively, the model also allows assessing the effects in levels. The results are presented for a selected set of countries for 2020, but all results could be also derived either at annual, country or sector level for sets of individual countries and country groups.

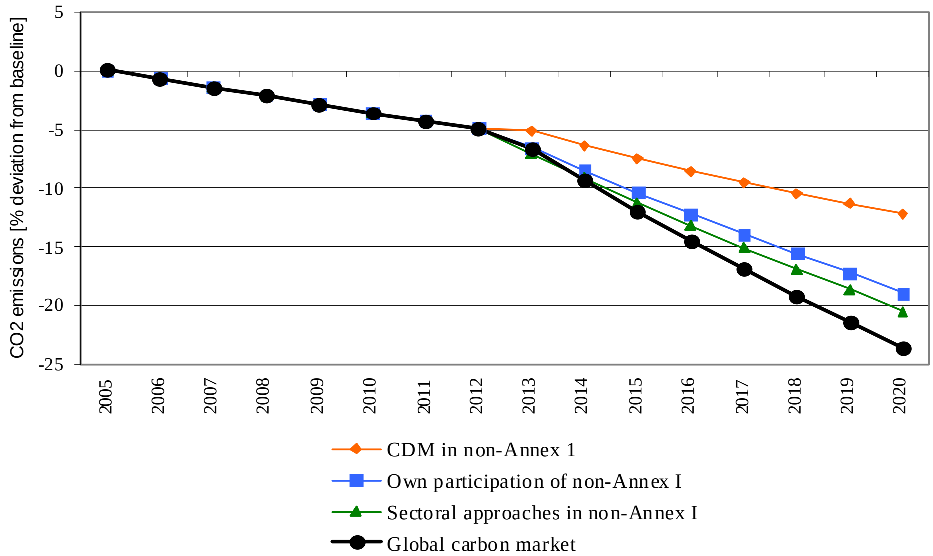
Table 3. Emissions reduction and macro-conomic costs of different policy options

	Annex I		Non-Annex I		World		Permit price
	Emissions	GDP p.c.	Emissions	GDP p.c.	Emissions	GDP p.c.	(€ / tCO2)
Global carbon market	-17.97	-0.17	-27.73	-0.84	-23.64	-0.37	19.86
CDM in non-Annex I	-12.16	-0.17	-12.27	-0.13	-12.23	-0.16	10.57
Own participation of non-Annex I	-15.20	-0.22	-21.73	-0.44	-18.99	-0.28	14.56
Sectoral approaches in non-Annex I	-15.94	-0.23	-23.81	-0.53	-20.51	-0.31	15.63

Note: Emissions and GDP p.c. are reported in % baseline deviation. Emission price in 2020 is reported in EUR per ton of CO2.
Source: WorldScan computations.

Exempting production sectors in non-Annex I countries from the CTS leads to a global reduction of emissions of 12% relative to baseline level in 2020. This is considerable less than under the global carbon market scenario (-24%). The CDM use allows Annex-I countries to meet their reduction targets at considerably lower CTS permit price (11 €/tCO_2) than under the global carbon market (GCM) (20 €/tCO_2). Although environmentally ineffective compared to the GCM, the CDM is less costly for non-Annex I countries in terms of GDP (-0.1%) compared to the GCM (-0.8%). While own participation raises the abatement effort of non-Annex I countries, it simultaneously increases the action of Annex I countries because of their reduced opportunities to rely upon the CDM. By contrast, the non-Annex I countries achieve large environmental gains (-22%) at moderate economic costs in terms of GDP (-0.4%). The emission reduction of almost 24% under the sectoral crediting mechanisms comes close to the emission reductions in non-Annex I countries under the global carbon market (-28%). Intuitively, the imposition of a relatively high carbon tax in the power sector yields a considerable reduction of emissions as the power sector is one of the main culprits for carbon dioxide emissions in non-Annex I countries. Figure 3 plots the carbon emissions reduction over time and shows that all three scenarios are environmentally superior to the CDM regime. It becomes clear from Figure 3 that the costly effort of developing countries is justified on environmental grounds. A further extension towards a system with the new sectoral approaches in the non-Annex I countries is almost as environmentally effective as the global carbon market already when the sectoral approaches are applied only to the power sector.

Figure 3. Global reduction of emissions comparing different policy options



Source: WorldScan computations.

Table 4 gives further insights by comparing the Annex I countries allowance imports across different policy options. The policy option in the third row of Table 4 considers that all sectors in Annex I countries are part of a common emissions trading system, but the production sectors in non-Annex I countries are a source of CDM credits. The CDM appears to be ineffective with higher emission levels in Annex I countries (14.5 $GtCO_2$) and non-Annex I countries (20.0 $GtCO_2$) relative to the counterfactual scenarios that improve upon the existing CDM by assuming own participation and the SCM in non-Annex I countries. That is, the higher the own effort of non-Annex I countries, the higher the benefits for climate change. Both variants push CDM use to the margin because they shift downwards the CDM benchmark. Both Annex I countries and non-Annex I countries gain in economic terms from the CDM system at the expense of the environment. The enhanced participation of non-Annex I countries results in a fall of CDM imports from 2.5 to 1.9 $GtCO_2$. An additional consideration of sectoral mechanisms in the power sector of non-Annex I countries reduces further CDM use to 1.7 $GtCO_2$ and reduces emissions from 14.0 to 13.8 $GtCO_2$. Stimulating own participation in developing countries leads to further action in the industrialized countries, simply because of reduced trading opportunities under the CDM.

