28

■

The contribution of the Clean Development Mechanism to national climate policies

Thierry Bréchet, Benoît Lussis

May 2005

ENVIRONMENTAL
ECONOMICS & MANAGEMENT
MEMORANDUM

UCL
Université
catholique
de Louvain

Chair Lhoist Berghmans
in Environmental Economics
and Management

Center for Operations Research
and Econometrics (CORE)

The contribution of the Clean Development Mechanism to national climate policies

Thierry Bréchet[*] and Benoît Lussis[†]

April 25, 2005

Abstract

The Clean Development Mechanism (CDM), one of the flexible mechanisms of the Kyoto Protocol, has not received noticeable attention in the applied modeling literature, been treated as a black box within the carbon market. In this paper we develop a trading model explicitly including the key features likely to influence the supply and demand of CDM projects. This model allows us to evaluate the contribution of the CDM to climate policies at the national level. With an application to Belgium we show that the CDM could reduce the cost of the Kyoto Protocol by a factor 10. Sensitivity analyses reveal that some features (*e.g.* market share) have much more influence on this result than others (*e.g.* transaction costs). Moreover, indirect spill-overs can sometimes exceed direct effects. Consequently, a larger domestic abatement could be justified by the desire to reduce what we call carbon dependence.

Keywords: Clean Development Mechanism, Carbon market modeling, Emission trading

JEL classification: Q28; Q48; Q25; Q43

Aknowledgements: This research was funded by the Scientific Support Plan for a Sustainable Development Policy (SPSD II, Belgium), contract CF/F5/261. Detailed results are available in Boulanger, Bréchet *et al.* (2004). Preliminary results were presented at the Environmental Workshop at CORE. We are greatful to Paul-Marie Boulanger, Gilles Grandjean, Henry Tulkens, Vincent van Steenberghe and Véronique Choquette for helpful comments.

---

[*] CORE, IAG and Chair Lhoist Berghmans in Environmental Economics and Management, Université catholique de Louvain, 34 voie du Roman Pays, B-1348 Louvain-la-Neuve, Belgium. Phone: 00.32.10.47.43.40. E-mail: brechet@core.ucl.ac.be.

[†] Institute for a Sustainable Development, 7 rue des Fusillés, B-1340 Ottignies, Belgium.

1 Introduction

The Kyoto Protocol allows industrialized countries (referred to as Annex 1 countries) to finance investment projects for greenhouse gases emission abatement in developing countries so as to generate credits which can be used to meet their own commitment. This instrument is known as the Clean Development Mechanism (hereafter, CDM) and raises a twin benefit. On the one hand, the industrialized countries abate carbon emissions at a lower marginal cost than domestically and, on the other hand, developing countries have the opportunity of accelerate technological transfers and to benefit from positive spin-offs in terms of development. This twin objective was confirmed in article 12 of the Protocol when introducing the CDM as a new climate policy instrument. In the literature, the CDM is always analyzed within the global carbon market and rarely as an instrument for climate policies in industrialized countries (see *e.g.* Zhang (2004) in this journal). The objective of this article is to evaluate the potential contribution of this instrument at the national level, with a numerical application to Belgium. This evaluation raises specific modeling questions so as to provide insights for climate policy.

In contrast with emission trading, the CDM has not received noticeable attention from the economists' community, particularly in applied modeling in support for decision-making. CDM has long been treated as a black box within the carbon market. Early theoretical discussions were provided by Bollen *et al.* (1999) but the institutional context has considerably evolved since then, in particular after the Conference of the Parties held in Marrakech in 2001 where guidelines were edicted[1]. In this context Jotzo and Michaelowa (2002) provide an analysis of the carbon market and discuss the contribution of the CDM at the global level. A more recent contribution is the one by Pane (2004) who focuses on the implications of such sector-limited projects on efficiency with a computable general equilibrium world model GEM-E3. Böhringer *et al.* (2003) consider CDM projects in the power sector between Germany and India by coupling a national German CGE model with an Indian Markal model for determining the supply of CDM projects within this sector. In the meantime, reduced-form partial equilibrium models originating from Ellerman and Decaux (1998) were developed. These trading models, based on marginal abatement cost curves, calculate least-cost abatement strategies. Even though our model is close, for example, to the CERT model used by Sager (2003), which is included in the Stanford

---

[1] A set of projects is now to be submitted to the Convention for accreditation. The list of the projects approved is continously updated on the UNFCCC website or on www.cdmwatch.org.

Energy Modeling Forum, it departs from all the existing tools in that it provides an in-depth description of the institutional features of the CDM at the international and national levels. To date, the literature has neglected two of the keystones of the CDM: *(i)* it is a project-based instrument, *(ii)* it involves bi-lateral carbon credits exchange between a single couple of buyer and seller partners. This article tackles these two key issues within a simple and transparent modeling framework and derives policy implications for Belgium.

The paper is organized as follows. The next section provides an overview of the institutional dimensions of the CDM, its design and implementation under the Climate convention. Section 3 describes the modeling framework. The contribution of the CDM to the Belgian climate policy is presented in section 4 and related sensitivity analyses are discussed in Section 5. In section 6, a short discussion is devoted to the benefits African countries would gain from the CDM. The last section concludes.

2 The Clean Development Mechanism: design and implementation

2.1 The procedure for accreditation

The advantage of the CDM for industrialized countries is having access to low-cost emission reductions. Nonetheless, the Kyoto Protocol states that CDM projects must contribute to the sustainable development of their host countries. This twin objective was explicitly confirmed in article 12 of the Protocol that introduced the concept of the CDM (UNFCCC, 1997). The contribution to sustainable development is not assessed on behalf of the Executive Board but by the host countries themselves. These indeed have the right to determine whether a project contributes or not to their sustainable development prior to the implementation of the project. However, despite the efforts of the developing countries and the scientific community there is not yet a common accepted methodology to assess the projects' impacts on sustainable development. On this issue see *e.g.* Winkler and Thorne (2002), Heuberger *et al.* (2003) or Gold Standard (2004).

