

# A regional perspective to achieve the future climate regime: a long-term analysis with the TIAM-FR model

**Sandrine Selosse and Nadia Maïzi**

MINES ParisTech, Centre for Applied Mathematics,  
Rue Claude Daunesse, BP207, 06904 Sophia Antipolis, France;  
sandrine.selosse@mines-paristech.fr; nadia.maizi@mines-paristech.fr

## **Introduction**

Global warming is in essence an economic and political problem. 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, some more than others, 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 behaviors. 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 over the period 2008-2012. The protocol's impact has however been limited, because of a lack of commitments from rapidly growing emerging countries such as China and India, and non-ratification by 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. Although negotiations during the summit failed to reach a global agreement, in late January 2010 some countries including major emerging nations pledged their commitment 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. These pledges occur until 2020 and constitute period 2 of the Kyoto Protocol (2013-2020). The challenge now is to get countries to converge towards a global and multilateral agreement to keep in line with ambitious targets to limit GHG emissions. This is the ultimate aim of the Conference of Parties due to take place in Paris in 2015. While the deadline for the implementation of this agreement is imminent, we propose to discuss the key points to reach these ambitious objectives by 2015.

The aim of this study is to analyze different paths of CO<sub>2</sub> emission mitigation targets and to discuss the future climate regime with the modeling tool TIAM-FR. More precisely, we investigate different

coordination schemes for regions pledging to reach CO<sub>2</sub> mitigation targets in line with 1) commitments occurring according to the Copenhagen Agreement by 2020, 2) an ambitious ultimate and global target by 2050 in line with the UNFCCC ultimate objective (limiting the global increase in temperature to 2°C) and the IPCC recommendations (AR4 and AR5), and 3) regional assumptions by 2050 according to the group of countries (industrialized, fast developing or developing). Drawing from regional scenarios of carbon constraints, we discuss possible futures for the next climate regime according to the rule of “What might happen if...?” e.g.: Can we reach the 2°C target if developing countries do not contribute to reducing GHG emissions in the future? What could happen if developed countries do not contribute enough to reducing CO<sub>2</sub> emissions in the future? What are the induced regional energy systems of these climate scenarios if fast developing countries do not contribute early to reducing CO<sub>2</sub> emissions in the future? and so on.

Our analysis mainly focuses on the effects of these environmental constraints on global and regional CO<sub>2</sub> emissions and the evolution of the energy system. This paper compares global efforts of CO<sub>2</sub> mitigation with the regional effort for a variety of climate policies and finally discusses the impact of the development of technologies in the energy mix in 2050.

## **Modeling approach and climate scenarios**

We analyze the environmental and economic impacts of long-term climate commitments by introducing climate pledges in the bottom-up optimization model TIAM-FR.

### **The TIMES Integrated Assessment Model (TIAM-FR)**

TIAM-FR is the French version of the *TIMES Integrated Assessment Model*, the global multiregional model from the TIMES family models developed by the *Energy Technology Systems Analysis Program* (ETSAP), under the aegis of the *International Energy Agency* (IEA). This linear programming model estimates an inter-temporal partial economic equilibrium on energy markets and, in other words, minimizes the total discounted cost of the world energy system over a long time period under environmental, technological and demand constraints. The model assumes perfect markets and unlimited foresight for the calculation period, the described economic sectors, and commodities. Cost of the energy system includes investment costs, operation and maintenance costs, costs of imported fuels, incomes of exported fuels, and the residual value of technologies at the end of the horizon. 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. End-use demands (i.e. energy services) are based on socio-economic assumptions and on external projections of the growth of regional GDP as well as population and volume of various economic sectors (transport, residential, industry, etc.) over the planning horizon. These drivers and IEA statistics for a given base year, in this case 2005, 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 energy services demands, the system includes the extraction, transformation, distribution, end-uses, and trade of various energy forms and materials. Indeed, TIAM-FR is a technology-rich, bottom-up model which depicts the energy system with a detailed description of different energy forms, resources, processing technologies and end-uses, on a Reference Energy System (RES). Each economic sector is described by means of technologies, each

characterized by its economic and technological parameters (Loulou and Labriet, 2008). Figure 1 gives a concise description of the RES covering the whole energy chain.

