Post-Kyoto policy implications on the energy system: A TIAM-FR long-term planning exercise

Sandrine Selosse, Edi Assoumou, Nadia Maïzi, Vincent Mazauric

POST-KYOTO POLICY IMPLICATIONS ON THE ENERGY SYSTEM: A TIAM-FR LONG-TERM PLANNING EXERCISE

Sandrine Selosse[*], Edi Assoumou[†] and Nadia Maïzi[‡]
Centre for Applied Mathematics, MINES ParisTech, France
Vincent Mazauric
Strategy and Technology, Schneider Electric

XXI^{e} World Energy Congress
Montreal, September 12 to 16, 2010

Abstract
The aim of this study is to discuss the long term analysis of post-Kyoto commitments, with the modelling tool ETSAP-TIAM-FR. Through the specification of CO_2 mitigation targets scenarios covering the period 2000-2050, this analysis focuses on the effects of these carbon constraints on several indicators such as global and regional CO_2 emissions, the cost of the climate policy, carbon marginal costs, the primary energy consumption and the energy mix. This paper compares global efforts of CO_2 mitigation with the cost of carbon and finally discusses the development of CCS technologies.

Keywords
CO_2 mitigation targets, global energy system, long-term modelling

Acknowledgement
This research was supported by the Chair Modeling for sustainable development, driven by MINES ParisTech, Ecole des Ponts ParisTech, AgroParisTech, and ParisTech, supported by ADEME, EDF, RENAULT, SCHNEIDER ELECTRIC and TOTAL.

1. INTRODUCTION

In the past couple of years the climate change debate has been marked not only scientifically by increased evidences reported in the fourth IPCC assessment report, but also politically by a

[*] *Corresponding author:*
MINES ParisTech, Centre for Applied Mathematics, BP n° 207, 06904 Sophia Antipolis cedex, France
E-mail address : sandrine.selosse@mines-paristech.fr
Tel: +33 (0)4 93 67 89 17; Fax: +33 (0)4 97 15 70 66
[†] E-mail address : edi.assoumou@mines-paristech.fr
[‡] E-mail address : nadia.maizi@mines-paristech.fr

number of major events: the approval of the EU climate package by the EU parliament in December 2008, the transition in US with greener positions expressed by the new administration, and the large participation of developed as well as developing countries in the Copenhagen Climate Change Conference (COP 15), in December 2009. The international agreement at COP 15 was the final step of the two-year negotiation process set by the Bali conference in 2007. Earlier, the Kyoto Protocol was signed in 1997 and aimed to address climate change. More precisely, the Kyoto Protocol aimed to reduce GHG emissions by 5% over the period 2008-2012 for industrialized countries included in Annex I.

For the post-Kyoto period, i.e. beyond 2012, no international agreements agreement is currently planned. In the event of failure of negotiations in Copenhagen, no process was thus in place. It was therefore essential to ensure the signing of a global agreement at the Copenhagen conference, including a share all major industrialized countries (and primarily the United States that had not ratified the Kyoto Protocol), and for the first time, the fastest developing countries whose economic activities and demographic prospects constitute real challenges for the coming decades. This was the major issue of 2009, both for Europe and for all other countries that are resolutely committed to fighting climate change. For the long-term, a noticeable convergence existed between the views expressed by European Union and the Obama-Biden new energy plan for America.

However, the deal on medium-term targets was far from being sealed. On the one hand, the European Union pledged to reduce its carbon dioxide (CO_2) emissions with 20% by 2020, compared to 1990's level, and is prepared to commit additional efforts in case of international agreements. In this case emissions reduction would reach 30% by 2020. On the other hand, the currently expressed short-term target for the USA is a 20% reduction on 2005 levels by 2020. While this represents a significant step, it roughly leads to just a stabilization at 1990 levels by 2020. In the same time, the USA also stressed the need for some mitigation efforts from fast growing transition countries such as China and India.

The key point to a global agreement in 2009 was for the industrialized countries to keep their promises of aid to developing countries for them to adapt to the impacts of climate change. After many years of discussion, the Poznan conference in December 2008 had finally allowed a better utilization of funds allocated to adaptation. Although still very inadequate, consensus concerning their utilization had proved difficult to reach. This commitment had to be confirmed in 2009 to provide tools and resources to meet the challenges that arise. Without these, developing countries which are the countries most vulnerable and most strongly affected by climate change, would not engage in reducing their own greenhouse gas (GHG) emissions.

However, it was imperative that such mitigation policies were promptly considered by these countries, primarily China, India, and Brazil, as they represent in the near future a majority share of global emissions. For example, China has already surpassed Germany in 2008 in terms of economic wealth, and the United States in terms of emissions of CO_2. All these positions left of course room for negotiations and one rule of the Copenhagen game seemed to be: what involvement is acceptable from others to define our own commitment level? European Union was thus waiting for signs from other developed countries and in particular US, who were in term waiting for positive signs from China.

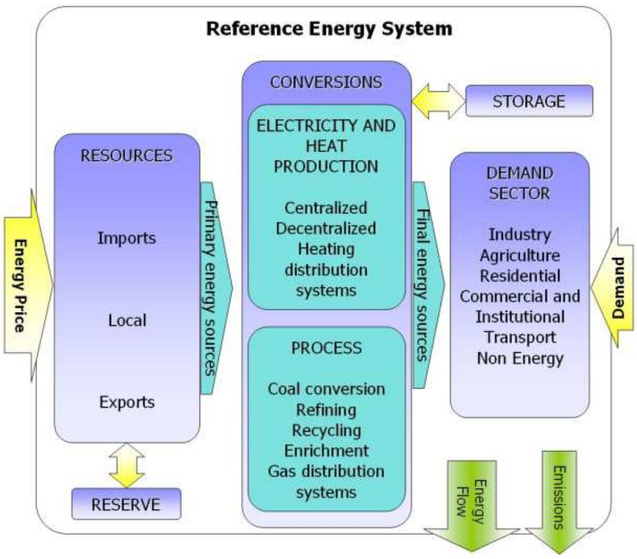
Even if negotiations during COP 15 failed to reach a global agreement on targets for reductions in greenhouse gas emissions to the post-Kyoto, the stakes are no less crucial and the announced pledges at the beginning of 2010 consolidate this position. At least, it appears to reinforce it. The aim of this paper is to analyze the outcomes of different coordination schemes for intermediate mitigation targets. Through scenario analysis based on the ETSAP/TIAM-FR modelling tool, we assess for the period 2000-2050 the evolution of primary energy consumption, global and regional emission levels, and global and regional costs of the climate policy. Section 2 presents the model we use for our investigation. Section 3 specifies the considerate pledges for different regions. Before concluding in the section 5, various results are presented in section 4.

