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Abstract
As part of the Copenhagen Accord, countries have submitted emissions reduction pledges for 2020. Using a long term optimization model (TIAM-FR), we evaluate the implications of these submissions for emission reductions, carbon prices and total cost of the energy system. Our study finds that the pledges are not sufficient to meet the global recommended 2-2.4°C objective. Furthermore, reaching the overall 2°-2.4C objective would involve significant costs for China and India that explains the difficulty of international negotiations.

Keywords
Global warming, Copenhagen Accord, long term optimization model, abatement cost

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1. Introduction

Global warming is in essence an economic and political problem. The atmosphere is a global public good. Greenhouse gas (GHG) emissions contributing to global warming have the same damaging effect regardless of the country in which they originate. All regions of the world are affected regardless of whether and to what extent they contribute to the problem. Protecting the atmosphere and therefore preventing global warming implies a drastic reduction in total greenhouse gas emissions. However, in the absence of an international agreement on emissions control, countries adopt free-riding behaviours. Each country counts on others to reduce emissions and to incur the resulting abatement cost. The Kyoto Protocol was the first international agreement in which some countries (Annex I to the protocol) committed to emission reduction targets on the period 2008-2012. A cap-and-trade system was introduced to enable the emergence of an international carbon price in order to efficiently to attain the overall objective. The protocol's impact has however been limited, because of the lack of commitments by rapidly growing emerging countries such as China, India and Brazil, and the non-ratification of the United States. The challenge of the Copenhagen summit in 2009 was to determine the rules for the post-Kyoto period. It was therefore essential to ensure the ratification of a global agreement on emission reduction targets and to include all major industrialized and emerging countries. Even if negotiations during the summit failed to reach a global agreement, in late January 2010 some countries including major emerging nations pledged their commitments to the United Nations Framework Convention on Climate Change (UNFCCC) as part of the Copenhagen Agreement. Emissions control commitments now cover 80% of 2005 global GHG emissions compared to barely more than a quarter for the Kyoto Protocol.

Those commitments, which have very different terms and conditions, remain to be evaluated. In fact, the Copenhagen Accord has adopted a different approach to the Kyoto Protocol by allowing "variable geometry" commitments depending on the country (Casella *et al*. 2010). Annexe I countries have committed to reducing emissions on an absolute basis while all major emerging counties made commitments in relative terms. For instance, China and India pledged to reduce emissions per unit of GDP relative to 2005. Published analysis of the Copenhagen pledges converge to the same conclusion: if the national commitments made in Copenhagen reflect a significant shift relative to trend scenarios, however, this shift remains far removed from the IPCC recommendations to limit temperature increase of over 2°C (Dellink *et al.* 2010; Den Elzen *et al.* 2011a, Casella *et al.* 2010; Peterson *et al.* 2011; Criqui and Ilasca 2010; Stern and Taylor 2010). Peterson *et al.* (2011) also showed that the pledges are not costly in either GDP or welfare terms. With partial and general equilibrium approach empirical studies found that the cost for developed countries is less than 0.5% of GDP in 2020 and that the effects are more heterogeneous across developing countries (Saveyn 2011; den Elzen *et al*. 2011b; Peterson *et al.*2011).

We contribute to the growing body of literature on the environmental and economic impact of the Copenhagen commitments by introducing the pledges in the bottom-up optimisation model TIAM-FR. The model depicts the energy system over the period 2005-2050 in such a way as to minimise the net total cost of the system under a number of environmental, technological and demand constraints. To evaluate those commitments we have considered the most optimistic pledges for 2020 and made assumptions on the 2050 targets based on announced political ambitions of each country. We then compared those pledges to a business-as-usual scenario and to a global scenario compatible with the IPCC consensual 2-2.4°C objective (IPCC, 2007) where all countries are constrained by a global mitigation target.

We aim to answer the following questions:

- Can we reach the 2°C with the most favourable pledges announced by countries?
- What are the induced regional energy system costs of those two climate scenarios?

2. Model and climate policies

2.1 TIAM-FR model

This analysis is based on TIAM-FR model (the French version of the TIMES Integrated Assessment Model) a bottom-up optimization model developed under the Energy Technology Systems Analysis Program (ETSAP). It depicts the world energy system with a detailed description of different energy forms, resources, technologies and end-uses (Ricci and Selosse 2012). End-use demands (i.e. energy services) are based on socio-economic assumptions and are exogenous over the planning horizon (2005-2050). The basic principle of the model is a large linear optimization of substitution possibilities in the energy system between explicit technologies and commodity flows under constraints. The model assumes perfect markets and foresight therefore, it is suitable for normative analysis. The model minimises the total discounted cost of the energy system over the entire model horizon.