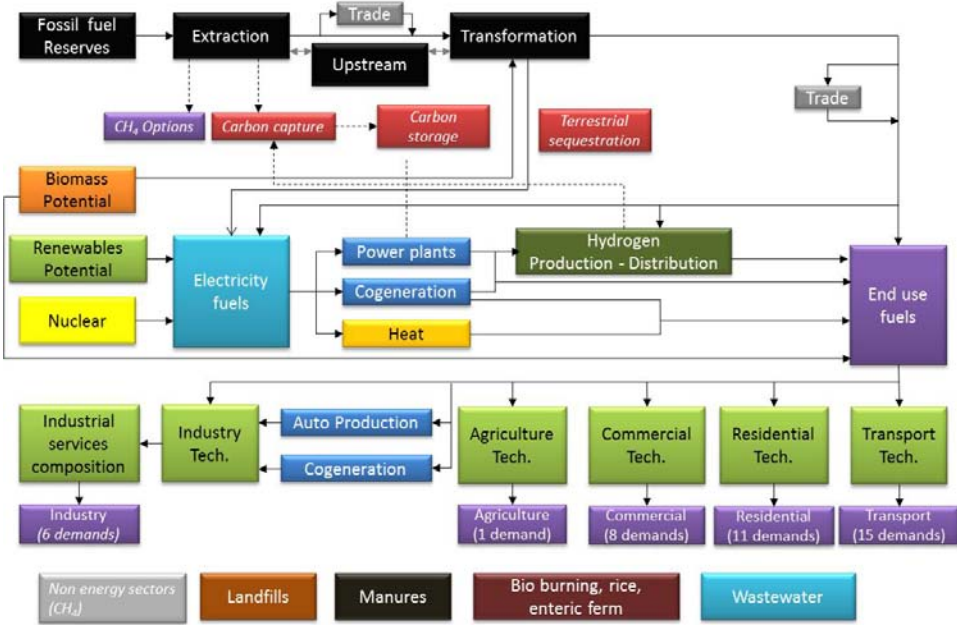


Figure 1: Overview of the reference energy system

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 calculates CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emissions from fuel combustion and processes and integrates a climate module which allows calculating or constraining atmospheric GHG concentration, radiative forcing and temperature changes. Emission reduction is brought about by technology and fuel substitutions (leading to efficiency improvements and process changes in all sectors), carbon sequestration (including CO<sub>2</sub> 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.

TIAM-FR is geographically integrated and offers a representation of the world energy system under a disaggregation in 15 regions : 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). In each region, TIAM-FR describes the entire energy system with the same level of technological disaggregation. The regions are linked by energy and material trades. Some results are discussed considering 3 groups of countries: Industrialized, Fast developing countries and developing countries.

To analyse possible alternative development paths of the system and discuss the future climate regime, we investigated a variety of environmental target scenarios on different regions of the world over the period 2005-2050 and 2005-2100.

### **The climate scenarios for the future climate regime**

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-COP15 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. We considered the Post-Copenhagen pledges for 2020 and made assumptions on the 2050 targets based on each country's announced political ambitions, expected ambitions or required contributions. We then compared these pledges to the BAU and a global scenario compatible with the UNFCCC ultimate objective of limiting temperature change to 2°C, where all countries are constrained or not to contribute to this global mitigation target.

The various scenarios we investigated include environmental targets for different world regions over the period 2005-2050. We analyze a combination of these scenarios in order to provide a framework for understanding the climate context of the future regime which is expected to be decided in 2015:

- (1) **BAU**: World reference scenario without any explicit policy measures on GHG mitigation
- (2) **UNFCCC**: World climate scenario in line with limiting temperature change to 2°C in 2100, i.e. a 50% reduction of the world CO<sub>2</sub> emissions by 2050 by comparison with 2000 (IPCC, AR4):
- (3) Regional Post-Copenhagen pledges scenario by 2020:
  - a. **COP+**: with an optimistic CO<sub>2</sub> emission reduction commitment to 2020 for countries that pledged commitments in the Copenhagen Accord, without a CO<sub>2</sub> emission reduction commitment for developing countries.
  - b. **COP-**: with a pessimistic CO<sub>2</sub> emission reduction commitment to 2020 for countries that pledged commitments in the Copenhagen Accord, without a CO<sub>2</sub> emission reduction commitment for developing countries.
  - c. **COP+DEV30**: with an optimistic CO<sub>2</sub> emission reduction commitment to 2020 for countries that pledged commitments in the Copenhagen Accord, with a CO<sub>2</sub> emission reduction commitment of 30% to 2020 compared to a business as usual scenario for developing countries.
  - d. **COP-DEV15**: with a pessimistic CO<sub>2</sub> emission reduction commitment to 2020 for countries that pledged commitments in the Copenhagen Accord, with a CO<sub>2</sub> emission reduction commitment of 15% to 2020 compared to a business as usual scenario for developing countries.

| Country or Area | Region TIAM | Reduction by 2020 | Reference Year | Reduction type      |
|-----------------|-------------|-------------------|----------------|---------------------|
| Australia       | AUS         | 5 to 25%          | 2000           | Emissions reduction |
| Canada*         | CAN         | 17%               | 2005           | Emissions reduction |
| European Union  | WEU-EEU     | 20 to 30%         | 1990           | Emissions reduction |
| Japan           | JPN         | 25%               | 1990           | Emissions reduction |
| United States*  | USA         | 17%               | 2005           | Emissions reduction |

|       |     |           |      |                  |
|-------|-----|-----------|------|------------------|
| China | CHI | 40 to 45% | 2005 | Carbon intensity |
| India | IND | 20 to 25% | 2005 | Carbon intensity |

|                    |     |               |      |                     |
|--------------------|-----|---------------|------|---------------------|
| Russian Federation | FSU | 15 to 25%     | 1990 | Emissions reduction |
| Mexico             | MEX | 30%           | BAU  | Emissions reduction |
| South Korea        | SKO | 30%           | BAU  | Emissions reduction |
| Brazil             | CSA | 36,1 to 38,9% | BAU  | Emissions reduction |

\* Intermediate targets are also introduced for the USA and Canada regarding their pledges to UNFCCC: 30% for 2025 and 42% for 2030

**Figure 2: Post COP 15 commitments for 2020 implemented in TIAM-FR**

(4) Regional long-term objectives scenario by 2050: according to international convergence and expressed ambitions:

- a. **IND80**: with a pessimistic CO<sub>2</sub> emission reduction commitment to 2050 for industrialized countries, without a CO<sub>2</sub> emission reduction commitment for developing countries and fast developing countries.
- b. **IND95**: with an optimistic GHG emission reduction commitment to 2050 for industrialized countries, without a CO<sub>2</sub> emission reduction commitment for developing countries and fast developing countries.
- c. **IND/FDC80**: with a pessimistic CO<sub>2</sub> emission reduction commitment to 2050 for industrialized countries and fast developing countries, without a CO<sub>2</sub> emission reduction commitment for developing countries.
- d. **IND/FDC95**: with an optimistic GHG emission reduction commitment to 2050 for industrialized countries and fast developing countries, without a CO<sub>2</sub> emission reduction commitment for developing countries.
- c. **IND/FDC80-DEV15**: with a pessimistic CO<sub>2</sub> emission reduction commitment to 2050 for industrialized countries and fast developing countries, with a CO<sub>2</sub> emission reduction commitment of 15% to 2050 compared to a business as usual scenario for developing countries.
- d. **IND/FDC95-DEV30**: with an optimistic GHG emission reduction commitment to 2050 for industrialized countries and fast developing countries, with a CO<sub>2</sub> emission reduction commitment of 30% to 2050 compared to a business as usual scenario for developing countries.