A CDM project must also comply with other requirements set by the UNFCCC in the Marrakech Accords (UNFCCC, 2001), which are verified by an Executive Board composed of representatives of countries that ratified the Kyoto Protocol. Beyond the quantity of GHG reduction, these requirements deal with the voluntary participation of the involved countries, the project's environmental impacts (other than GHG emissions) and the stakeholders' participation, among others issues. The question of GHG emission reduction, known as the additionality issue (see below), is probably the most controversial and the most difficult condition to demonstrate for a project developer. In order to comply with the UNFCCC requirements a CDM project will have to follow several steps before generating any credits: validation, registration, verification, monitoring, verification and finally credits insurance (UNFCCC, 2001). All these steps are sources of additional costs which may be rather significant regarding to the credit value obtained.

It is worth noting that, with the notable exception of nuclear power, no technology or type of project can be excluded *a priori*. Hence, afforestation or reforestation projects, which allow for carbon storage in plants, are also eligible for the first commitment period, even if they are subject to special procedures and incur only temporary credits.

The Marrakech Accords made way for different CDM structures. A project can be financed by a partner from an industrialized country (bilateral CDM), by funding that gathers financial contributions from different partners from industrial countries (multilateral CDM) or by a partner from a developing country who agrees to finance emissions reduction before selling the credits to Annex 1 countries (unilateral CDM). These three structures have different impacts on transaction costs, profits gained by developing countries and technology transfer (see Lussis (2004), Baumert and Kete (2000) and Jahn *et al.* (2003))

A CDM project has a life-cycle, called *crediting period*, of 10 years (non-renewable) or 7 years (renewable twice). This period, which cannot be shortened, was introduced in order to allow host countries to benefit from spin-offs of projects for a relatively long time-scale (*i.e.* beyond the 5-years of the first Kyoto commitment period). In addition, CDM projects are allowed to generate credits from 1^{st} January 2000. This specification has been set in order to promote a prompt start of the CDM and is referred to as the *early crediting* issue in the literature.

2.2 The measurement of GHG emission abatement

The issue of assessing emission reductions, compared to what would have happened without the implementation of the CDM, is not only crucial for the environmental integrity of the instrument, but also controversial from a methodological viewpoint within Framework Convention institutions and the scientific community. This problem is known under the name of *additionality*. The credits resulting from a CDM project are calculated according to the difference between the emissions which would have been produced without the project (the business-as-usual scenario, or baseline) and the emissions observed in the project's actual conditions. The measurement of the baseline in this calculation constitutes the main source of uncertainty since, by definition, these emissions will never take place. It has been decided that baselines are to be calculated for each project with methodologies suitable for a kind of projects and approved by the UNFCCC. These methodologies have to produce the means to determine whether the project would have been carried out without the CDM. If this is the case, the project will be unable to reduce greenhouse gas emissions and therefore be ineligible. A project does not constitute a BAU scenario if there is at least one barrier to its implementation and if this barrier can be overcome because of the CDM nature of the project. Different kinds of barriers can prevent the implementation of the most effective technologies from an environmental point of view: financial barriers (profitability, capital resources), technological, cultural and institutional barriers, etc. The methodologies have then to demonstrate the project impact on the greenhouse gas emissions. (CDM Executive Board, 2004)

Ideally, all emissions affected by the project should be accounted for and integrated into the calculation of emission credits. However, listing all emissions involved in a project can be a difficult procedure because that would include emission on the project site (technology change) but also all direct off-site emissions (the emissions of the inputs' life cycle) and indirect off-site emissions (effects on fuel demand, for example). In practice, the project boundary is defined as the area within which the emissions in the business-as-usual scenario and with the project are measured. Emissions outside boundaries should also be integrated into the calculation of emission credits, but their measurement may be rougher and, consequently, requires a less strict monitoring procedure (see Chomitz (2002), Geres and Michaelowa (2002), Laurikka (2002) or Lazarus *et al.* (2001)).

3 Modeling the CDM within the carbon market

Our modeling framework consists of two nested models: a world model of the carbon market and a single-nation partial equilibrium model of optimal climate strategy. Modeling the world market allows us to determine the equilibrium price for carbon whereas the single nation market model sets the optimal strategy for a given country in terms of domestic abatement, purchase of permits, funding of Joint Implementation projects in other industrialized countries and funding CDM projects in developing countries. This model explicitly takes into account the key features of CDM projects, both on the demand side (coming from the developed countries) and on the supply side (coming from the developing countries, those being considered either jointly or separately). In this section we characterize the carbon abatement cost functions, the key features of the CDM and market equilibrium conditions.

3.1 The technology and abatement costs

We consider macroeconomic carbon abatement costs for any country $i \in I$, the set I standing for the set of the world economies. Let consider the business-as-usual (BAU) scenario and describe the economy i in a reference year (say in 2010). Let e_i^{BAU} be the expected carbon emissions level (in tons). Pollution abatement (noted a_i) is defined as the difference between actual emissions and the BAU emissions level,

$$a_i = e_i^{BAU} - e_i \tag{1}$$

Let $c_i(a_i)$ be the abatement cost function of country i. This function satisfies the usual following properties, *i.e.* twice continuously differentiable, strictly increasing ($c_i' > 0,\ \forall a_i > 0$) and strictly convex ($c_i'' > 0,\ \forall a_i > 0$). Furthermore, there is no free lunch ($c_i(0) = 0$) and it is infinitely costly to abate the last unit of emissions ($\lim_{a_i \to e_i^{BAU}} c_i'(a_i) = +\infty$).

Each country is committed with an emission target e_i^{KYOTO}. This means that it owns an assigned amount of emission credits (called Assigned Amount Units, or AAUs). Those emission credits can be exchanged on the world carbon market, whether they result from the funding of CDM or Joint Implementation projects, the selling of tradable permits or domestic abatement[2]. For developing countries this target coincides with the BAU emissions level since they are not committed to emission abatement under the Kyoto protocol. Hence, while committed to the Kyoto protocol, the GDP of country i in 2010 will write

$$y_i = y_i^{BAU} - c_i(a_i) + p\left(e_i^{KYOTO} - e_i\right) \tag{2}$$

where y_i^{BAU} stands for the expected GDP level in real terms at this year and p stands for the carbon price. Given (1) it can be rewritten as

$$y_i = y_i^{BAU} - c_i(a_i) + p(e_i^{KYOTO} - e_i^{BAU} + a_i) \tag{3}$$

---

[2] In the UNFCCC literature, this is refered to as the fungibility assumption.