2. METHODS

Two types of models are commonly being used to assess the implications of climate change mitigation: top-down general equilibrium macroeconomic models which assess the whole economy but with a limited description of the energy system, and bottom-up models which focus on the energy system, thus providing increased precision on this portion of the economic system. The analyses carried out in this paper are based on the ETSAP/TIAM-FR (the French version of the TIMES Integrated Assessment Model) bottom-up model developed under the Energy Technology Systems Analysis Programme (ETSAP) under the aegis of IEA (International Energy Agency).

TIAM-FR is a technology-rich, bottom-up energy system model. It depicts the world energy system with a detailed description of different energy forms, resources, processes/technologies and end-uses. The link between the commodities and the technologies is described via a Reference Energy System (RES). More precisely, the RES is a network of interlinked technologies (anything that produces and/or consumes commodities) and commodities (an energy form, an emission, a material, or an energy service). TIAM-FR includes several thousand technologies in all sectors of the energy system (energy procurement, conversion, processing, transmission, and end-uses). Figure 1 gives a synthetic description of the RES covering the whole energy chain.

Figure 1: Synthetic view of the reference energy system



Source: Maïzi, Assoumou, Bordier, Guerassimoff, Mazauric, 2006

The system includes the extraction, transformation, distribution, end-uses, and trade of various energy forms and materials. Each economic sector is described by means of technologies, each characterized by its economic and technological parameters.

TIAM-FR is a global multiregional model. It is geographically integrated and offers a representation of the global energy system in 15 regions covering the entire world: Africa (*AFR*), Australia-New Zealand (*AUS*), Canada (*CAN*), China (includes Hong Kong, excludes Chinese Taipei; *CHI*), Central and South America (*CSA*), Eastern Europe (*EEU*), Former Soviet Union (includes the Baltic states, *FSU*), India (*IND*), Japan (*JPN*), Mexico (*MEX*), Middle-East (includes Turkey; *MEA*), Other Developing Asia (includes Chinese Taipei and Pacific Islands; *ODA*), South Korea (*SKO*), United States of America (*USA*) and Western Europe (EU-15, Iceland, Malta, Norway and Switzerland; *WEU*).

TIAM-FR describes the entire energy system of each region with regard to all essential current technologies from the primary energy supply (through the processing, conversion, transport, distribution of energy carriers) to the end-use sectors as well as energy demands. The regions are linked by energy, material, and emission permit trading variables, if desired. The trade variables transform the set of regional modules into a single multiregional (possibly global) 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. More detailed description of the model is given in Appendix 1.

3. SCENARIO SPECIFICATION

To analyze possible alternative development paths of the system we investigated a variety of environmental target scenarios on different regions of the world over the period 2000-2050. A baseline business as usual (BAU) scenario without any emission constraints was first calculated. In the reference scenario, no climate policy and thus no post-Kyoto policy are assumed. The BAU scenario outlined some key patterns in the evolution of the energy system, and served as the starting point for the analysis. Carbon constraints scenarios allowed us to investigate the changes induced by a strong environmental policy. Thus, the BAU scenario was compared to the emission mitigation scenarios to assess the implications on the future development of the energy system and to formulate policy recommendations.

In total, three scenarios were defined according to different assumptions of carbon mitigation:

- **COP 15**: International scenario with a CO_2 emission mitigation commitment for China, Japan, United States and Western Europe. **This scenario represents the CO_2 mitigation targets for post-Kyoto commitments expressed during COP 15**.

- **Post COP 15** and **Post COP 15 (2)**: International scenarios with a CO_2 emission mitigation commitment for China, Japan, United States, Western Europe, Canada, and Australia (and New Zealand). **These scenarios present environmental commitments constructed for analyzing more or less ambitious future developments**.

The international community appears to converge on its long-term objectives. In this context, we consider in our model that all countries have committed over the long-term to reduce their GHG emissions by 80% in 2050, compared to 1990 or 2005 depending the reference year considered by the regions. Alternative scenarios concerning the outcome of international negotiations and mid-term commitments, and with a more pessimistic view for United States, Canada and Australia are also created. We create the scenarios under the assumptions that Australia and Canada align themselves with the US commitment.

The following figure presents the analyzed various scheme of international coordination.

Figure 2: Scenarios specification

Regions	Ref. year	Target COP 15 2020	Target COP 15 2050	Target Post COP 15 2020	Target Post COP 15 2050	Target Post COP 15 (2) 2020	Target Post COP 15 (2) 2050
Australia	2005	NO	NO	34%	80%	34%	60%
Canada	2005	NO	NO	34%	80%	34%	60%
China	2005	40% (carbon intensity)	80% (carbon intensity)	60% (carbon intensity)	80% (carbon intensity)	10%	20%
Japan	1990	25%	80%	25%	80%	25%	80%
United States	2005	17%*	80%	34%	80%	34%	60%
Western Europe	1990	30%	80%	30%	80%	30%	80%

*COP 15: United States: 42% by 2030

Note that for China, the commitment is not on the emission level but on the carbon intensity. This means that China's GDP will pursue its rise but carbon emissions will have to increase at a lower rate due to greater energy efficiency and investment in greener technologies.