Table 4. Emissions and allowance trade in GtCO2, 2020

	Emissions			Allowance permits		
	World	Annex I	Non-Annex I	Total	Permits imports	CDM
Baseline	39.2	16.5	22.8	-	-	-
Global carbon market	30.0	13.5	16.5	1.6	1.6	-
CDM in non-Annex I	34.4	14.5	20.0	2.6	0.1	2.5
Own participation of non-Annex I	31.8	14.0	17.8	2.1	0.2	1.9
Sectoral approaches in non-Annex I	31.2	13.8	17.4	2.0	0.2	1.7

Source: WorldScan

5.2. The Volume of the Financial Flows through the Carbon Market

The total financial flows through the carbon market amount roughly to €32 billion at 2004 prices, as shown in Table 5. At the global level, the order of magnitude is comparable across different policy scenarios. Moving from the CDM through the sectoral approaches towards the global carbon market gradually increases the financial flows. Table 5 presents the financial flows for individual Annex I countries and non-Annex I countries. Column (1) of Table 5 refers to the reference scenario 1 assuming the global carbon market, where all Annex I and non-Annex I sectors take part in the common emissions trading system. The bulk of financial transfers come from the EU27 (€13 billion), while China is the largest recipient of the funds (€28 billion). The financial transfers from the carbon market for China are substantially lower under the other scenarios.

Table 5. International financial flows through the carbon market in 2020

	Global carbon market	CDM in non-Annex I	Own participation of non-Annex I	Sectoral approaches in non-Annex I
	(1)	(2)	(3)	(4)
Annex I	-32.2	-27.2	-30.2	-30.5
EU27	-13.3	-9.4	-11.2	-11.6
EU15	-13.6	-8.9	-11.0	-11.5
EU12	0.3	-0.5	-0.2	-0.1
USA	2.0	-3.2	-1.5	-0.8
Former Soviet Union	-9.1	-6.5	-7.8	-8.1
Non-Annex I	32.2	27.2	30.2	30.5
Brazil	4.9	1.2	1.5	1.6
China	28.0	10.8	11.0	11.1
India	-0.5	4.5	3.6	3.2

Note: Financial flows are reported in billion EUR at 2004 prices.
Source: WorldScan computations.

5.3. The Global Carbon Market

Scenario 1 is a reference policy scenario, which is modelled against the background of the baseline with no consideration of the current financial crisis. In a nutshell, this scenario considers the Kyoto Protocol continuously in place until 2012 and a perfect global carbon market in the post-2012 period.

Table 6 gives a detailed overview of the environmental and economic effects for individual countries. The outcomes of the global carbon market scenario show an emission reduction of -18% compared to the baseline in 2020, which comes at 0.3% loss in national income in Annex I countries. In addition to more standard measures of economic activities like GDP and national income, the second column of Table 6 reports the welfare effects. The welfare measure includes consumption and leisure activity. The magnitude of economic effects in terms of welfare comes close to the national income effects in most economies, except for the new EU Member States and emerging countries. However, regardless of the measure of economic activity used, the economic cost at the global level approaches -0.37% relative to the baseline in 2020.

Table 6. Detailed simulation results of scenario "Global carbon market", 2020

	C02 Emissions	Welfare	GDP p.c.	National income	Real average wage	Export volume	Import volume
Annex I	-17.97	-0.29	-0.17	-0.27	-0.55	-0.73	-1.34
EU27	-15.09	-0.28	-0.13	-0.30	-0.35	-0.52	-1.30
EU15	-13.73	-0.26	-0.10	-0.28	-0.28	-0.39	-1.36
EU12	-20.79	-0.44	-0.55	-0.57	-1.33	-1.23	-0.94
USA	-20.85	-0.16	-0.12	-0.13	-0.59	-1.74	-1.29
Former Soviet Union	-21.16	-1.85	-0.99	-1.41	-3.29	-1.04	-4.59
Non-Annex I	-27.73	-0.58	-0.84	-0.57	-2.53	-2.64	-1.69
China	-31.28	-0.32	-0.70	-0.18	-2.58	-3.09	-0.93
India	-33.10	-0.86	-1.12	-1.10	-3.42	-4.07	-2.43
Brazil	-23.11	0.38	-0.17	0.27	-0.46	-4.87	-1.24
World	-23.64	-0.36	-0.37	-0.36	-1.00	-1.54	-1.47

Note: The results are reported as % deviation from baseline in 2020.
Souce: WorldScan computations.

The non-Annex I countries appear to have a considerably larger scope for environmental improvements in the global carbon market compared to the project-based CDM (see Table 6 and Table 7). In particular, the emission reductions in non-Annex I countries (-12%) reach less than one half of the potential (-28%) of the global carbon market. Looking at the cross-regional differences, two systematic patterns seen in the global carbon scenario hold also in counterfactual policy scenarios. First, the order of magnitude of economic costs depends on the type of indicator used to assess the cost-efficiency of policies. For example in China, the abatement action costs 0.7% of GDP, while it leads to a considerably lower welfare loss (0.3%) and income loss (0.2%) in the global carbon market scenario (Table 6). Second, the abatement action appears to be relatively more costly in the new Member States (EU12) than in the old Member States (EU15), which is likely associated with the relative carbon-intensity of their industries.

A possible explanation for these two observations is the following. With regard to the choice of a cost measure, a loss of GDP indicates reduced production, while the welfare indicator is linked more closely to national income than to production as consumer expenditure is simply determined as a fraction of the former. The changing wedges between income and production value result in trade adjustments, which are presented in the last two columns of Table 6. In the global carbon market scenario, imports have decreased by less than exports in non-Annex I countries, respectively by -1.7% and -2.6% relative to the baseline, while the opposite is observed for the Annex I countries, where exports have on average declined by far less (-0.7%) than imports (-1.3%). These results imply that the financial transfers from Annex I countries to non-Annex I countries are partly spent on imports from Annex I countries.