Let us consider that each country maximizes its GDP y_i as stated in (3) in terms of its abatement policy, a_i, given its assigned amount of emission credits and knowing that these credits can be bought or sold on the international carbon market. Under perfect competition [3] the first-order condition for this maximization problem is that emissions abatement be such that the marginal abatement cost be equal to the market price for credits

$$c_i'(a_i) = p \tag{4}$$

From this optimality condition we define the net demand function for carbon credits, φ_i, as

$$\varphi_i = c_i'^{-1}(p) \tag{5}$$

Considering e_i^{KYOTO} and e_i^{BAU} as given, the net demand for carbon credits may be either positive, negative or nul depending on p.

From this very standard modeling, what is of particular interest is to explicitly model the key features of the CDM within the carbon market.

3.2 The key features of the Clean Development Mechanism

Under the Kyoto protocol the world is split into two sets of countries: Annex 1 countries ($A1$) and developing countries, referred to as non-Annex 1 countries ($NA1$). Note that $A1 \cap NA1 = \varnothing$ and $I = A1 \cup NA1$. Clearly, working at the aggregate level of $A1$ and $NA1$ sets of countries is the simplest way to characterize supply and demand behaviors and market equilibrium on the world carbon market. Heterogeneity within these sets will be re-introduced later on when considering climate policies at the national level. Let us describe the modeling of supply and demand.

The supply of CDM projects comes from $NA1$ countries. It is given by the inverse net demand function (5) where $e_i^{KYOTO} - e_i^{BAU} + a_i$ is always positive since $e_i^{KYOTO} = e_i^{BAU}$ for this set of countries. The project-based nature of the CDM results in three technical features. First, the presence of transaction costs constitutes a major issue for which Michaelowa and Jotzo (2005) provide an in-depth analysis. Transactions costs may result from many reasons, starting from the project research and design to registration, certification and monitoring with the Executive Board.

---

[3] We assume that there exists no quantitative constraint on trading volumes, which will be the case under the Kyto protocol in most countries.The market power of Russia on this market will be considered later on in the article.

These costs have long been considered as strongly reducing the attractiveness of CDM projects and it is of particular interest to quantitatively test this issue. Technically, transaction costs operate as a fixed abatement cost and reduce, for a given carbon price, the level of supply.

Secondly, it is widely acknowledged that all the projects that could theoretically be accepted as CDM projects by the Executive Board could not be implemented practically. Reasons range from failures in local infrastructures, local administrations to risk analysis. Introducing an accessibility rate on the projects supplied by developing countries reduces the quantity supplied for a given carbon price.

Thirdly, the so-called early crediting opportunity is introduced with the ratio between the crediting period of the projects considered and the Kyoto commitment period. As an example, consider a project which raises credits from 2004 until 2012. Thus, it is a 9-year crediting period project which must be accounted for during the 5 years of the first Kyoto commitment period. Hence, from a technical viewpoint, early crediting increases the supply of carbon reductions through CDM projects during the Kyoto period. Formally, taking into account these three features modifies the specification of the function (5) and leads to the following supply function:

$$s_i\left(p\right) = \alpha_i \gamma_i \left(c_i'\right)^{-1} \left(p - \tau_i\right) \qquad i = NA1 \tag{6}$$

where $c(.)$ represents the abatement cost function and p the carbon price, while the parameter α_i stands for the accessibility rate $(0 > \alpha_i > 1)$, γ_i for the early crediting coefficient $(\gamma_i \geqslant 1)$ and τ_i for the transaction unit cost $(\tau_i \geqslant 0)$.

The demand for CDM projects comes from Annex 1 countries. This demand is altered by the presence of carbon sinks within these countries. As it is established from the literature, we acknowledge the fact that sinks, when available, have negligible marginal costs, *i.e.* far below the market price. This entails that total carbon abatement available from sinks in Annex 1 countries can be seen as independent from the market price: we denote it Ω_i. The demand function for CDM projects resulting from Annex 1 countries thus reads

$$d_i\left(p\right) = c_i'\left(p\right) - \Omega_i \qquad i = A1 \tag{7}$$

Interestingly, it can be noticed that assigning transaction costs, early crediting, accessibility rates or sinks to one or the other side of the market does not alter the equilibrium. However, it does modify the redistributive effects of the CDM among developing and industrialized countries. The implications of this issue will be discussed below.

Let now turn to the domestic model. This model determines the optimal cost-minimization strategy for an Annex 1 country operating as price taker on the carbon market. In this paper, Belgium is to be considered, but any other country or group of countries could be. The Belgian abatement cost curve represents its demand for foreign abatement, *i.e.* the net purchase of permits and Joint Implementation projects to other Annex 1 countries, and the funding of CDM projects in non-Annex 1 countries. The former is naturally given by the international carbon price set across Annex 1 countries under their Kyoto commitment. The latter further requires to define the supply of CDM projects addressed to Belgium: we consider here that the global CDM market is shared among all the Annex 1 countries. This market share is noted λ_i, with $\sum \lambda_i = 1$, $\forall i \in AI$. Note that all the parameters above can be defined for any country, *i.e.* the accessibility rate (α_i), the early crediting (γ_i), the transaction cost (τ_i) and the amount of carbon sinks (Ω_i).

The table 1 displays a sketch of this modeling framework.

< *Table 1 here* >

3.3 Market equilibrium

The equilibrium on the carbon market is set at the world level. Given the properties of the cost functions $c_i(.)$ the supply and demand functions are well-behaved, continuous, increasing (resp. decreasing) and concave (resp. convex). For every country, and for a given carbon price $p > 0$, the excess supply for carbon credits on the market is given by

$$x_i(p) = e_i^{KYOTO} - e_i = e_i^{KYOTO} - e_i^{BAU} + a_i(p) \qquad \forall i \in I \tag{8}$$

The country or set of countries i is a net seller (resp. a net buyer) of credits when $x_i(p) > 0$ (resp. $x_i(p) < 0$). The equilibrium is defined as the market price p^* such that the market clears, *i.e.*

$$\sum_{i \in I} x_i(p^*) = 0 \tag{9}$$

Given the properties of the abatement cost functions, this equilibrium exists and is unique.

3.4 Calibration and assumptions

The reference scenario for 2010 is based on three sets of assumptions: *(i)* the calibration of the marginal abatement cost curves, *(ii)* the worldwide and Belgian business-as-usual scenario for carbon emissions and *(iii)* the institutional scenario for the first Kyoto commitment period.