An important and well-known observation to note concerns the choice of reference year. Indeed, while Western Europe and Japan pledge for a CO_2 emission mitigation of respectively 30% and 25% to 2020 compared to 1990 level, other regions consider 2005 as reference year. This induces of course an important impact on the target to reach.

More precisely, if we translate these pledges on the same reference year and following the same type of reduction, i.e. emission mitigation, what does it mean?

For example, in the case of China, reducing CO_2 by 40% to 2020 (*by 80% to 2050*) its carbon intensity compared to 2005 level is equivalent to limiting the increase of its CO_2 emission at 292% in 2020 (*at 485% in 2050*) compared to 1990 level for the COP 15 scenario. For the Post COP 15 (2) scenario for which China pledges to reduce its CO_2 emission level by 10% to 2020 (*by 20% to 2050*) compared to 2005 level, this is equal to limit the increase of its CO_2 emission at 109% in 2020 (*at 86% by 2050*) compared to 1990 level. Therefore, due to wide variation in GDP projections it is obvious that China cannot reasonably pledge an emission reduction, with 1990 as a base year. Indeed, the annual average growth rate of the China GDP for the period 2000-2050 is 6.37%, with a GDP which reach US$30 000 billions in 2050.

For United States, we can note that for the COP 15 scenario, reducing its CO_2 emission by 17% to 2020 (*by 80% to 2050*) compared to 2005 levels, is equivalent to reducing by 0.33% to 2020 (*by 76% to 2050*) its CO_2 emission compared to 1990 level. For the Post COP 15 (2) scenario, where we are more optimistic on the court-term but less optimistic on the long-term, reducing by 34% to 2020 (*by 60% to 2050*) its CO_2 emission compared to 2005 level is equivalent to reducing by 20% to 2020 (*by 52% to 2050*) its CO_2 emission compared to 1990 level. So, it appears clearly the lesser effort committed by United States in the mid-term, notably compared to European Union, whereas they have emitted a larger share of CO_2 emissions. In other words, United States, while they have ratified the agreement, are unlikely willing to pledge on a short-term target.

So, through the different targets we already can note the level of commitments announced by the regions, particularly the lesser efforts of China and United States. We can now analyze the impact of these environmental measures on the energy system and on the cost of this policy for each region.

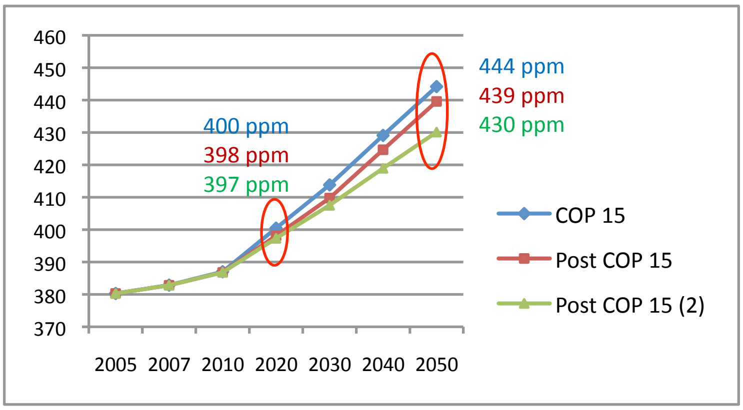
4. Results

The created scenarios were utilized to compare effects of international coordination on main environmental and economic indicators. Impacts of different commitment levels under post-Kyoto negotiations could thereby be discussed. In a first part, the analysis of the optimization results focuses on the effects on world and regional CO_2 emissions, and, in a second part on total costs of the policy, and carbon prices associated with the different CO_2 mitigation targets. The level of ambition of the CO_2 reduction targets could be discussed. In a third part, the model shows the impact of international climate change strategies on the energy system. Analyses were performed to investigate the long-term development of CCS technologies in answer to the constraint which influence the energy mix.

4.1. Global CO_2 stakes and regional ambitions

In this section, we introduce major impact of these climate targets in terms of CO_2 emissions. Then we turn to mitigation costs and provide an overview of the global and regional costs associated to the different scenarios. Firstly, the pathway of global carbon emissions consistent with achieving the regional CO_2 emissions mitigation targets lead to an atmospheric CO_2 concentrations for all scenarios below 450 parts per million (ppm) in 2050. If the global climate stake involves a long-term CO_2 concentration stabilization at or below 450 ppm (550ppm CO_2-eq), this global target will require more drastic measures than those pledged by these regions.

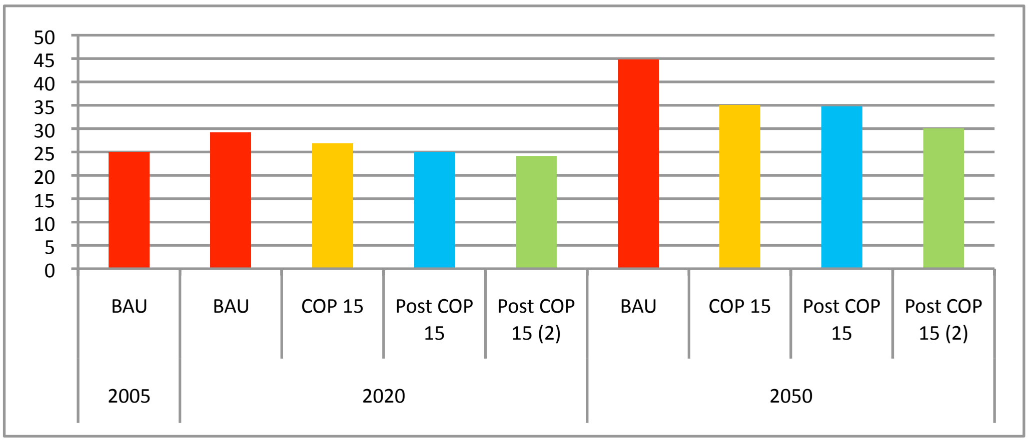
Figure 3: CO_2 concentration (ppm)