Table 7. Detailed simulation results of scenario "CTS in Annex I, CDM in non-Annex I", 2020

	C02 Emissions	Welfare	GDP p.c.	National income	Real average wage	Export volume	Import volume
Annex I	-12.16	-0.20	-0.17	-0.20	-0.35	-0.56	-0.71
EU27	-10.54	-0.23	-0.20	-0.26	-0.20	-0.44	-0.66
EU15	-9.61	-0.21	-0.18	-0.24	-0.17	-0.38	-0.66
EU12	-14.40	-0.43	-0.49	-0.54	-0.75	-0.76	-0.69
USA	-14.00	-0.11	-0.11	-0.10	-0.37	-1.06	-0.63
Former Soviet Union	-13.79	-0.98	-0.28	-0.50	-1.80	0.29	-2.27
Non-Annex I	-12.27	-0.06	-0.13	-0.02	-0.14	-0.82	-0.49
China	-16.08	-0.02	-0.08	0.02	-0.17	-0.80	-0.37
India	-17.32	0.07	-0.15	0.08	-0.12	-1.35	0.28
Brazil	-12.43	0.12	-0.13	-0.11	0.02	-1.53	0.08
World	-12.23	-0.16	-0.16	-0.15	-0.31	-0.68	-0.62

Note: The results are reported as % deviation from baseline in 2020.
Souce: WorldScan computations.

With regard to the differences between the new Member States and the old Member States, relatively more costly abatement actions could be due to the relative carbon-intensity of industries in the new Member States. To understand better this wedge between the EU12 and the EU15, we look for further sector-specific evidence in Table 8. The EU12 countries are more carbon-intensive in the production of electricity than the EU15 countries, since carbon-intensive coal represents 35% of total output in the EU12 countries. The EU15 countries instead rely more on carbon-extensive sources, such as natural gas (23%), nuclear plants (36%) and renewables (2%). The environmental policy could indirectly affect the energy-intensive manufacturing industries, if the environmentally constrained price of energy is streamed down the supply chain but there is hardly any supportive evidence of this link. For example, Convery et al. (2008) do not find any effect on the link between the carbon price and competitiveness in the EU looking across all sectors, but Bassi et al. (2009) suggest that this could be the case for some US manufacturing industries depending on their carbon intensity, the mix of energy sources and the energy efficiency of production.

Table 8. Primary energy for electricity production, % share ot total in 2004

	Coal	Oil	Natural gas	Nuclear	Wind/Solar	Hydro
EU12	34.71%	4.94%	12.98%	33.92%	0.08%	13.37%
EU15	20.44%	5.25%	23.04%	36.26%	2.33%	12.68%
EU27	21.92%	5.21%	22.00%	36.01%	2.10%	12.75%

Note: The reported values are the % output share of the total primary energy used for electricity production in 2004, which is the starting year of the model.
Source: Eurostat (October, 2009).

The discussion of the results above highlights two issues. First, there is a large scope for environmental improvements in non-Annex I countries and those Annex I countries with large abatement possibilities, as for example the new EU Member States. The economic impact of abatement actions can be interpreted with a range of macro-economic cost measures. Second, the results highlight the need for the effort-sharing principles between high-income and low-income regions. In the case of the European Union, the Council has already adopted the effort-sharing decision by which no EU Member State should be asked to make an investment that diverges too far from 0.5% of GDP by 2020 (European Union, 2009a). In particular, the specific requirements of each Member State are to be adjusted to a realistic level of investment from lower-income Member States.[37]

[37]The adjustment thus affects different aspects of the Commission proposals, including the national targets set for reductions in greenhouse gases outside the ETS (presented in Annex Table A2), the national targets set for the share of EU

5.4. Enhanced Participation of Developing Countries

Scenario 2 is a counterfactual policy scenario, which is modelled against the background of the baseline with no consideration of the current financial crisis. In a nutshell, Scenario 2 assesses the theoretical possibility of enhanced participation of developing countries, which take half as much of the abatement effort as Annex I countries. Table 9 presents the simulation results for individual Annex I and non-Annex I countries.

Comparing the results of this policy scenario to the CDM scenario, it becomes clear that enhanced participation of non-Annex I countries helps to reduce global emissions (-19%) with considerable improvements in non-Annex I countries (-22%). At the global level, the welfare effects (-0.26%) resemble the economic effects in terms of GDP and national income. As expected, the economic costs for non-Annex I countries are somewhat lower than under the global carbon market scenario, because their sectors can partially benefit from the CDM. The consideration of different cost measures is nonetheless useful to understand better the cost-efficiency of mitigation action across different countries. It appears that non-Annex I countries lose relatively less in terms of welfare than in terms of GDP, while the estimates of national income loss come very close to the welfare loss estimates. Among non-Annex I countries, Brazil achieves high environmental improvements (-23%) at considerably lower cost (-0.2%) than India (-0.6%).

Among Annex I countries, the new EU Member States and the US have greater scope for environmental improvements than the EU15. However, the US mitigation action appears to be less costly, since the comparable reductions of 17% are achieved at 0.1% loss in GDP in the US, while the EU12 lose 0.6% of GDP. Comparing different measures of cost-efficiency, the results imply relatively small differences across Annex I countries, while the opposite is true for non-Annex I countries. Table 9 also presents other macro-economic results. In sum, this policy scenario results in considerably smaller macro-economic costs than the global carbon market scenario.

Table 9. Detailed simulation results of scenario "Own participation of non-Annex I", 2020

	C02 Emissions	Welfare	GDP p.c.	National income	Real average wage	Export volume	Import volume
Annex I	-15.20	-0.25	-0.22	-0.24	-0.47	-0.90	-1.04
EU27	-12.99	-0.27	-0.23	-0.31	-0.31	-0.68	-0.96
EU15	-11.85	-0.25	-0.20	-0.28	-0.26	-0.61	-0.98
EU12	-17.79	-0.45	-0.58	-0.58	-1.05	-1.11	-0.85
USA	-17.46	-0.14	-0.14	-0.12	-0.49	-1.69	-0.97
Former Soviet Union	-17.51	-1.32	-0.56	-0.86	-2.43	-0.26	-3.20
Non-Annex I	-21.73	-0.30	-0.44	-0.34	-0.60	-1.50	-1.19
China	-27.40	-0.26	-0.41	-0.32	-0.69	-1.40	-0.95
India	-28.67	-0.38	-0.61	-0.46	-1.03	-1.99	-0.76
Brazil	-23.50	0.09	-0.20	-0.18	-0.11	-2.49	-0.79
World	-18.99	-0.26	-0.28	-0.27	-0.51	-1.16	-1.10

Note: The results are reported as % deviation from baseline in 2020.
Souce: WorldScan computations.