Our model is based on marginal abatement cost (MAC) curves which represent the macroeconomic marginal cost of any abatement effort in any country or group of countries. This approach is characterized by two specific features: the macroeconomic dimension and the partial equilibrium. The macroeconomic dimension relies on the fact that what is evaluated is a macroeconomic cost, *i.e.* at the country level, and not project-specific costs as they could be evaluated from engineers or bottom-up models. The partial equilibrium dimension results from the underlying assumption that the MAC curves remain unaltered when abatement policies are implemented. Ellerman and Decaux (1998) show that such MAC curves are robust in the sense that they remain almost identical whatever the trading scheme. This reveals that the technological set from which these MAC curves are derived plays a more prominent role than general equilibrium feedback effects. Hence, partial equilibrium is a good proxy for general equilibrium only if the impacts are not too large, which is in fact the case under the Kyoto protocol at the macroeconomic level. Obviously this would not hold for more stringent carbon abatement or long run analyses. Our MAC curves are calibrated on data coming from the GEM-E3 model (see Eyckmans *et al.*, 2002) and following the methodology originated by Ellerman and Decaux (1998).

The business-as-usual scenario consists in the time profile of carbon emissions over the period between the last available data and the middle of the first Kyoto commitment period, 2010. It is based on the BAU scenario of the GEM-E3 model and the World Energy Outlook of the International Energy Agency. For Belgium we considered the latest medium term forecast provided by the Federal Planning Bureau (Bossier *et al.*, 2004). Considering these forecasts[4], Annex 1 countries would have to abate 2,067 $MtCO_2$ and Belgium 14.8 $MtCO_2$ in 2010.

The institutional scenario consists in various parameters (the parameter values are displayed in table 2). First, let consider transaction costs. Michaelowa and Jotzo (2005) compare several kinds of CDM projects. They suggest a benchmark transaction cost of \$0.75 per tonne CO_2. Considering the 'hot air', two intrinsically related

---

[4] For Belgium, the reference emissions level in 1990 has been recently updated, which slightly modify the abatement effort. Here we retain this new figure.

questions arise: what will be the Russia's strategy and what amount of 'hot air' will be put on the carbon market? We assume that Russia will act as a rational monopsoner and supply the carbon quantity which maximizes its return. Our reference BAU scenario gives an amount of hot air of 959 $MtCO_2$ in 2010: under our strategic assumption, 74.6% of this would be sold on the carbon market. The accessibility rate of CDM projects is rather tricky to assess at the aggregate level and we retain the conservative value of 33% as Eyckmans *et al.* (2002). Sinks within the Annex 1 countries would amount to 370 $MtCO_2$ and would be fully exploited. In Belgium these would amount to 1.3 $MtCO_2$. The early crediting parameter is set at 9/5, which means that we assume that crediting for CDM projects will start from 2004. This value is consistent with the evidence to date, since only a few projects are to fully benefit from this rule. For the Belgian market share, we assumed that this share corresponds to the share of the Belgian abatement in the Annex 1 countries emission abatement, *i.e.* 0.7%. This assumption boils down to admitting that no country has a proactive strategy on the CDM market[5]. Another solution would be to consider the share of Belgium in foreign direct investment in developing countries.

<*insert table 2* >

The model runs under a worksheet and the algorithm to determine the carbon price at equilibrium is based on the bracketing method [6]. It must be kept in mind that our results strongly depend on the assumptions made: their predictive value must not be overestimated. Consequently, after having presented the results of the reference scenario we shall pay a special attention to sensitivity analyses. In fact, most of the policy insights for national climate policies will be drawn from the sensitivity analyses.

4 The contribution of CDM projects to climate policies

We present the results of the reference scenario in 2010, both at the world level and for Belgium.

---

[5] We already know that it is far from being the case in reality and that some countries are already leaders on this market: this will be discussed in detailed later on in the paper.

[6] The model is available online at: www.iddweb.be.

4.1 The world carbon market

Under our reference scenario, carbon would be priced at \$6.9 per tonne CO_2 in 2010. The CDM would contribute to 21% of the abatement in Annex 1 countries, *i.e.* 434 $MtCO_2$. This figure differs from the ones provided in the literature to date. The reason for this is that those studies generally neglected the empirical evidence showing that not all of the projects that may be eligible are realizable in practice, which we represent with our accessibility rate parameter. This feature affects not only the supply of CDM projects but also the equilibrium on the carbon market. Assuming that only one third of the projects are technically feasible, as we do, reconciliates our result with those of previous studies, in particular Zhang (2004) who evaluates the share of CDM projects in Annex 1 reduction at 47%. What is more important, however, is the impact of this assumption on the equilibrium price: shrinking the supply of low-cost CDM projects increases the carbon price at equilibrium. This clearly impacts on the optimal abatement strategy within industrialized countries in favor of domestic abatement.

4.2 Optimal national policies

The model is suitable to evaluate the optimal climate strategy for any industrialized country. As a small open country, Belgium takes the world carbon market as given and maximizes its objective function with respect to the world carbon price. Table 2 displays the optimal mix of policy measures for Belgium in the international context displayed above. The most salient feature provided is the prominent role played by tradable permits and Joint Implementation, *i.e.* carbon transfers within Annex 1 countries. Belgium would be a net buyer of credits and these would contribute up to 63% of the national emission abatement in 2010. Unexpectedly, however, the contribution of CDM projects would amount to 20% of the total abatement effort. Important policy implications can be drawn from this result. This contribution is far from being quantitatively negligible and flows from the fact that, despite a reduced accessibility rate, many CDM projects are supplied at very low marginal prices. Moreover, the higher the price of permits, the higher this contribution. Tradable permits and CDM considered jointly would represent 83% of the carbon abatement. This illustrates the dependence of a country like Belgium on the Kyoto flexible mechanisms. About 17% of the overall abatement is to be met domestically, including the sinks.

The macroeconomic cost of the Kyoto commitment would represent only 0.03% of the GDP in 2010, which is quite low from a macroeconomic viewpoint. Interestingly we can calculate that, without these flexible mechanisms, this cost would reach 0.3% of the GDP: even if this remains rather low, it reveals that the Kyoto flexible mechanisms allow to reduce this cost by a factor 10 in Belgium. Of course, we cannot say to what extent each agent or productive sector would bear this cost. Although the redistributive impacts within the Belgian economy cannot be captured in our model, it is now well established that these may be important and play a crucial role from a political point of view (see Bossier and Bréchet, 1995).