This relative indicator of environmental effectiveness, measured as atmospheric concentration of CO_2 allows us to discuss the global impact of these different regional targets. If we compare the three scenarios, CO_2 concentrations are closer until 2020. The targets variations don't impact in a large measure the mid-term level of CO_2 concentration. But differences widen if we compare the three scenarios on the long-run. The CO_2 concentration evolves in a parallel manner between COP 15 and Post COP 15 scenarios; the difference can be explained by the CO_2 emissions constraints imposed to Australia and Canada regions. In the Post COP 15 (2) scenario, the impact is more important on the CO_2 concentration mitigation. Despite the fact that long-term US targets have been reduced by 2050 (from 80% to 60%), in this scenario, the bigger effect results to the China constraint: CO_2 reduction is expressed in term of level of CO_2 emission and not through the carbon intensity which is dependent of the GDP evolution.

The following figure presents the global CO_2 emissions according to the BAU scenario and the climate constraint scenarios. The impact of the Post COP 15 (2) scenario is still noticeable in terms of CO_2 emissions. Firstly, in 2020, not only, the level of CO_2 emission for this scenario is lower than the BAU one, but also, it is lower than the BAU one in 2005. The effect is less marked for COP 15 and Post COP 15 scenarios. Then, in 2050, carbon constraints from Post COP 15 (2) scenario involve a CO_2 emissions decrease of 15 Gt by comparison with BAU, against 10 Gt for COP 15 and Post COP 15 scenario.

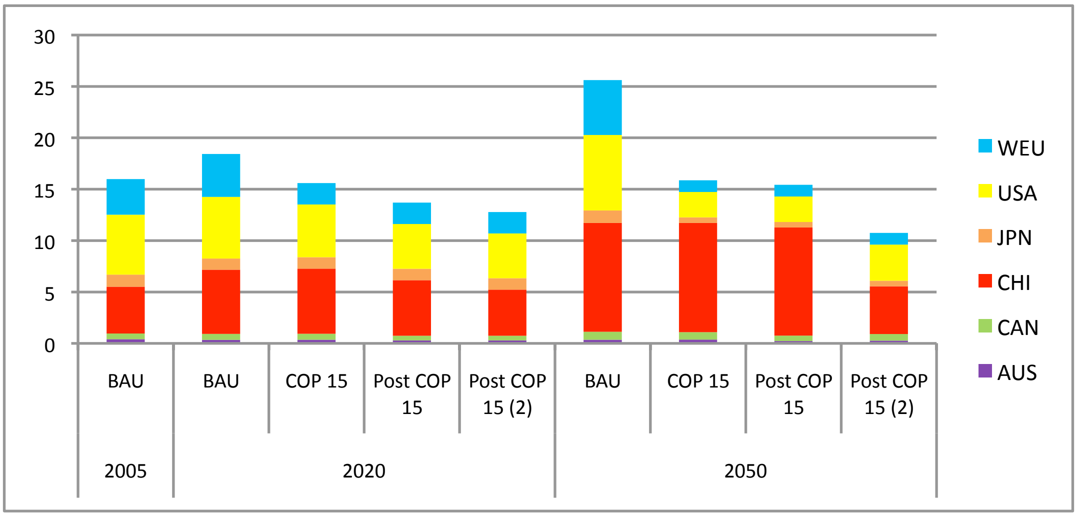
Figure 4: Global CO_2 emissions (Gt CO_2)



While environmental stakes involve a global action, a more interesting observation concerns the impact of these various targets on the regional scale. Indeed, the level of ambition for CO_2 mitigation by developed countries (especially the USA) and developing countries (particularly fast developing countries like China) is a determinant point in the post-Kyoto international agreement to establish a course of action for climate change. Global impact of the international agreement is the result of regional policies expressed here in terms of CO_2 emission mitigation targets on mid and long-term. As we saw above, these targets expressed a more or less ambitious participation from various regions in the fight against climate change. More precisely, European Union, which was alone before COP 15 to engage in international agreement for post-Kyoto, had pledged to reduce by 20% its CO_2 emission by 2020 compared to the 1990 level, and was prepared to commit additional effort in case of international agreements, i.e. increasing its pledge from 20% to 30%.

Another point concerns the commitment of fast growing transition countries and particularly China. Indeed, while European Union was waiting for signs from other developed countries and in particular the USA, the USA stressed the need for some mitigation efforts from China, and to a lesser extent India. China has pledged and committed itself to the international agreement but only to marginal measurements. Equally, the USA announced pledge and the result of what this induces are far from being ambitious and so satisfying in the mid-term. So, clearly, in the international agreement investigated in this analyse, European Union is together with Japan willing to pledge the biggest effort for the climate change fight. This point is apparent in the figure 5 showing the regional CO_2 emissions according to the different scenarios. Note that this graph expresses only the CO_2 emissions of the constrained regions. Appendix 2 highlights the share of CO_2 emissions from all world regions relative to the global CO_2 emissions.

Figure 5: Regional CO_2 emissions (Gt CO_2)



This graph obviously highlights how strong is the European targets on the mid- and long-term and for all carbon constraints scenarios. The CO_2 emissions of Western Europe in 2020 decrease from 4.2 Gt in the BAU scenario to 2 Gt in COP 15, Post COP 15 and Post COP 15 (2) scenario. In 2050, CO_2 emissions decreased from 5.3 Gt to 1.1 Gt. The effect of the Japanese policy is higher on the long-term than on the mid-term. So, if we compare climate scenarios results with the BAU scenario, CO_2 emissions are sensitively the same in 2020, around 1 Gt. But, in 2050, CO_2 emissions reach 1.2 Gt in the BAU scenario against 0.5 Gt in COP 15, Post COP 15 and Post COP 15 (2).