5.5. Sectoral Crediting Mechanisms

Scenario 3 has been developed as a counterfactual policy scenario and is modelled against the background of the baseline with no consideration of the current financial crisis. In a nutshell, this scenario assesses the role of sectoral approaches by considering an additional tax on carbon emissions in the power sector of non-Annex I countries.

energy consumption to be taken by renewables, and auctioning rights under the ETS with the distribution of auctioning rights spread to increase the share of lower-income Member States (European Commission, 2009b).

A modification of the CDM with the new sectoral approaches improves further the global environmental outcomes relative to a consideration of enhanced participation of developing countries in climate change mitigation, but not as much as the global carbon market scenario. Table 10 presents the simulation results for the individual Annex I and non-Annex I countries. Compared to the scenario with enhanced mitigation efforts of non-Annex I countries, the sectoral approaches in non-Annex I countries reduce the global emissions (-20%) with considerable improvements in non-Annex I countries (-24%). At the global level, the welfare effects (-0.29%) come close to the economic costs in terms of GDP and national income.

In sum, a detailed analysis of environmental and economic effects of different policy scenarios shows that the environmental outcome in non-Annex I countries systematically improves as more countries take on more ambitious targets. Market mechanisms do not result in more reduction, but primarily lower cost in achieving given targets. In particular, the enhanced action of non-Annex I countries and moreover the sectoral approaches substantially improve the environmental outcome of the existing CDM mechanism applied on a project-by-project basis in non-Annex I countries.

Table 10. Detailed simulation results of scenario "Sectoral approaches in non-Annex I", 2020

	C02 Emissions	Welfare	GDP p.c.	National income	Real average wage	Export volume	Import volume
Annex I	-15.94	-0.26	-0.23	-0.25	-0.51	-0.98	-1.12
EU27	-13.60	-0.28	-0.24	-0.32	-0.34	-0.75	-1.03
EU15	-12.41	-0.26	-0.21	-0.29	-0.29	-0.66	-1.05
EU12	-18.59	-0.46	-0.60	-0.59	-1.12	-1.20	-0.88
USA	-18.29	-0.14	-0.15	-0.12	-0.52	-1.85	-1.05
Former Soviet Union	-18.43	-1.41	-0.63	-0.95	-2.60	-0.38	-3.40
Non-Annex I	-23.81	-0.38	-0.53	-0.44	-0.77	-1.64	-1.36
China	-29.78	-0.33	-0.50	-0.42	-0.87	-1.54	-1.08
India	-31.64	-0.54	-0.77	-0.66	-1.32	-2.11	-1.05
Brazil	-25.28	0.08	-0.22	-0.19	-0.15	-2.69	-0.98
World	-20.51	-0.29	-0.31	-0.30	-0.57	-1.27	-1.20

Note: The results are reported as % deviation from baseline in 2020.
Souce: WorldScan computations.

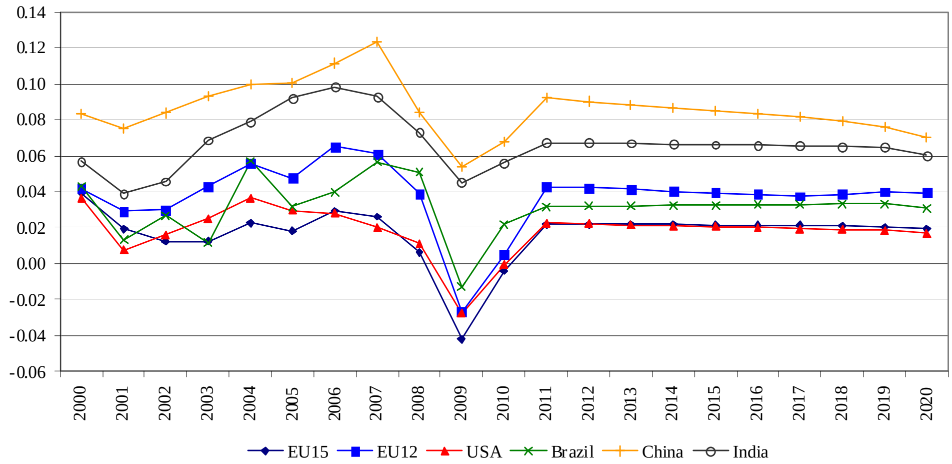
6. Potential Impacts of the Current Economic Crisis

6.1. A Baseline Adjusted by Taking into Account the Current Economic Crisis

The current economic crisis is likely to affect the macro-economic costs of the climate-policy instruments. On the one hand, the crisis will cut emissions in the short run due to lower economic activity and energy demand. On the other hand, it may jeopardize the long-term private and public investments in low-carbon technologies. A greater need for liquidity by firms could flood the supply of emission permits and result in a lower carbon price making polluting less expensive. Such market imperfections would consequently reduce the financial flows generated through the carbon market.

Figure 4 plots the projected evolution of economic growth across different regions based on recent Commission (European Commission, 2009c, 2009d) and the IMF (IMF, 2009) projections of the current economic crisis. The evolution of real GDP growth follows the same path as in Figure 4, except for the period 2008-2012 during which the crisis is projected to fade. Figure 4 shows that the outlook for economic growth is rather optimistic as the economic crisis appears to have reached its turning point by late 2009. Although a high degree of uncertainty persists in the markets, the policy interventions have succeeded in achieving some stabilization in the financial system and supported economic activity (European Commission, 2009d).

Figure 4. Real GDP growth rate in baseline scenario with crisis, 2000-2020



Source: WorldScan computations based on the European Commission (2009d and 2009e) and IMF (2009) forecast reports until 2008 and own computations afterwards.