As advocated when introducing the model, all the results crucially depend on our set of assumptions. In other words, the predictive value of these results must not be overestimated. However, our model particularly fits for sensitivity analyses and important insights for policy implications can be drawn from these tests, to a great extent independently from the degree of realism of the business-as-usual scenario.

5 Sensitivity analyses and policy implications

Given the rather large set of parameters considered in our model it would be vain to try to test everything. More importantly, our objective with this model is to draw policy implications rather than to compute the whole set of stochastic solutions. Consequently, we focus here on a set of scenarios regarded as the most meaningful from a policy viewpoint. All these scenarios are to be considered with respect to the reference case presented above. The alternative scenarios are the following (table 3 displays the numerical values of the parameters):

- S-1: Belgium experiences a higher business-as-usual CO_2 emissions profile from 2004 (last observation available) to 2010
- S-2: Russia supplies a lower quantity of hot air than the optimal one
- S-3: the accessibility rate for CDM projects is raised for every developing country
- S-4: the transaction costs are higher than expected for all CDM projects
- S-5: Belgium adopts a proactive strategy so as to enhance its market share in the worldwide CDM market

< *insert table 3* >

The reader must keep in mind that the magnitude of these changes in the parameters value is less important than the mechanisms they allow to highlight and the economic interpretation of their impacts. Let us turn now to the analysis of these impacts (all the results are gathered in table 4).

< *insert table 4* >

Scenario S-1: a higher CO_2 business-as-usual scenario for Belgium

In this first scenario we assume that the profile of emissions under the business-as-usual scenario is higher than in the reference case in Belgium. This may result from many causes, *e.g.* more economic growth, lesser technical progress or lesser substitutions than expected between fuels or sectors. The alternative macroeconomic forecast considered here comes from the GEM-E3 model (Eyckmans *et al.*, 2002). It results in a higher abatement effort in 2010, 26 $MtCO_2$ instead of 14.8 Mt. Given that Belgium is a small country, this does not significantly affect the equilibrium of the world carbon market, the carbon price remains unchanged and so does the domestic abatement effort. Hence, an increase of the abatement effort in a single country induces a higher purchase of permits and, to a lesser extent, more CDM projects[7]. This test shows that, *ceteris paribus*, an increase of the abatement effort in Belgium by 1 $MtCO_2$ in 2010 would raise the overall compliance cost by 6 million Euros.

Scenario S-2: a lower supply of hot air

Under the reference scenario we assumed that the cartel providing hot air maximizes its revenue, thus supplying 75% of the overall amount of hot air provided by the Kyoto protocol in 2010. Let us now assume that this quantity is 50% smaller. The rationale behind this may be, for example, a wrong expectation about the carbon price or successful market reforms inducing more economic growth (see Golub and Strukova (2004) for further analyses in this issue). Under this assumption, the supply of hot air would amount to 358 Mt in 2010 instead of 715 Mt. As shown in Table 4, this unambiguously raises the world carbon price at equilibrium. Starting from $6.9 in the reference scenario it reaches $10.6. This raise alters the overall picture on the carbon market, as well as in Belgium. The share of the CDM and domestic

---

[7] In this test we assume that the budget share of Belgium in the CDM market is unchanged.

measures increases while the purchase of permits drops. The rationale behind these effects is that the carbon price increase makes the permits more expensive while the marginal costs of domestic measures and CDM projects remain unchanged. Consequently, the higher the price of the permits, the more appealing CDM projects and domestic abatement are. Considering the large contribution of the purchase of permits in Belgium, this scenario results in a quite higher macroeconomic compliance cost. What is enlightening is to compare the relative magnitude of these two effects. The sensitivity of the compliance cost of meeting Kyoto in Belgium is quite high since a 54% increase of the carbon price raises the macroeconomic cost by 41%.

Scenario S-3: an increase of the accessibility rate

Assessing the accessibility rate of CDM projects in the host countries is particularly tricky. The value for this parameter remains subject to many debates. Any improvement in the capacity of developing countries to host projects would have a major impact on the supply of low-cost abatement projects, upsetting the world carbon market and lowering the price of carbon. Let assume that the accessibility rate is 50% higher than in our reference scenario (50% instead of 33%). This results in two preliminary mechanisms. First, the supply curve for CDM projects becomes less steep. Second, more low-cost projects being supplied, the carbon price at equilibrium decreases, going from \$6.9 to \$5.2. As a consequence the purchase of permits drops (-4.3%) and the share of CDM projects increases (+23.3%) at the expense of domestic measures. All in all, the cost of compliance decreases by 25% in Belgium. What is interesting here is that a substitution occurs between CDM and the purchase of permits, depending on the decrease of the carbon price. If the decrease of the carbon price is important enough as the accessibility rate increases, then the share of CDM projects decreases. In other words, the higher the demand elasticity for CDM projects on the carbon market, the less the developing countries would benefit from an increase in the supply of CDM projects at equilibrium. However, it is always beneficial for industrialized countries.

Scenario S-4: an increase of transaction costs

The transaction cost in the reference scenario is \$0.75 per tonne CO_2. We consider here an alternative value of \$1.125 per tonne CO_2, *i.e.* a 50% increase. This makes CDM projects more expensive. Consequently the carbon price on the world market at equilibrium rises, but only slightly: \$7.0 instead of \$6.9. This limited impact comes from the fact that CDM supply 'only' counts for 21% of the global carbon reduction. These two effects (the shrink of supply and the slight increase of carbon price at equilibrium) result in a decrease in the share of CDM projects in Belgian abatement and a small increase in the share of tradable permits and JI projects. Similarly, due to the increase of the carbon price, the share of domestic measures also slightly increases. This sensitivity analysis highlights the fact that (*i*) transaction costs have minor impacts on the optimal mix between abatement opportunities at the national level, and that (*ii*) equilibrium effects (*i.e.* through the adjustment of the carbon price) also contribute to the final outcome. Overall, the macroeconomic cost of compliance is raised by 3.4% in Belgium only. So, one preliminary conclusion is that transaction costs are far from being that crucial as far as national strategies are concerned, though they directly affect the amount of CDM projects implemented.