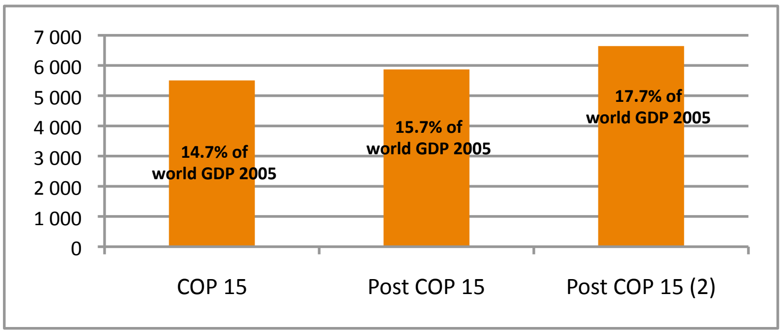
Like for Australia and Canada but in a lesser manner, carbon mitigation targets from the USA involve a higher decrease of CO_2 emission at long-term than at short-term. In 2050, COP 15 and Post COP 15 scenarios ensure the USA to reduce their CO_2 emissions by almost two third in comparison with the BAU scenario (Post COP 15 (2) scenario halves the US CO_2 emission compared with BAU scenario). More precisely, CO_2 emissions in 2020 represent 5.1 Gt in COP 15 and 4.3 Gt in Post COP 15 and Post COP 15 (2) against 6 Gt in the BAU scenario. In 2050, CO_2 emissions represent 2.5 Gt in COP 15 and Post COP 15 and 3.5 in Post COP 15 (2) against 7.3 Gt in the BAU scenario.

Results for China appear like a telltale sign of the effort that the Chinese government is willing to do in the climate change context and its economic context of fast growth, like its CO_2 mitigation target on the carbon intensity basis let suppose. So, in 2020, CO_2 emissions represent 6.2 Gt in the BAU scenario and respectively 6.3 Gt, 5.4 Gt and 4.5 Gt in the climate scenario. And, in 2050, CO_2 emissions represent 10.6 Gt in the BAU scenario and respectively 10.6 Gt, 10.5 Gt and 4.6 Gt in the climate scenario. Considering these results, the impact of the climate target expressed in the COP 15 and Post COP 15 scenarios, (i.e. respectively CO_2 mitigation target expressed in COP 15 and a more ambitious target) on the CO_2 emissions pathway is hardly noticeable. Based on the level of CO_2 emissions, 10% and 20% of mitigation involve not only effective impact but also ambitious and concrete participation in the fight against climate change. But the question could be at what cost. This is the object of the following sub-section.

4.2. The cost of the regional ambition

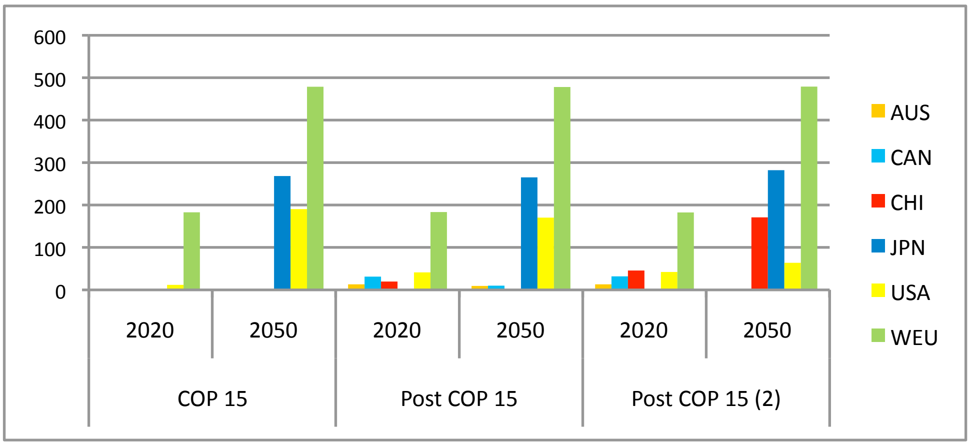
We studied the cost implications of these climate policy. First of all, scenarios analysis provides the total discounted cost on the energy system, on the market of energy services. This cost represents the global additional cost of the CO_2 emissions mitigation constraints in comparison with the BAU scenario. Figure 6 expressed this additional cost involved by climate policy.

Figure 6: Global CO_2 mitigation targets costs (billion 2005 USD)



The cost increases with the stringency of the carbon target reaching 17.7% of the world GDP (2005) with the Post COP 15 (2) scenario, where China is constrained on its CO_2 emissions level and despite the weaker long-term target for US, Canada and Australia. The cost increase resulting from the stronger global constraints is also reflected in the carbon marginal costs of the various regions. The carbon target imposed by the Post COP 15 (2) scenario for China increase the carbon marginal costs in this region, particularly in 2050 where it reaches \$170/tCO_2. In the Post COP 15 scenario, the CO_2 mitigation target of China by 2020 (a reduction of 60% of carbon intensity) involves a little pressure on the carbon marginal cost which reaches \$19/tCO_2. The pressure disappears in 2050 under the GDP growth effect which limits at minimum the mitigation effort (like for the COP 15 scenario in 2020 and 2050). This element raises the question of how far China could be in capacity to support more ambitious targets. It is important to make the regional CO_2 emission mitigation on perspective with effort supported. In this analysis, marginal cost of CO_2 reduction constitutes an indicator of what each region need to support to reach its commitment but also of the level of effort of the various targets. The regional carbon marginal cost according to the various scenarios are given in the Figure 7.