The new baseline adjustments take into account the heterogeneous responses of countries to the crisis rather than a common baseline shift. For example, Figure 4 shows that the advanced economies have been hit harder than the emerging economies with presumably larger abatement possibilities. The current medium-term output projections are, however, on a much lower path than before the crisis, consistent with a permanent loss of potential output (IMF, 2009). Hence, Figure 4 shows that the post-crisis economic growth returns to the pre-crisis growth average levels. Table 11 presents the differences between the baseline with crisis and the baseline without the crisis projections. The average annual growth rate is lower by 0.8% points, which implies a loss in potential output by 2020. While population is held constant, the other environmental and economic parameters are systematically lower in the baseline scenario with crisis.[38]

Table 11. Difference between baseline with crisis and baseline without crisis projections (% points)

	CO2 emissions	GDP volume	Population	Real wage	Energy demand
Annex I	-1.02	-0.89	0.00	-0.88	-1.04
EU27	-0.87	-0.91	0.00	-0.91	-0.88
EU15	-0.89	-0.91	0.00	-0.90	-0.89
EU12	-0.81	-0.99	0.00	-0.99	-0.81
USA	-0.89	-0.75	0.00	-0.76	-0.90
Former Soviet Union	-1.74	-1.79	0.00	-1.87	-1.75
Non-Annex I	-0.38	-0.58	0.00	-0.61	-0.38
Brazil	-0.24	-0.35	0.00	-0.39	-0.26
China	-0.45	-0.70	0.00	-0.75	-0.46
India	-0.14	-0.30	0.00	-0.34	-0.17
World	-0.67	-0.80	0.00	-0.82	-0.69

Note: Comparison between baseline scenario with the crisis projections and baseline scenario without the crisis projections is calculated as the difference between average annual growth rates in 2004-2020 of baeline with crisis and baseline without crisis. Unit of observation is thus a percentage point. The growth rates of parametes related to economic activity of a region are systematically lower in baseline that includes the crisis projections compared to baseline without the crisis projections.
Source: Baseline scenario with crisis projections, the WorldScan climate change model.

[38]In the model, total factor productivity growth rates of sectors are adjusted to arrive at the real GDP growth rate series and energy use is adjusted endogenously with respect to the real GDP growth series.

6.2. The Potential Impact of the Crisis on the Outcomes of Policy Options

A consideration of the current economic crisis translates into lower macro-economic costs of the climate policy scenarios. This is due to the fact that the required reduction effort has become smaller in terms of the size of the reduction below baseline, because the emission targets are defined in terms of pre-crisis emission levels. Table 12 presents the results of counterfactual policy scenarios against the benchmark global carbon market scenario. These results are directly comparable to those of Table 3.

The current crisis potentially reduces the impact of the climate policy instruments, as shown in Table 12. In particular, the crisis drives down the CTS price from 20 €/tCO_2 to 12 €/tCO_2 under the global carbon market. A similar effect is observed in the two counterfactual policy scenarios. As the economic effects of the financial crisis deepen, it becomes relatively cheaper to pollute. Such a low price is worrying for the longer term as it reduces the incentives for firms to cut back their emissions. The firms may postpone their investment decisions as it becomes less efficient for them to consider low-carbon options.

Table 12. The potential impact of the economic crisis in 2020

	Annex I		Non-Annex I		World		Permit price
	Emissions	GDP p.c.	Emissions	GDP p.c.	Emissions	GDP p.c.	(€/tCO2)
Global carbon market							
Baseline with crisis [1]	-13.05	-0.12	-20.19	-0.52	-17.33	-0.25	11.78
Baseline without crisis [2]	-17.97	-0.17	-27.73	-0.84	-23.64	-0.37	19.86
Difference [1] - [2]	*4.92*	*0.04*	*7.53*	*0.33*	*6.31*	*0.12*	*-8.08*
Own participation of non-Annex I							
Baseline with crisis [1]	-8.93	-0.14	-14.71	-0.22	-12.39	-0.17	6.76
Baseline without crisis [2]	-15.20	-0.22	-21.73	-0.44	-18.99	-0.28	14.56
Difference [1] - [2]	*6.27*	*0.07*	*7.02*	*0.21*	*6.60*	*0.11*	*-7.80*
Sectoral approaches in non-Annex I							
Baseline with crisis [1]	-9.34	-0.15	-16.45	-0.27	-13.60	-0.19	7.20
Baseline without crisis [2]	-15.94	-0.23	-23.81	-0.53	-20.51	-0.31	15.63
Difference [1] - [2]	*6.60*	*0.08*	*7.36*	*0.26*	*6.91*	*0.12*	*-8.43*

Note: Emissions and GDP p.c. are reported as % difference with the baseline adjusted to crisis in [1] and not adjusted in [2]. The difference between the baseline with crisis [1] and the baseline without crisis [2] is reported in % points. With consideration of the crisis in the baseline, the scope for emission reduction below the baseline in 2020 is lower than in the case of the baseline without the crisis projections.
Source: WorldScan computations.

The crisis influences the effectiveness of policy options differently across the Annex I and non-Annex I countries, because the adjusted baseline considers the emission targets defined in terms of pre-crisis emission levels. The economic costs in the Annex I countries do not depend much on the baseline, that is, the difference between both cases is less than 0.1% point in terms of GDP per capita (column 2 in Table 12). By contrast, the crisis matters more for the non-Annex I countries in terms of cost-efficiency as indicated by the difference between both cases in the order of 0.3% points for GDP (column 4 in Table 12).

Figure 4 illustrates the heterogeneous impact of the crisis on the non-Annex I and Annex I countries. The crisis could have additionally affected the windfall profits of the non-Annex I countries. Although these countries partially still benefit from the CDM system, their benefits from it could be reduced due to a lower price wedge between the CTS price and the carbon tax rate.[39] The lower CTS price also drives down the financial flows generated through the carbon market. Their order of magnitude at the global level is considerably lower (€9 billion) in the case of the baseline scenario taking into account the crisis (Table 13).