Scenario S-5: an increase in Belgium's market share

What would happen if a country adopt a proactive strategy towards abatement opportunities through CDM projects? Clearly, some countries are more involved in this market while others stay behind. Technically this means that market shares are probably different from one country to another. Let assume here that Belgium, thanks to a proactive strategy, is able to increase its market share on the CDM market by 50%, *i.e.* from 0.7% to 1.05%. The market share of all other countries is reduced proportionally [8]. Since global supply and demand remain unchanged, the carbon price at equilibrium remains the same. Hence, only direct effects play a role in this scenario. The contribution of CDM projects is raised mechanically by 50% in Belgium at the expense of the purchase of permits. Domestic abatement remains the same. Overall, the cost of compliance is reduced by 7%.

6 The geographical structure of CDM projects supply

To date very few studies have paid attention to the geographical structure of the supply of CDM projects. Yet, this structure will heavily influence (negatively or positively) the response of industrialized countries towards the CDM in the sense that they may already have geostrategically oriented relationships with these countries. Moreover it will impact on the contribution of the CDM in its role of promoting

---

[8] Actually, because the weight of Belgium in the world carbon market is very marginal, the decrease of the market share of the other countries is quantitatively negligible.

development. In this section we will focus on the supply from African countries. Zhang (2004) provides the most recent comprehensive overview of this issue. He shows that the supply of CDM projects would be very concentrated in a limited number of countries. Indeed, 60% of the world supply would come from China, 15% from India, 6% from emerging Asian countries and 5% from Brazil. Only 0.2% would be supplied by African countries.

We will illustrate this issue considering two quite different African countries: South Africa and Senegal. An international study carried out on behalf of the UNEP and the World Bank National Strategy Study (NSS Program, 2002) provides estimates for the greenhouse gases abatement options in these countries (using bottom-up approaches). From these figures, the options eligible as CDM projects are picked up and a marginal abatement cost curve is built. These curves are adapted to our set of assumptions on transaction costs and accessibility. Obviously, such figures are far being reliable, yet it is interesting to use them as a rough approximation. As a result, under our reference scenario (*i.e.* with a carbon price of $6.9 per tonne) the model shows that Belgium would support CDM projects up to 56 ktCO_2 in South Africa and 7 ktCO_2 in Senegal. This represents respectively 0.37% and 0.04% of Belgian carbon abatement in 2010. The lesson from these figures is clear. Even though low-carbon abatement opportunities do exist in Africa, their potential contribution to Annex 1 carbon abatement is quantitatively marginal. Industrialized countries will look at more polluting countries, such as China or India. This raises doubts on the potential impact of the CDM in the less-developed countries and its contribution to poverty alleviation.

7 Conclusion

In this paper we analyzed the contribution of the Clean Development Mechanism to national climate policies with an application to Belgium. For this purpose we developed a partial equilibrium model of trading of carbon explicitly including the key features susceptible to influence both the supply and demand for CDM projects. These features encompass the technical characteristics of the CDM (accessibility rate of the projects in developing countries, transaction costs, market share of Belgium in the CDM market, possibility of early crediting), the design of institutional scenarios (Russia's strategy) and assumptions on the business-as-usual profiles for carbon emissions (which imply the abatement effort for each country under the Kyoto protocol). The model allows for many sensitivity analyses thanks to its low computational cost.

The main results for climate policy are the following. First, under a cost minimization strategy the CDM would contribute to 20% of the carbon abatement in 2010 in Belgium. Interestingly, it can be shown that the so-called flexible mechanisms (tradable permits, CDM and joint implementation) contribute to shrink the cost of compliance by a factor 10 in this country. While many in the business community consider the CDM to be excessively bureaucratic and risk-prone[9], our result (reinforced by the sensitivity analyses) shows that a country would largely benefit from investing in capacity building in this field.

Many sensitivity analyses were performed. They revealed that, in Belgium, the macroeconomic cost of compliance is much more influenced by indirect effects (*i.e.* which originate from the modification of the carbon price in the world market) than by direct effects. This flows from the large contribution of the flexible mechanisms in the Belgian abatement strategy and the slope of supply and demand functions. It provides a rationale for the new concept of *carbon dependence*, inspired by the one of energy dependence widely advocated in the 80s to motivate ambitious energy policies in the industrialized economies. For a country eager to minimize the costs associated to excessive fluctuations of the world carbon price or the risks associated with supply disruptions, restricting the contribution of foreign reductions may be a suitable strategy.

We pointed out the fact that the predictive value of all these figures must not be overestimated. Hence, the major insights stem from the analysis of the economic mechanisms rather than from the figures themselves. Moreover, the domain of reliability of such partial equilibrium models is restricted to small macroeconomic changes, *e.g.* close enough to the initial equilibrium so that the marginal abatement cost curve can be regarded as stable. Clearly this is the case for the Kyoto protocol under which the global carbon abatement remains quite limited at the global level. More ambitious analyses would require to use of a full general equilibrium modeling framework. Considering explicitly the key features of the CDM, as we did, but within such a model would be of particular interest and opens the door for further research.

---

[9] Actually, this opinion is reinforced by the continued stalling of the first projects due to be registered by the Executive Committee to date (see *www.cdmwatch.org*).

References

[1] Baumert, K., Kete, N. (2000). Designing the Clean Development Mechanism : Operational and Institutional Issues, Organization for Economic Cooperation and Development, Paris.

[2] Böhringer, C., Conrad, K., Loschel, A. (2003). Carbon taxes and Joint Implementation. An Applied General Equilibrium Analysis for Germany and India. *Environmental and Ressource Economics*, 24, 49-76.

[3] Bollen, J., Gielen, A., Timmer, H. (1999). Clubs, ceilings and CDM. *The Energy Journal*, Special Issue, *The costs of the Kyoto Protocol: a Multi-Model Evaluation*, 177-206.

[4] Bossier, F., Bracke, I., Vanhorebeek F. (2004). Projection des émissions de gaz à effet de serre à l'horizon 2010 pour la Belgique, Federal Planning Bureau, Working Paper 9-04, Brussels.

[5] Bossier, F., Bréchet, Th. (1995). A fiscal reform for increasing employment and mitigating CO_2 emissions in Europe. *Energy Policy*, 23, 789-798.

[6] Boulanger, PM, Bréchet, Th., Brismé, Ch., Germain, M., Grandjean, G., Huppen, I., Lussis B. (2004). *Le Mécanisme pour un Développement Propre: conception d'outils et mise en oeuvre*. Final Report to the Belgian Scientific Support Plan for a Sustainable Development Policy under SPSD II, Institute for a Sustainable Development, Ottignies (http://www.iddweb.be).