Figure 7: Regional carbon marginal costs (\$/tCO_2)



This question of marginal cost also applies to Japan and Western Europe. The cost reflects well the effort assented by the region to fight the climate change. These burdens appear important in all scenarios for Western Europe, and in a lesser extend for Japan. More precisely, Japanese carbon marginal cost reaches \$271/tCO_2 in the mean in 2050 (against around \$11/tCO_2 in 2020 reflected the lower impact of its mid-term target). For Western Europe, carbon marginal cost reaches the high level of \$479/tCO_2 in 2050 (against around \$183/tCO_2 in 2020). An interesting observation to note concerns USA. Their mid-term target like pledged for COP 15 induces a carbon marginal cost in 2020 only reaching \$11/tCO_2. The doubling of the 2020 target (from 17% to 34% of the 2005 level) induces a carbon marginal cost of \$41/tCO_2. In 2050, for COP 15 and Post COP 15 scenarios, carbon marginal cost reaches \$180/tCO_2 in the mean, and for Post COP 15 (2) (whit lower long-term target, from 80% to 60% to the 2005 level), cost decreases until \$63/tCO_2.

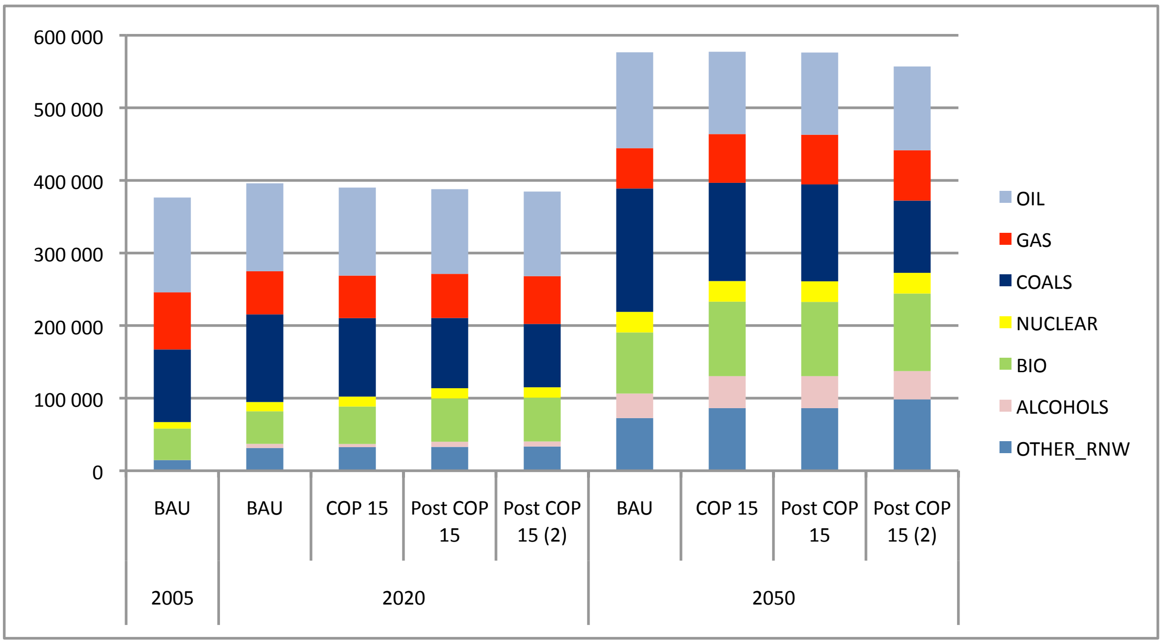
4.3. Policy implications on the energy system

Additional constraints imposed on the energy system involve a variation on the energy and technology choices. Here, climate policy with carbon emission mitigation influences on the structure of the energy mix. However, impact is weak on the total volume of the primary energy consumption which noticeably increases, especially in 2050 for all scenarios.

In the BAU scenario, primary energy consumption represents 376 053 PJ (8 990 Mtoe) in 2005 and reaches 576 512 PJ (13 769 Mtoe) in 2050. The volume is similar for COP 15 and Post COP 15 scenario. However, for Post COP 15 (2) scenario, carbon constraints involve effect on the primary energy consumption which decreases to 3.39% in 2050 by comparison with BAU level.

Figure 8 highlights the evolution of the primary energy supply mix in 2020 and 2050 according to all scenarios and figure 9 presents the fuels shares in the energy mix.

Figure 8: Total Primary Energy Supply (PJ)



In 2005, in the BAU scenario, the world energy mix relied on 35% oil, 27% coal, 21% gas, 15% renewables and 2% nuclear. In 2020, the market is still dominated by fossil fuels but renewables share increases and becomes higher than gas. More precisely, in 2020, in the BAU scenario, the world energy mix relied on 31% oil, 31% coal, 21% renewables, 15% gas and 3% nuclear. If we compare the BAU and climate scenarios in 2020, carbon constraints lead to an increase of other renewables and biomass and in a lesser extend of nuclear.

Gas is essentially influenced on Post COP 15 (2) scenario and the impact of the climate policy is weak on the oil consumption in 2020 by comparison with the BAU scenario. Also, environmental targets lead to reducing coals supply. For Post COP 15 and Post COP 15 (2) scenarios, coals supply in 2020 is lower than the 2005 level.

Figure 9: Fuel shares in the energy mix (%)

Year	Scenarios	Oil	Gas	Coals	Nuclear	Biomass	Alcohols	Other renewables
2005	BAU	34.7	20.9	26.6	2.4	11.5	0.0	3.9
2020	BAU	30.6	15.0	30.5	3.2	11.3	1.4	7.9
	COP 15	31.1	15.0	27.7	3.5	13.2	1.1	8.3
	Post COP 15	30.1	15.6	24.9	3.6	15.4	1.8	8.5
	Post COP 15 (2)	30.3	17.1	22.7	3.7	15.7	1.8	8.7
2050	BAU	22.9	9.6	29.5	4.9	14.6	5.9	12.6
	COP 15	19.7	11.6	23.5	4.9	17.8	7.7	14.9
	Post COP 15	19.7	11.9	23.5	4.9	17.7	7.7	15.0
	Post COP 15 (2)	20.7	12.5	17.9	5.1	19.2	7.0	17.7

In 2050, in all scenarios but in a larger extent in the carbon constraints scenarios, there is a further decline of oil share which reaches around 20% (and 23% in the BAU scenario). Moreover, apparent differences occur in 2050.