[39]The non-Annex I countries could still exploit the price wedge of 6 €/tCO_2 between the CTS price (12 €/tCO_2) and the carbon tax set at the half of the CTS price under the global carbon market. However, the CTS price is higher (20 €/tCO_2) in the absence of crisis, which implies a relatively higher price wedge of 10 €/tCO_2 and thus higher potential profits in the non-Annex I countries.

Table 13. International financial flows in 2020 through the carbon market with a consideration of the crisis in baseline

	Global carbon market (1)	CDM in non-Annex I (2)	Own participation of non-Annex I (3)	Sectoral approaches in non-Annex I (4)
Annex I	-9.0	-8.4	-9.2	-9.4
EU27	-5.1	-3.3	-3.8	-4.0
EU15	-5.6	-3.2	-3.8	-4.0
EU12	0.5	-0.1	0.0	0.0
USA	3.6	-0.3	0.3	0.5
Former Soviet Union	-3.2	-2.1	-2.4	-2.5
Non-Annex I	9.0	8.4	9.2	9.4
Brazil	2.8	0.5	0.6	0.7
China	12.5	2.7	2.8	2.8
India	-2.2	1.4	1.2	1.0

Note: Financial flows are reported in billion EUR at 2004 prices.
Source: WorldScan computations.

Under the Copenhagen Accord, developed countries committed themselves to a goal of mobilising up to $100 billion (€80 billion at 2004 prices) per year by 2020. This figure covers public and private finance for mitigation and adaptation, whereas our estimates of financial flows through the carbon market cover only private finance for mitigation.[40] The actual level of financial flows from developed to developing countries will depend on the level of action by developed and developing countries.

7. Conclusion

This paper has provided some insights into the post-2012 options for the global financing of climate change mitigation. The modelling exercise in this paper focuses on new crediting mechanisms by providing an assessment of the theoretical potential of sectoral approaches and participation of developing countries in financing climate change actions compared to the Clean Development Mechanism (CDM) projects. The analysis provides a crude estimate of carbon market financial flows needed for global climate change mitigation, while evaluating the environmental effectiveness, cost efficiency and macro-economic impacts of underlying policy instruments. Following the outcome of the UNFCCC conference in Copenhagen, the paper makes no specific assumptions about the future international climate regime. However, it assumes that no use is made of excess Assigned Amount Units issued under the first commitment period of the Kyoto Protocol to meet emission reduction commitments after 2012.

A detailed analysis of the environmental and economic effects of different policy scenarios shows that the environmental prospects in non-Annex I countries systematically improve in a transition from the CDM towards the global carbon market, while the opposite is foreseen for their economic costs. The largest global emission reductions of about 24% in 2020 are achieved under the global emission trading system at the cost of 0.3% global income. The international financial transfers to developing countries would under this scenario amount to a tentative €32 billion. The benefits in terms of reduced global emissions with respect to the baseline range from 12% under the existing CDM to 19% with enhanced participation of developing countries and 20% with the sectoral approaches in developing countries.

[40] The order of magnitude of financial flows has to be interpreted with caution in line with the assumptions about low emission targets and oil price considered in the model.

In particular, the results suggest that the more of a carbon market we have when moving from the project-based CDM to sectoral crediting mechanisms and internationally linked cap-and-trade, the more private finance the carbon market will channel to developing countries. The improved environmental outcome comes foremost from enhanced participation of developing countries that start to take on targets and hence the carbon price leads to reductions above and beyond the own action. The analysis also shows that the crisis is associated with lower costs of the climate policy options. The latter results in a lower carbon price and reduced financial flows generated through the carbon market. The baseline adjusted by taking into account the crisis is lower than the pre-crisis baseline, because the emission targets are defined in terms of pre-crisis emission levels. Although rather indicative and economically intuitive, these results have to be interpreted with caution by taking into account the assumptions adopted in the scenarios.

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ANNEX A: Data Sources

In specific modelling blocks, the model employs other sources than the GTAP-7 (Narayanan and Walmsley, 2008). The energy baseline, for example, is supplied by the Netherlands Environmental Assessment Agency (PBL), providing energy use by carrier and carrier prices. The description of data in different modelling blocks is derived from the WorldScan climate change model, which is supported by the CPB document describing the model (Lejour et al., 2006).

Note that all prices in the GTAP-7 database are expressed in US dollars. The values of GDP in national currencies are translated into US dollars by using market exchange rates, because the GTAP-7 database highlights international trade relations, and trade values are always expressed in the US dollars using market exchange rates. GDP values in market prices are not a good indicator for purchase power comparisons, because non tradable goods and services are differently priced in the various regions. By consequence, GDP developments of various regions can not be used for purchase power comparisons.

Concordance Matrix

The GTAP-7 database contains information for 57 basic sectors. To keep the WorldScan model tractable, it is helpful to reduce this set of basic sectors to a smaller set of aggregated sectors, usually a number below 25. Basic sectors are subsumed under an aggregated sector based on their similarity from the perspective of the producer. However, in consumption studies considerably different aggregated sectors arise. Here the similarity of basic sectors is defined from the consumers' perspective.

Correspondingly, the modelling of a sectoral consumption demand system in WorldScan must also be founded on aggregated consumption categories. This requires information on the relation between the aggregated production sectors and the aggregated consumption categories, which can be derived from the GTAP-7 database in the form of a concordance matrix. For that purpose, every GTAP-7 basic sector is classified in a more comprehensive producer based aggregated sector and a consumer based aggregated consumption category. This procedure yields a matrix with consumption values for every aggregated producer sector and consumer category combination within each region. The data matrix supplies the weights of the production sectors in the consumption categories for every region. The tax on consumption is calculated as the difference between consumption in market prices (before taxation) and in user prices (after taxation), which are both available from the GTAP-7 database.

Consumption

The Linear Expenditure System (LES) is suitable to model the consumption decision, because it combines simplicity with some flexibility. An extension of the GTAP-7 database provides a sound empirical underpinning for calibration of the LES. The GTAP-7 database is used to assign values to the parameters of the Linear Expenditure System. The standard GTAP-7 database contains input-output tables per region and trade data connecting these regions. From this dataset the sectoral consumption shares can be obtained. Besides that, additional consumption data are available from the GTAP-7 database: the elasticity of income per sector and region and the so-called Frisch-parameter per region. The GTAP-7 database (Narayanan and Walmsley, 2008) derives the income elasticities for the food sectors from the FAO-model and bases the other income elasticities on previous empirical studies (see Lejour et al., 2006).