The model is geographically integrated in 15 global regions (*Industrialized countries:* Australia-New Zealand (AUS); Canada (CAN), United-States of America (USA), Western Europe (EU-15, Iceland, Malta, Norway and Switzerland, WEU), Eastern Europe (EEU), Japan (JPN); *Fast developing countries*: India (IND), China (includes Hong Kong excludes Chinese Taipei, CHI); *Developing countries:* Africa (AFR), Central and South America (CSA), Middle-East (includes Turkey, MEA), Mexico (MEX), South-Korea (SKO), Other developing Asian countries (includes Chinese Taipei and Pacific Islands, ODA), Former Soviet Union (include the Baltic states, FSU)). The regions are linked by energy trading variables. The trade variables transform the set of regional modules into a single multiregional energy model, where actions taken in one region may affect all other regions. This feature is essential when global as well as regional energy and emission policies are simulated. For each region, a total net present value of the stream of annual costs, discounted to the year 2005 is computed. These regional discounted costs are then aggregated into a single total cost which is the objective function to be minimized by the model. Annual costs include investment costs, operation and maintenance costs, costs of fuels (mining and imports), the cost of trade and the residual value of technologies at the end of the horizon.

The objective function is:

$$NPV = \sum_{r=1}^{R} \sum_{y \in years} (1 + d_{r,y})^{refy-y} * ANNcost(r, y)$$

where NPV is the net present value of the total cost; ANNcost(r,y) is the total annual cost in region r and year y; d(r,y) is the discount rate, refy is the reference year for discounting, years is the set of years and R the set of regions (Loulou, 2008).

Through its integrated climate module, the model makes it possible to analyse and make assumptions on atmospheric GHG concentrations and temperature changes. It integrates CO_2, CH_4 and N_2O.

2.2 Climate policies

Two climate scenarios and a business-as-usual (BAU) scenario are simulated in the model:

- ***BAU scenario:*** In the BAU scenario, no climate policy is assumed.

- ***Glob_50 scenario:*** The *Glob_50* scenario assumes that world CO_2 emissions are reduced by 50% in 2050 compared to 2000 level. This scenario is compatible with the UNFCCC consensual 2-2.4°C objective (as specified by IPCC, 2007). All regions are bounded by the global climate constraint.

- ***Cop_15 scenario:*** This scenario represents the most optimistic CO_2 mitigation targets by 2020, as expressed in the Copenhagen Agreement by Europe, the United States, Australia, Canada, Japan, China and India. Targets for 2050 were assumed according to political ambitions of each country expressed in the literature. This is a regional scenario where only those countries are bounded by the climate constraint. Table I presents the Copenhagen pledges.

Table I: Cop 15 targets and 2050 assumptions for CO_2 emissions

Regions	Year ref.	Year target	Targets	Reduc. type
WEU-EEU	1990	2020	*Pessimistic:* 20%	Emissions reduction.
			***Optimistic:* 30%**	
		2050*	**80%**	
USA	2005	2020	**17%**	Emissions reduction.
		2050	**83%**	
AUS	2000	2020	*Pessimistic:* 5%	Emissions reduction.
			***Optimistic:* 25%**	
		2050	**80%**	
CAN	2005	2020	**17%**	Emissions reduction.
		2050	**83%**	
JPN	1990	2020	**25%**	Emissions reduction.
		2050	**80%**	
CHI	2005	2020	*Pessimistic:* 40%	CO_2 intensity reduction
			***Optimistic:* 45%**	
		2050	**10%**	Emissions reduction.
IND	2005	2020	*Pessimistic*: 20%	CO_2 intensity reduction
			***Optimistic:* 25%**	
		2050	**10%**	Emissions reduction.

*2050 values are assumptions based on announced political ambitions for each country except China and India when we purposely chose a stringent emission reduction target

3. Results

The results focus on the impact of the climate policies on CO_2 emissions and energy system costs.

3.1. Environmental impact of climate policies

In the BAU scenario, the atmospheric concentration of CO_2 reaches 472 ppm in 2050, while beyond 400 ppm CO_2, it will not be possible to stabilise global warming below 2-2.4°C (IPCC, 2007). In *Cop_15* atmospheric CO_2 concentration continues growing to reach 433 ppm in 2050. Meanwhile, the global constraint (*Glob_50*) that consists in reducing CO_2 emissions by 50% compared to the year 2000 allows a stabilization of the atmospheric concentration of CO_2 at 403 ppm in our model. To meet the 2-2.4°C target (*Glob_50*), global CO_2 emissions should decrease by 4.47 Gt by 2020 and by 40.99 Gt by 2050 compared to the BAU pathway. However, in *Cop_15* global emissions are only reduced by 2.23 Gt by 2020 and by 28.46 Gt by 2050 compared to the BAU. Table II shows how the emission reduction effort is shared out between countries in the two target scenarios.

Table II: CO_2 emissions reductions compare the BAU (Gt CO_2)

Regions	2020		2050	
	Glob_50	*Cop_15*	*Glob_50*	*Cop_15*
Industrialized countries	-1.138	-2.174	-11.54	-13.58
Fast developing countries	-1.405	-0.135	-17.87	-15.067
Developing countries	-1.927	+0.072	-11.57	+0.181
World	-4.47	-2.237	-40.99	-28.46

In *Cop_15*, CO_2 emissions are primarily led by industrialized countries in 2020. In 2050, ambitious assumptions for China and India (10% emission reductions) lead to a reduction of 15 Gt of CO_2 emissions compare to the BAU. India and China contribute more than 50% of the overall objective. *Glob_50* benefits industrialized countries in 2020 and 2050 compare to *Cop_15*, while developing countries are heavily constrained in 2020 and 2050. Contribution from fast developing countries is also higher in this scenario.