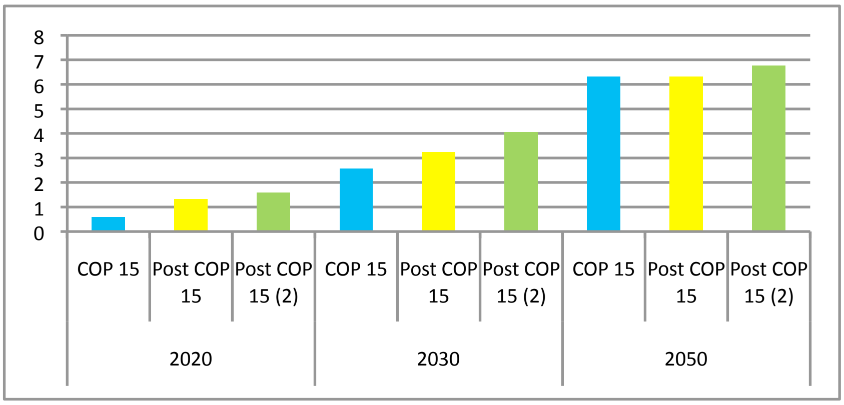
In the Post COP 15 (2) scenario, the environmental constraints lead to an increase of renewables up to a 43.8% share against 33% in the BAU scenario (with respectively 14.6%, 5.9% and 12.6% for biomass, alcohols and other renewables). COP 15 and Post COP 15 scenarios lead up to 40% (with respectively 17.7%, 7.6% and 14.9% for biomass, alcohols and other renewables).

We can note the progress of nuclear but not on an extended measure, and without comparison with renewables and biomass evolution. An important observation is that energy mix is still dominated by fossils fuels but in a clearly lesser extent due to the large progression of renewables. Indeed, the share of renewables in all scenario increases, and more in the Post COP 15 (2) scenario.

While fossil fuels remain the dominant fuels in 2020 for all scenario with a share reaching more than 70% (even if the share diminishes with the stringency of the carbon targets), this structure is less clear in 2050 with a share of 51.1% in the Post COP 15 (2) scenario, and 54.7% in the COP 15 and Post COP 15 scenarios.

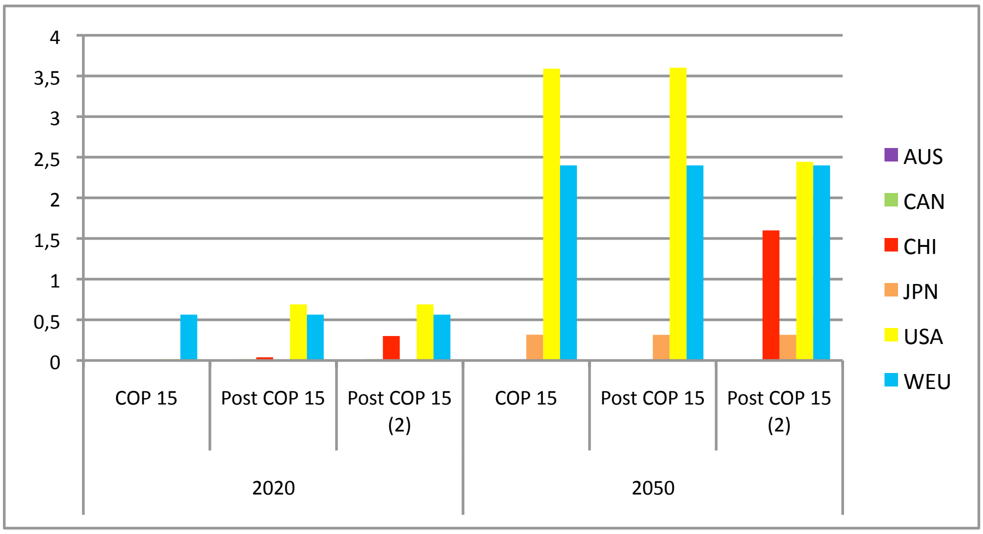
The consumption of all fossil fuels decreased in 2020 and 2050 whatever the climate scenario except for coal which can be explained by the development of carbon capture and storage technologies. Note that in the Post COP 15 (2) scenario, where the China target is higher, the coals share is clearly reduced. The choice between gas and coals is influenced by this CCS development, to the detriment of gas.

Figure 10: CO_2 storage (Gt)



Indeed, as is presented in the figure 10, environmental constraints lead to the development of CCS technologies. In 2050, more than 6 Gt of CO_2 are sequestrated to reach the carbon emission mitigation target. Note that the stringency of the various climate policy expressed in the scenarios investigated here is reflected in the CCS development, and particularly if we consider the regional development of this technology, given in the figure 11.

Figure 11: Regional CO_2 storage (Gt)



The stronger constraint imposed to China directly leads this country to develop CCS technologies. The more ambitious is the Chinese target, the more important is the sequestrated CO_2 in China. Strong long-term constraint for the USA involves an important growth of the CO_2 sequestration. In COP 15 scenario, 0.01 Gt of CO_2 sequestrated result from the 17% CO_2 mitigation target and 0.7 Gt from the 34% expressed in COP and Post COP 15 scenarios.

On the other hand, CO_2 sequestrated reaches 3.6 Gt in 2050 for COP 15 and Post COP 15 scenarios where the target is 80% of reduction (and 2.4 Gt for Post COP 15 (2) scenario where the target is 60% of reduction). In addition to the renewables development, CCS technologies deployment is a solution at CO_2 mitigation targets. The same is true for Western Europe and Japan (for the long-term). In 2050, Western Europe sequestrates 2.4 Gt of CO_2 to fulfil its commitment, and Japan 0.3 Gt.