Economic Growth

The model considers the most recent developments of real GDP growth rates retrieved from the Commission services (European Commission, 2009) data and the IMF World Economic Outlook data (IMF, 2009) to ensure the consistency of the data for all countries of the world. To construct the regional aggregates, we use the real GDP values at constant prices in 2004 (i.e. corresponding to the starting year of the model calibration) for the weights w_i of individual country (i), so that the real GDP growth rate per region (r) is $\dot{Y}_r = \sum_i y_i w_i$, where, for example, $i = AT, BE, ..., UK$ for $r = EU15$. The adjustment of the baseline scenario to the current financial crisis in the sensitivity analysis is based upon the most recent GDP growth forecast data from the Commission services (European Commission, 2009c and 2009d) and the IMF World Economic Outlook (IMF, 2009) available for individual countries of the EU27 and the world. For consistency reasons, both baselines contain the same GDP time series for the periods of 2000-2007 and from 2012 onwards. For the case of baseline without the crisis projections, the model trajectories of the economic growth are adjusted with respect to the recent update of GDP data to smoothen the transition from the real GDP series until 2007 and projections afterwards, as shown by Figure 1. For the case of the baseline with the crisis projections, the forecasted GDP data retrieved from the Commission services (European Commission, 2009c and 2009d) and the IMF-WEO (IMF, 2009) is used for the period from 2008 until 2012, as shown by Figure 2. The total factor productivity growth at sector-level is adjusted to arrive at the real GDP growth rate series and the energy use is endogenous with respect to economic activity. That is, the sectoral TFP growth is expressed as a function of macro-TFP growth and sectoral TFP growth relative to the macro-TFP growth rate. The latter variable is an exogenous variable in the model's counterfactual simulations. Energy and Climate

The data on the coal and oil reserves come from the EPPA model, explained by Lejour (2006). These reserves include identified, undiscovered and currently uneconomic recoverable resources. For simulation over periods of 50 years or more, this broad definition is appropriate. For the gas, WorldScan uses data from the International Environment Agency (IEA), because this source provides more recent measurements and contains specific information on European countries. The excise duties are not explicitly defined in the model, but rather treated collectively in a taxation block of the model. The GTAP-7 database (Narayanan and Walmsley, 2008) supplies the data necessary to calibrate the parameters for the energy sectors. Additionally, the cost share data for biomass and non-fossil fuels derive from the IMAGE-TIMER model of the Dutch National Institute for Public Health and Environment (RIVM) and the Netherlands Environmental Assessment Agency (PBL). Data for non-CO2 greenhouse gas emission are provided by the RIVM. The current version of the climate change model includes carbon dioxide gas, but not the other non-CO_2 green-house emissions. The sectoral flexibility of WorldScan allows consideration of as many types of the GHG as they are accounted for in the data. These non-CO2 greenhouse gases account for a considerable share of the total emissions (CO2 plus non-CO2), ranging from roughly 15% in the USA, the Rest of OECD and the EU-15 countries to almost 40% in Latin America.

Human Capital

The classification of high- and low-skilled workers follows the approach described by the recent CPB document (Boeters and Van Leeuwen, 2009). In sum, Boeters and Van Leeuwen (2009) construct value splits from independent information on quantities and prices, namely skill-specific employment information from the International Labour Office (ILO 2008) and information on relative wages provided by the Union Bank of Switzerland (UBS 2006). As explained thoroughly by Boeters and Van Leeuwen (2009) there are certain concerns related to the current labour input value split in the GTAP database, which motivated their revision. First, the value split per sector and region relies on a relatively old and small dataset. Second, the skill-specific input values cannot be decomposed into a volume and a price component. Therefore, Boeters and Van Leeuwen (2009) propose the following procedure, which is applied in the model. In the first step, skilled and unskilled shares for employees per sector are derived from ILO (2008) statistics. In the second step, a skilled-to-unskilled wage ratio is retrieved from UBS (2006) statistics and it is assumed to be uniform across sectors. Finally, skilled to unskilled value ratios per sector are computed by combining the information from the previous two steps. These ratios are then used to split the value share of labour in GTAP.

Labour

Supplies of skilled and unskilled labour are exogenous in the baseline. They depend upon demography, participation rates and the share of the high skilled in the total workforce. It uses certain mechanisms in projecting these developments until the year 2050. These projections are prerequisite for the assessment of the impacts of ageing. Population projections for the countries of the EU-15 are taken from Eurostat and for all other countries from the UN. For 24 population cohorts participation rates are projected using time series analysis. The data are a mixture of past observations and ILO-projections up to 2010. Aggregation of the projected rates over cohorts and individual countries yields macro participation rates for specific regions. Projections of skilled labour shares finally yield time series of the skilled and unskilled labour force. Though, in the climate policy version of WorldScan, the labour markets can be endogenized, this option has not been enabled in the simulations for this paper.

Population

Population projections are mainly taken from the revision 2002 of the UN World Population Prospects. These consist of alternative demographic projections until 2050 for all countries. The data and projections are provided in considerable detail, showing annual population sizes by gender and 5-year age cohort over the period 1950-2050 at country-level. Of the four projection alternatives available -- low, medium, high and constant fertility -- the medium variant is chosen. For the countries of EU-15, the baseline projections for the period 1999-2050 of Eurostat are used.

Research and Development

In the climate change version of WorldScan used in this paper, R&D is treated exogenously. However, WorldScan structure allows for endogenizing this parameter by employing the R&D data. In the R&D version of WorldScan, these data are retrieved as share of national income from OECD and UNESCO. The empirical relation between TFP growth and the R&D stocks is based on data of 14 OECD countries and 12 sectors for the period 1980 to 1999 in the R&D version of WorldScan. The data are from the ANBERD database of the OECD for the R&D expenditures, and from the STAN data base of the OECD to construct total factor productivity (TFP) growth and value added. The growth of TFP is related to the growth of the own sectoral spillovers, the domestic R&D spillovers from other sectors and the foreign R&D spillovers.