We find that the optimistic commitments pledged by countries in *Cop_15* do not reduce emissions enough in 2020 and, even favourable assumptions for 2050 are not sufficient to meet the global 2-2.4°C objective. Moreover, to achieve the expected global objective we show that fast developing countries should reduce their emissions to a greater extent and that developing countries will need to participate to CO_2 emission reduction efforts.

3.2. Economic impact of climate policies

This section evaluates the energy system cost implications of the two climate scenarios. The total system cost resulting from the Copenhagen pledges (*Cop_15*) and the global constraint (*Glob_50*) consists of investment cost, variable cost, cost of fuels (mining, import), annual fix operation and maintenance costs as well as the cost of trade (import-export). Table III shows the abatement costs and carbon marginal cost (carbon price) per regions.

In *Cop_15*, total system abatement cost expressed as the cost of additional mitigation expenditure compared to the BAU scenario in 2020 is estimated at US$ 61 billion (increase of 0.5% compare to the BAU). The largest share of this cost is incurred by industrialized countries (92% of the global cost). Abatement cost is relatively high for Europe, Australia and Japan. These are also the countries with the highest emission reduction constraint for 2020 (table I). The carbon marginal costs are also the highest for those regions, reflecting the severity of the constraint (34 USD/tCO_2 for Australia, 58 USD/tCO_2 for Europe and 92 USD/tCO_2 for Japan). In 2050, fast developing countries (India and China) are more constrained by our emissions reductions assumptions than their commitments for 2020, therefore additional abatement costs (compared to BAU 2050) are higher for those regions (about US$ 600 billion). In 2050, the marginal carbon cost reaches 447 USD/tCO_2 in Japan, 245 USD/tCO_2 in Europe, 86 USD/tCO_2 in China and 75 USD/tCO_2 in India.

In *Glob_50*, the model minimises the global cost of the system. Abatement cost is higher than *Cop_15* for almost all developing countries and it increases sharply for China and India from 2020. In 2050, 45% of the total abatement cost is incurred by China. Developing and industrialized countries contribute to the global abatement cost at respectively 22% and 23%. Japan and Europe, where marginal abatement costs are high benefit from this policy. In 2050, abatement costs in those countries are 60% less important than in *Cop_15*. The carbon price in *Glob_50* for all regions is 11 USD/tCO_2 in 2020, 48 USD/tCO_2 in 2030, 74 USD/tCO_2 in 2040 and 94 USD/tCO_2 in 2050.

The additional global discounted cost on the period 2005-2050 with a discount rate at 5% (in absolute terms, compared to the BAU) is US$ 3610 billion in *Glob_50* and US$ 3050 billion in *Cop_15*. In relative terms it represents an increase of 2% in the global scenario and of 1.6% in *Cop_15*. In *Glob_50*, the countries with the lowest discounted cost are industrialized countries. Even if this last scenario minimises the global discounted cost of the system it appears to be costly for fast developing and developing countries. For instance, the actualised cost of the system increases by 6.3% compare to the BAU for China, by 5.8% for India and by 3.1% for Africa.

Table III: Abatement costs and carbon prices per regions

Regions	**Regional abatement cost (M US$)***				**Carbon marginal cost in Cop_15 (USD/tCO_2)**	
	Glob_50		**Cop_15**			
	2020	**2050**	**2020**	**2050**	**2020**	**2050**
AFR	3,542	40,412	259	13,585	-	-
AUS	3700	6,114	2,877	660	34	41
CAN	-886	6,784	727	4,443	12	16
CHI	***24,676***	***639,203***	2,353	***493,888***	-	86
CSA	5,203	39,885	3,523	6,533	-	-
EEU	1,345	35,195	***18,616***	***49,629***	58	245
FSU	1,897	75,136	-1553	4,608	-	-
IND	***6,207***	147,698	-97	***81,294***	-	70
JPN	31	24,424	***17,842***	***88,034***	92	447
MEA	-462	36,374	3,879	-9427	-	-
MEX	847	12,518	1,014	2,103	-	-
ODA	657	87,752	-4112	2,599	-	-
SKO	2834	30,722	-503	-1453	-	-
USA	-1658	181,594	75	***251,722***	-	183
WEU	3521	87,561	***16,575***	***226,091***	58	245

*The regional abatement cost is the cost of additional mitigation expenditure compared to the BAU scenario for each region. Negative sign indicates benefits due to exports.

4. Conclusion

This paper assesses the environmental and economic effects of the Copenhagen Accord through a specific analysis of the pledges announced by countries in 2010. It compares it with the least cost option of a global agreement compatible with the 2°C target. Even applying the most ambitious Copenhagen pledges for 2020 and favourable assumptions for 2050, the emissions trend remains incompatible with the 2°C recommendation. Furthermore, reaching the overall 2°C target involves significant costs for China and India that explains the difficulty of international negotiations. The 2°C objective seems very unlikely unless large financial transfers for financing abatement cost in emerging countries are considered.

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