## **Results and discussion: a long-term decoding of the commitments for the future climate regime beyond 2020**

First of all, it is worth taking a look at the post-COP 15 targets. In late January 2010, at the end of the fifteenth Conference of the Parties, some countries pledged their commitment to the United Nations Framework Convention on Climate Change as part of the Copenhagen Agreement to mitigate CO<sub>2</sub> emissions in line with various targets. Although this international agreement did not meet up to expectations, it laid the first foundations of the post-Kyoto global fight against climate change, which was not an easy task. Over recent years, the climate change debate has not only seen increased scientific evidence published in the fourth and fifth IPCC assessment reports, but also a number of major political events: the approval of the EU climate package by the EU parliament in December 2008, a shift in the US, with greener positions expressed by the new administration, and the high participation of developed and developing countries at the Copenhagen Climate Change Conference (COP 15), in December 2009 and since that date. The international agreement made at COP 15 was to be the last step in the two-year negotiation process determined at the 2007 Bali conference. The Kyoto Protocol was signed ten years earlier in 1997 and aimed to address climate change, and more precisely a 5% reduction in GHG emissions over the period 2008-2012 for the industrialized countries included in Annex I. For the post-Kyoto period, i.e. beyond 2012, no international agreement had been planned, and this was the aim of COP 15. In the event of a failure in negotiations at Copenhagen, no process would be in place. It was therefore essential to ensure the signing of a global agreement at the Copenhagen conference, including all major industrialized countries (and primarily the United States, which 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 a major issue for 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 the European Union and the Obama-Biden new energy plan for America. However, the deal on medium-term targets was far from sealed. On the one hand, the European Union pledged to reduce its carbon dioxide (CO<sub>2</sub>) emissions by 20% compared to its 1990s level by 2020, and was prepared to commit to additional efforts ratified by international agreements. This would involve a 30% reduction in emissions by 2020. On the other hand, the current medium-term target for the USA was a 17% reduction on 2005 levels by 2020. While this represents a significant step, it roughly leads to a mere stabilization at 1990 levels by 2020. At the same time, the USA also stressed a need for mitigation efforts from fast-growing transition countries such as China and India. A crucial factor to finding global agreement in 2009 was whether industrialized countries would keep their promises of aiding developing countries so that they could adapt to the impacts of climate change. After many years of discussion, the Poznan conference in December 2008 finally allowed a better utilization of funds allocated to adaptation. Although still highly inadequate, consensus concerning their utilization had proved difficult to reach. This commitment had to be confirmed in 2009 to provide tools and resources for meeting arising challenges. Without these, developing countries, which are vulnerable and highly affected by the climate change, would not commit to reducing their own GHG emissions. It was imperative that such mitigation policies be promptly considered by these countries, primarily China and India, which will represent a majority share of global emissions in the near future. For example, in 2008 China surpassed Germany in terms of economic wealth, and the United States in terms of CO<sub>2</sub> emissions. Naturally, such positions left ample room for negotiations and one rule of the Copenhagen game

was: what involvement is acceptable from others to define our own commitment level? The European Union was thus waiting for signs from other developed countries and in particular the US, who were in turn waiting for positive signs from China.

What is at stake now and for the future? Even though negotiations during COP 15 failed to reach a global agreement on post-Kyoto greenhouse gas emission reductions, the stakes are no less crucial and the pledges announced at the beginning of 2010 consolidate this position. Now commitments for CO<sub>2</sub> emissions mitigation pledged by lots of countries, developed and developing countries, and covers 80% of 2005 global emissions. The major question is to determine what will happen after 2020. Decisions adopted at the Durban Conference, in 2011, highlight the emergency character of the situation and emphasize the need to radically increase the level of ambition of pledges beyond 2020 to cut GHG emissions in order to achieve the objective of limiting the increase global temperature to 2°C. Indeed, this agreement will aim to increase the overall effort to the extent that existing commitments will not allow containing the rise in temperature below 2°C. UN climate negotiations therefore continue in order to lead to the signing in 2015 of a new international framework from 2020 with commitments for all countries to better combat global warming. The principle of common but differentiated responsibilities played a major role in negotiating the post-2012 and will remain in structuring the post-2020 negotiations. However, an ambitious emission mitigation objective appears not to be realistically achieved without the contribution of developing countries, especially from the viewpoint of technological challenges. Considering the pledged targets by countries or regions under the framework of the Conferences of Parties, three groups of countries can be distinguished according to the level of their commitments<sup>1</sup>:

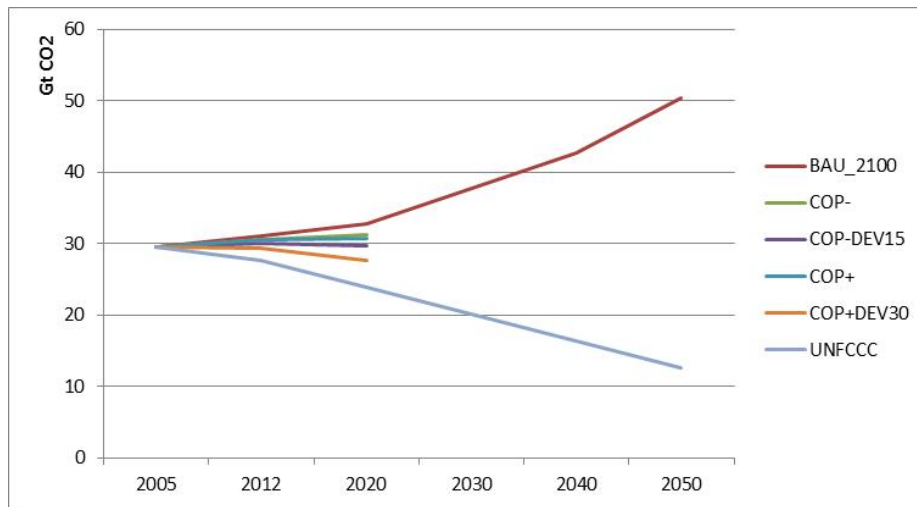
- The "industrialized countries" (**IC**), who are committed to absolute emission reduction targets (Europe, USA, etc.).
- The "fast-growing countries" (**FDC**), who are committed to relative targets (e.g. in relation to their level of growth as China and India).
- The "developing countries" (**DC**), which for some implement national actions, others support the establishment of a future agreement but do not initiate action, and generally are not committed not a target of mitigation, such as Africa, for example (excluded South Africa).

In 2005, industrialized countries represented 48% of the world GHG emissions against 25% for fast developing countries and 27% for developing countries. The latter are thus not constrained by a commitment to reduce emissions of greenhouse gas emissions but, given the commitments of developed countries and fast developing countries, it is unlikely to achieve the ultimate objective of UNFCCC to limit the increase in global temperature to 2°C without their participation as highlights the figure 3. Indeed, while 30 Gt of CO<sub>2</sub> were emitted in 2005, a climate safe pathway (in line with the 2°C objective) implies a level of emissions to 24 Gt in 2020 (*scenario UNFCCC*) and so, a decrease of 9 Gt of CO<sub>2</sub> if we consider the level of emissions in 2020 in the *BAU scenario* and, a decrease of 6 Gt of CO<sub>2</sub> by comparison with 2005. However, if we consider the lowest commitments pledged by

---

<sup>1</sup> More precisely, considering the political ambitions of the parties, five groups of countries could be distinguished : 1) Absolute commitments (industrialized countries: past, present and future responsables for the high level of CO<sub>2</sub> atmospheric concentration); 2) Relative commitments (generally fast developing countries: present and future responsables); 3) Political actions and support to a global agreement (developing countries: essentially future responsables); 4) Support without action (61 countries, essentially least advanced and supporting the highest climate change consequences); 5) No association or no communication (51 countries, a majority of oil-producing countries).

parties, CO<sub>2</sub> emissions still increase and reach more than 31 Gt in 2020. The highest commitments pledges by parties allow a relative stabilization in 2020 of the level of CO<sub>2</sub> emission by comparison with 2005.



**Figure 3: CO<sub>2</sub> emissions in COP and UNFCCC scenarios (Gt CO<sub>2</sub>)**

Considering a contribution of developing countries as recommended by IPCC, in other words a reduction between 15% and 30% by 2020 by comparison with BAU (IPCC, 2007; den Elzen and Höhne, 2008), the level of CO<sub>2</sub> emission is not yet reduced enough. In the *COP-DEV15* scenario, CO<sub>2</sub> emissions are almost stabilized in 2020 at 2005 levels and they decrease by 2 Gt by comparison with 2005 in the *COP+DEV30* scenario. Compared with the *BAU 2020* level of emissions, 2.9 Gt of CO<sub>2</sub> are avoided in the world in *COP-DEV15* and 5 Gt of CO<sub>2</sub> in the *COP+DEV30* scenario (Figure 4).