[7] CDM Executive Board, (2004). Draft consolidated tool for demonstrating additionality, Annex to the report of the 15th Executive Board meeting.

[8] Chomitz, K., M. (2002). Baseline, leakage and measurement issues: how do forestry and energy projects compare? *Climate Policy*, 2, 35-49.

[9] Ellerman, D., Decaux, A. (1998). Analysis of post-Kyoto CO2 emissions trading using marginal abatement curves, MIT Joint Program on the Science and Policy of Global Change, Report #40, Cambridge MA.

[10] Eyckmans, J., Van Regemorter, D., van Steenberghe, V. (2002). Is Kyoto fatally flawed?, FEEM Working Paper 43.

[11] Geres, R., Michaelowa, A. (2002). A qualitative method to consider leakage effects from CDM and JI projects. *Energy Policy*, 30, 461-463.

[12] Gold Standard (2004). The Gold Standard Project Design Document: Main Document (available at http://www.cdmgoldstandard.org).

[13] Golub, A., Strukova, E. (2004). Russia and the GHG market. *Climatic Change*, 63, 223-243.

[14] Heuberger, R., Sutter, Ch., and Imboden, D. (2003). CDM Projects under the Kyoto Protocol of the UNFCCC: A Methodology for Sustainable Development Assessment and an Application in South Africa, Institute of Environmental Physics, Energy & Climate, Swiss Federal Institute of Technology (ETH).

[15] Jahn, M., Michaelowa, A., Raubenheimer, S., Litow, H. (2003). Unilateral CDM Chances and Pitfalls, Deutsche Gesellschaft für technische Zusammenarbeit (GTZ).

[16] Jotzo, F., Michaelowa, A. (2002). Estimating the CDM market under the Marrakech Accords. *Climate Policy*, 82, 1-18.

[17] Laurikka, L. (2002). Absolute or relative baselines for JI/CDM projects in the energy sector? *Climate Policy*, 2, 19-33.

[18] Lazarus, M., Kartha, S., Bernow, S. (2001). *Project baselines and boundaries for project-based GHG emission reduction trading: a report to the greenhouse gas emission trading pilot program.* Tellus Institute, April.

[19] Lussis, B. (2004). Le MDP unilatéral, Working paper, Institute for a Sustainable Development, Ottignies.

[20] Michaelowa, A., Jotzo, F. (2005). Transaction costs, institutional rigidities and the size of the clean development mechanism. *Energy Policy*, 33(4), 511-523.

[21] NSS Program (2002). South African National Strategy Study on the Clean Development Mechanism: Executive Report, National Strategy Study, World Bank, Washington DC.

[22] Pane, H. (2004). The cost efficiency of Kyoto flexible mechanisms: a top-down study with the GEM-E3 world model. *Environmental Modeling & Software*, in press.

[23] Sager, J. (2003). An analysis with the CERT model of the FSU market power in the carbon emissions trading market. *Environmental Modeling & Assessment*, 8(3), 219-238.

[24] UNFCCC (1997). The Kyoto Protocol to the Framework Convention on Climate Change.

[25] UNFCCC (2001). *The Marrakech Accords and the Marrakech declaration: Decision 17/*CP*7*, United Nations Framework Convention on Climate Change.

[26] Winkler, H., Thorne, S. (2002). *Baselines for suppressed demand: CDM projects contribution to poverty alleviation*, SouthSouthNorth, February.

[27] Zhang, Z.X. (2004). Meeting the Kyoto targets: the importance of developing country participation. *Journal of Policy Modeling*, 26, 3-19.

Table 1
A sketch of the modeling framework

	Assumptions	Outcomes
World carbon model	Transaction cost : t_i Accessibility rate : a_i Early crediting : γ_i Carbon sinks: W_I Hot air	- World carbon price - Size of the CDM market
Domestic carbon model	Market share: l_i Transaction cost : t_i Accessibility rate : a_i Early crediting : γ_i Carbon sinks: W_i	Optimal mix between: - domestic abatement - purchase of tradable permits - JI projects - CDM projects

Table 2
Abatement in the reference scenario

	Annex I countries		Belgium	
	$MtCO_2$	%	$MtCO_2$	%
CDM projects	434	21.0	3.0	20.3
JI projects	547	26.5	9.3	62.8
Purchase of permits				
Domestic measures			1.2	8.1
Sinks	370	17.9	1.3	8.7
Hot air	715	34.6		
Total abatement	2 067	100	14.8	100
Carbon price (US$/t)	6.9			

Table 3.
Sensitivity analyses: parameters value

	Reference value	Rule	Alternative value
S1. Abatement effort (Mt CO_2)	14.8	--	26
S2. Hot air (Mt CO_2)	716	- 50%	358
S3. Accessibility rate (%)	1/3	+ 50%	1/2
S4. Transaction cost (US$/t CO_2)	0.75	+ 50%	1.125
S5. Belgian market share (%)	0.7	+ 50%	1.05

Table 4.
Results of sensitivity analyses for Belgium

	Ref	S1.	S2	S3	S4	S5
CDM projects						
- $MtCO_2$	3.0	3.0	4.1	3.7	3.0	4.5
- % w.r.t. Ref		+0.0	+36.7	+23.3	+0.0	+50.0
Purchase of permits						
- $MtCO_2$	9.2	20.4	7.7	8.8	9.2	7.7
- % w.r.t. Ref		+121.7	-16.3	-4.3	+0.0	-16.3
Total cost						
- $M€_{95}$	76.7	153.5	107.9	57.5	79.3	71.0
- % w.r.t. Ref		+100.1	+40.7	-25.0	+3.4	-7.4
Carbon price						
- US$	6.9	6.9	10.6	5.2	7.0	6.9
- % w.r.t. Ref		+0.0	+53.6	-24.6	+1.4	+0.0

Environmental Economics & Management Memoranda

38. Paul-Marie BOULANGER and Thierry BRECHET. Models for policy-making in sustainable development: The state of the art and perspectives for research. November 2005.