5. Discussion

In this paper, we have analysed different path of CO_2 emissions mitigation targets and focused on their implication on costs, total energy consumption, and the energy mix. A key feature of the post-Kyoto agreement was the participation of non-Annex I countries, especially China, and United States, as they represent a large share of the global CO_2 emissions.

China and the USA are the major emitters of CO_2 globally and without their participation on a climate agreement, the latter cannot really ensure to reach a CO_2 concentration and global temperature stabilisation. But this scenario analysis shows that the impact of their mid-term CO_2 mitigation target on the global CO_2 emission is far for being ambitious and satisfying, especially for the USA if we consider the higher CO_2 marginal cost that China has to support for ensure its pledge. It is indeed important for each region to evaluate what are the costs of the GHG emission targets.

This question of technological plausibility is a critical design for Post-Kyoto international Climate policy. The higher policy costs for China in the Post COP 15 (2) scenario can to some extent be explained by investments in CCS technologies made to reach this high target. Other regions invest in these technologies in the long run; however, the feasibility of avoiding 7 Gt of CO_2 emissions by investing on CCS technologies is questionable. This also concerns renewables. Indeed, as we can see in the total primary energy supply, share of renewables, biomass, and alcohols appears important but below the use of fossil fuels. However, if cost and efficiency of renewables technologies are comparable to fossil fuels, there importance might increase significantly. Alone, one country cannot mitigate climate change; international cooperation is needed to face the energy-climate problem. However, not only countries must significantly act but also technological progress has to respond adequately to their ambition expanding the pool of available (or not) technologies and their mitigation potential. This concerns not only the CCS technologies but also non fossil energies, like wind, solar, biomass, etc.

This study is not yet a final analyse. However, it shows the way for further development. Firstly, carbon constraints scenario could be adapted to the new announced pledges and developments. We also could add other regions following their announced pledges, like India, Russian Federation or South Korea according to the possibility given by our model in term of regions distribution. Comparative analyse with scenarios expressing optimistic or pessimistic views regarding long-term efforts could then be performed. Secondly, non-CO_2 gases and CO_2 emissions permits market could be included to be considered in the analyses. Thirdly, it might be worthwhile to investigate new scenarios with limited CCS technologies expressing optimistic or pessimistic view of their future development. Finally, the potential of renewables development could be discuss further in the same perspective.

6. References

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7. Appendix 1: The ETSAP TIMES Integrated Assessment Model

In TIAM-FR, end-use demands (i.e. energy services) are based on socio-economic assumptions and are specified exogenously by the user in physical units (number of houses, commercial area, industrial production, vehicle-kilometers, etc.) over the planning horizon. However, contrary to traditional bottom-up models, TIAM acknowledges that demands are elastic to their own prices. This feature insures the endogenous variation of the demands in constrained runs (on emission or concentrations), thus capturing the vast majority of the macroeconomic feedback of the energy system. Thereby, the energy consumption in TIAM-FR is based on external projections of the growth of regional GDP as well as population and volume of various economic sectors (transport, residential, industry, etc.). These drivers and IEA statistics for a given base year, in this case 2000, are the basis for future projections of the consumption of different energy such as road passenger transportation, steel demand or residential heating. In order to satisfy the demands, energy sources are extracted and in series number of steps, transformed into the end-use demand commodities. The model contains of a vast number of technology descriptions for energy production, transformation and end-use demands. The description of the technologies includes data on investment and operation costs, efficiencies and, sometimes, market potentials. The model also consists of a number of other elements, such as user-defined constraints and international trade links.

TIAM-FR is the global multiregional version of the TIMES model generator, a linear programming model that estimates an inter-temporal partial economic equilibrium on integrated energy markets. The model assumes perfect markets and unlimited foresight for the calculation period, the described economic sectors, and commodities. In other words, the model minimizes, under environmental and technical constraints, the total discounted cost of the energy system over the entire model horizon [2000-2100]. Cost of the energy system includes investment costs, operation and maintenance costs, costs of imported fuels, incomes of exported fuels, the residual value of technologies at the end of the horizon, and welfare loss due to endogenous demand reductions. The model computes both the flows of commodities (energy forms, materials, and environmental), as well as their prices. The prices of the commodities are computed in such that at the prices computed by the model, the suppliers of energy produce exactly the amounts that the consumers are willing to buy. The equilibrium feature is present at every stage of the energy system: primary energy forms, secondary energy forms, and energy services. TIAM-FR aims to supply energy services at minimum global cost by simultaneously making decisions on equipment investment, equipment operation, primary energy supply, and energy trade.

The main outputs of the model are future investments and activities of technologies for each time period. Furthermore, the structure of the energy system is given as an output, i.e. type and capacity of the energy technologies, energy consumption by fuel, emissions, energy trade flows between regions, transport capacities, a detailed energy system costs, and marginal costs of environmental measures as GHG reduction targets. The model tracks emissions of CO_2, CH_4, and N_2O from fuel combustion and processes. Emission reduction is brought about by endogenous demand reductions, technology and fuel substitutions (leading to efficiency improvements and process changes in all sectors), carbon sequestration (including CO_2 capture at the power plant and hydrogen plant level, sequestration by forests, and storage in oil/gas fields, oceans, aquifers, etc.). An additional output of the model is the implicit price, or opportunity cost (shadow price), of each energy form, material and emission.

8. APPENDIX 2: THE REGIONAL CO_2 EMISSIONS SHARES

This figure represents the regional CO_2 emissions shares for all world regions:

- The CO_2 constrained regions: Western Europe (WEU), the USA (USA), Japan (JPN), China (CHI), Canada (CAN) and Australia and New Zealand (AUS):
- The other countries (OC): Africa (AFR), Central and South America (CSA), Eastern Europe (EEU), Former Soviet Union (FSU), India (IND), Middle East (MEA), Other Developing Asia (ODA) and South Korea (SKO).

Figure 12: Regional CO_2 emissions shares