Savings and Capital

The data are derived from a variety of sources. Information on the age composition of economies is taken from the United Nations. Data on GDP per worker are taken from the Penn World Table (Mark 6.1). The measure for savings is average Gross Domestic Savings for the five-year periods distinguished in the analysis and is taken from the World Bank (World Development Indicators Database). Their data have been aggregated to the mentioned four age-groups. The savings come from the GTAP-7 database, depreciation is an exogenous variable, and labour supply growth follows from population and labour-market participation projections.

Trade and Transport

The data on exports and imports come from the GTAP-7 database (Narayanan and Walmsley, 2008). The allocation of sectoral demand over varieties from different regions is based on so-called Armington preferences. The market shares of domestic and foreign producers depend on the preferences and relative prices. In the calibration the market shares are directly derived from the GTAP-7 database. This database provides information on the value of the trade flows and total demand within a region. The market shares are calculated based on these data. The market prices are a composite of the exogenous producer price (in the calibration year) and taxes and subsidies. Taxes and subsidies (including trade taxes) are also directly calculated from the GTAP-7 database. The values of the Armington substitution elasticities are derived from other studies. The transport margins are calibrated using the GTAP-7 database. The database includes CIF-FOB margins for each bilateral trade relation and for each commodity. The CIF-FOB margins measure the difference between the value at the importer's border and the value at the exporter's border. This margin is interpreted as the transport costs between the country of origin and destination. The import, export, and production tariffs are fixed as a percentage of the relevant prices according to the values in the GTAP-7 database. The non-tariff barriers are also expressed as tax rates. These rates are derived from estimations of gravity equations.

ANNEX B: Art. 12 of the Kyoto Protocol (UNFCCC)

A clean development mechanism is hereby defined. The purpose of the clean development mechanism shall be to assist Parties not included in Annex I countries in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I countries in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.

Under the clean development mechanism:

- Parties not included in Annex I countries will benefit from project activities resulting in certified emission reductions; and

- Parties included in Annex I countries may use the certified emission reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments under Article 3, as determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol.

The clean development mechanism shall be subject to the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to this Protocol and be supervised by an executive board of the clean development mechanism.

Emission reductions resulting from each project activity shall be certified by operational entities to be designated by the Conference of the Parties serving as the meeting of the Parties to this Protocol, on the basis of:

- Voluntary participation approved by each Party involved;

- Real, measurable, and long-term benefits related to the mitigation of climate change; and

- Reductions in emissions that are additional to any that would occur in the absence of the certified project activity.

The clean development mechanism shall assist in arranging funding of certified project activities as necessary.

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, elaborate modalities and procedures with the objective of ensuring transparency, efficiency and accountability through independent auditing and verification of project activities.

The Conference of the Parties serving as the meeting of the Parties to this Protocol shall ensure that a share of the proceeds from certified project activities is used to cover administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

Participation under the clean development mechanism, including in activities mentioned in paragraph 3 (a) above and in the acquisition of certified emission reductions, may involve private and/or public entities, and is to be subject to whatever guidance may be provided by the executive board of the clean development mechanism.

Certified emission reductions obtained during the period from the year 2000 up to the beginning of the first commitment period can be used to assist in achieving compliance in the first commitment period.

ANNEX C: Additional Tables

Table A1. Overview of regions, sectors and production inputs in climate version of WorldScan

Regions	Sectors	Additional sector aggregates
EU27	Cereals	Manufacturing
EU15	Oilseeds	Services
EU12	Sugar crops	Value added
Other Europe	Other agriculture	Emissions Trading System
Former Soviet Union	Minerals	Sectors where emissions occur
United States	Oil	Energy sectors
Other OECD	Coal	Fuels
China and Hong Kong	Petroleum and coal products	Total
India	Natural gas	
Other South -East Asia	Electricity	**Factors**
Brazil	products	Low-skilled labour
America	Paper products and publishing	High-skilled labour
Middle East and North Africa	Mineral products nec	Capital
Rest of World	Ferrous metals	Land
World	Metals nec	Natural resources
	Vegetable oils and fats	
Climate policy related aggregates	Other consumer goods	**Energy carriers**
CDM demand & supply holders	Capital goods and durables	Coal
Kyoto parties	Road and rail transport	Petroleum, coal products
Annex I	Other transport (water and air)	Natural gas
Non-Annex I	Other services	Biodiesel
Emissions trading participants	Biomass	Ethanol
	Biodiesel	
	Ethanol	
	Renewables	

Source: WorldScan.

Table A1. Emissions ceilings for non-ETS sectors in the EU27

	Member State greenhouse gas emission limits by 2020 compared to 2005 greenhouse gas emission levels	Member State greenhouse gas emissions in 2020 resulting from the implementation of Article 3 (in tonnes of CO_2 equivalent)
Belgium	-15%	70954356
Bulgaria	20%	35161279
Czech Republic	9%	68739717
Denmark	-20%	29868050
Germany	-14%	438917769
Estonia	11%	8886125
Ireland	-20%	37916451
Greece	-4%	64052250
Spain	-10%	219018864
France	-14%	354448112
Italy	-13%	305319498
Cyprus	-5%	4633210
Latvia	17%	9386920
Lithuania	15%	18429024
Luxembourg	-20%	8522041
Hungary	10%	58024562
Malta	5%	1532621
Netherlands	-16%	107302767
Austria	-16%	49842602
Poland	14%	216592037
Portugal	1%	48417146
Romania	19%	98477458
Slovenia	4%	12135860
Slovakia	13%	23553300
Finland	-16%	29742510
Sweden	-17%	37266379
United Kingdom	-16%	310387829

Source: European Union (2009).