37. Johan EYCKMANS an Henry TULKENS. Optimal and Stable International Climate Agreements. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

36. Thierry BRECHET and Benoît LUSSIS. The Clean Development Mechanism in Belgian Climate Policy. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

35. Vincent VAN STEENBERGHE. The impact of banki!ng on permits prices and compliance costs. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

34. Johan EYCKMANS, Denise VAN REGEMORTER and Vincent VAN STENBERGHE. Kyoto-permit prices and compliajce gosts: an analysis with MacGEM. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

33. Johan EYCKMANS, Bert WILLEMS and Jean-Pascal VAN YPERSELE. Climate Change: Challenges for the World. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

32. Marc GERMAIN, Stef PROOST and Bert SAVEYN. The Belgian Burden Sharing. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

31. Ingmar SCHUMACHER. Reviewing Social Discounting within Intergenerational Moral Intuition. June 2005.

30. Stephane LAMBRECHT. The effects of a demographic shock in an OLG economy with pay-as-you-go pensions and property rights on the environment: the case of selfish households. January 2005.

29. Stephane LAMBRECHT. Maintaining environmental quality for overlapping generations: Some Reflections on the US Sky Trust Initiative. May 2005.

28. Thierry BRECHET, Benoît LUSSIS. The contribution of the Clean Development Mechanism to national climate policies. April 2005.

27. Thierry BRECHET, Stéphane LAMBRECHT, Fabien PRIEUR. Intergenerational transfers of pollution rights and growth. May 2005.

26. Maryse LABRIET, Richard LOULOU. From non-cooperative CO_2 abatement strategies to the optimal world cooperation: Results from the integrated MARKAL model. April 2005.

25. Marc GERMAIN, Vincent VAN STEENBERGHE, Alphonse MAGNUS. Optimal Policy with Tradable and Bankable Pollution Permits : Taking the Market Microstructure into Account.*Journal of Public Economy Theory*, 6(5), 2004, 737-757.

24. Marc GERMAIN, Stefano LOVO, Vincent VAN STEENBEGHE. De l'impact de la microstructure d'un marché de permis de polluer sur la politique environnementale. *Annales d'Economie et de Statistique*, n° 74 – 2004, 177-208..

23. Marc GERMAIN, Alphonse MAGNUS, Vincent VAN STEENBERGHE. Should developing countries participate in the Clean Development Mechanism under the Kyoto Protocol ? The low-hanging fruits and baseline issues. December 2004.

22. Thierry BRECHET et Paul-Marie BOULANGER. Le Mécanisme pour un Développement Propre, ou comment faire d'une pierre deux coups. *Regards Economiques*, Ires n° 27, janvier 2005.

21. Sergio CURRARINI & Henry TULKENS. Stable international agreements on transfrontier pollution with ratification constraints. In C. Carrarro and V. Fragnelli (eds.), *Game Practice and the Environment*. Cheltenham, Edward Elgar Publishing, 2004, 9-36. (also available as CORE Reprint 1715).

20. Agustin PEREZ-BARAHONA & Benteng ZOU. A comparative study of energy saving technical progress in a vintage capital model. December 2004.

19. Agustin PEREZ-BARAHONA & Benteng ZOU. Energy saving technological progress in a vintage capital model. December 2004.

18. Matthieu GLACHANT. Voluntary agreements under endogenous legislative threats and imperfect enforcement. November 2004.

17. Thierry BRECHET, Stéphane LAMBRECHT. Puzzling over sustainability: an equilibrium analysis. November 2004.

16. Vincent VAN STEENBERGHE. Core-stable and equitable allocations of greenhouse gas emission permits.. October 2004. (also available as CORE DP 2004/75)

15. Pierre-André JOUVET Philippe MICHEL, Pierre PESTIEAU. Public and private environmental spending. A political economy approach. September 2004. (also available as CORE DP 2004/68.)

14. Thierry BRECHET, Marc GERMAIN, Vincent VAN STEENBERGHE. The clean development mechanism under the Kyoto protocol and the 'low-hanging fruits' issue. July 2004. (also available as CORE DP 2004/81).

13. Thierry BRECHET, Philippe MICHEL. Environmental performance and equilibrium. July 2004. (also available as CORE DP 2004/72).

12. Luisito BERTINELLI, Eric STROBL. The Environmental Kuznets Curve semi-parametrically revisited. July 2004. (also available as CORE DP 2004/51).

11. Axel GOSSERIES, Vincent VAN STEENBERGHE. Pourquoi des marchés de permis de polluer ? Les enjeux économiques et éthiques de Kyoto. April 2004. (also available as IRES discussion paper n° 2004-21).

10. Vincent VAN STEENBERGHE. CO_2 Abatement costs and permits price : Exploring the impact of banking and the role of future commitments. December 2003. (also available as CORE DP 2003/98).

9. Katheline SCHUBERT. Eléments sur l'actualisation et l'environnement. March 2004.

8. Marc GERMAIN. Modélisations de marchés de permis de pollution. July 2003.

7. Marc GERMAIN. Le Mécanisme de Développement Propre : Impacts du principe d'additionalité et du choix de la baseline. January 2003.

6. Thierry BRECHET et Marc GERMAIN. Les affres de la modélisation. May 2002.

5. Marc GERMAIN and Vincent VAN STEENBERGHE. Constraining equitable allocations of tradable CO_2 emission quotas by acceptability, *Environmental and Resource Economics*, (26) 3, 2003.

4. Marc GERMAIN, Philippe TOINT, Henry TULKENS and Aart DE ZEEUW. Transfers to sustain dynamic core-theoretic cooperation in international stock pollutant control, *Journal of Economic Dynamics & Control*, (28) 1, 2003.

3. Thierry BRECHET, Marc GERMAIN et Philippe MONTFORT. Spécialisation internationale et partage de la charge en matière de réduction de la pollution. (also available as IRES discussion paper n°2003-19).

2. Olivier GODARD. Le risque climatique planétaire et la question de l'équité internationale dans l'attribution de quotas d'émission échangeable. May 2003.

1. Thierry BRECHET. Entreprise et environnement : des défis complémentaires ? March 2002.

Environmental Economics & Management Memorandum

Chair Lhoist Berghmans in Environmental Economics and Management
Center for Operations Research & Econometrics (CORE)
Université catholique de Louvain (UCL)
Voie du Roman Pays 34
B-1348 Louvain-la-Neuve, Belgium

Hard copies are available upon request : env@core.ucl.ac.be
Papers are available in pdf format on line : www.core.ucl.ac.be/chlhoist