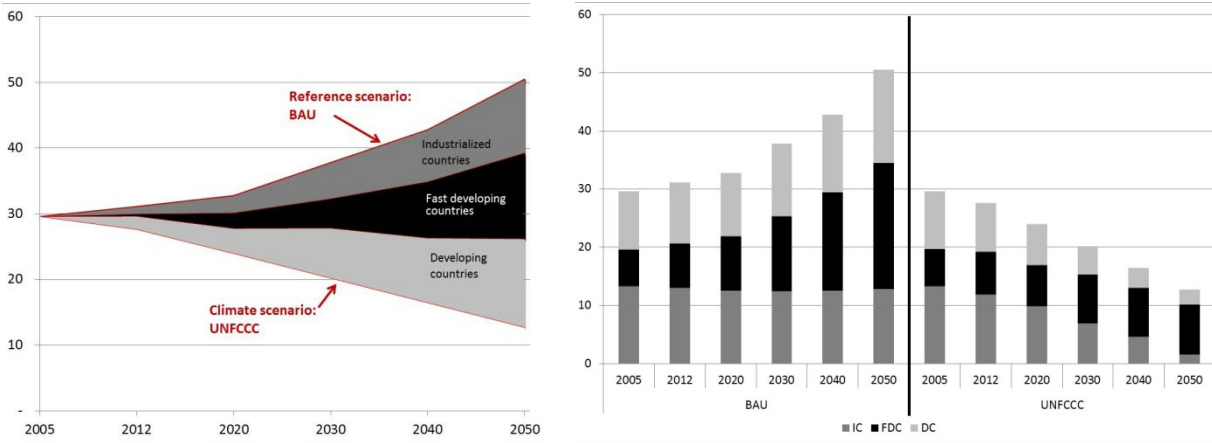
| Scenario  | Industrialized |          | Fast developing |          | Developing |          | World    |          |
|-----------|----------------|----------|-----------------|----------|------------|----------|----------|----------|
|           | BAU 2005       | BAU 2020 | BAU 2005        | BAU 2020 | BAU 2005   | BAU 2020 | BAU 2005 | BAU 2020 |
| COP-      | -2.1           | -1.3     | +3              | -0.002   | +0.7       | -0.3     | +1.6     | -1.6     |
| COP-DEV15 | -2.1           | -1.3     | +3              | -0.01    | -0.7       | -1.6     | +0.2     | -2.9     |
| COP+      | -2.5           | -1.8     | +3              | -0.05    | +0.7       | -0.3     | +1.2     | -2       |
| COP+DEV30 | -2.5           | -1.8     | +3              | +0.06    | -2.3       | -3.3     | -1.8     | -5       |
| UNFCCC    | -3.4           | -2.6     | +0.7            | -2.4     | -2.9       | -3.8     | -5.6     | -8.8     |

**Figure 4: CO<sub>2</sub> emissions evolution in 2020 by climate scenario and by group of regions, compared with the 2005 and 2020 CO<sub>2</sub> emission level in the BAU scenario**

It is interesting to note two major facts. First, as previously stated, the commitments pledged by countries appear too low by comparison with the required level of decrease in order to stay in line with the 2°C target. Second, in the *UNFCCC* scenario, the main contributors, if we consider the less costly approach, are industrialized countries with a reduction of CO<sub>2</sub> emission in 2020 by 3.4 Gt by comparison with 2005, followed by developing countries with a reduction of 2.9 Gt of CO<sub>2</sub> in 2020 compared with the 2005 level. But considering the *BAU* level in 2020, developing countries become the main contributors to the CO<sub>2</sub> mitigation effort with 3.8 Gt of avoided CO<sub>2</sub> against 2.6 Gt from industrialized countries. The weight of the constraint on developing countries is even more important, compared to industrialized countries, in the *COP+DEV30* scenario. The main contributors are also developing countries in the *COP-DEV15* scenario if we consider the level of CO<sub>2</sub> in 2020 by

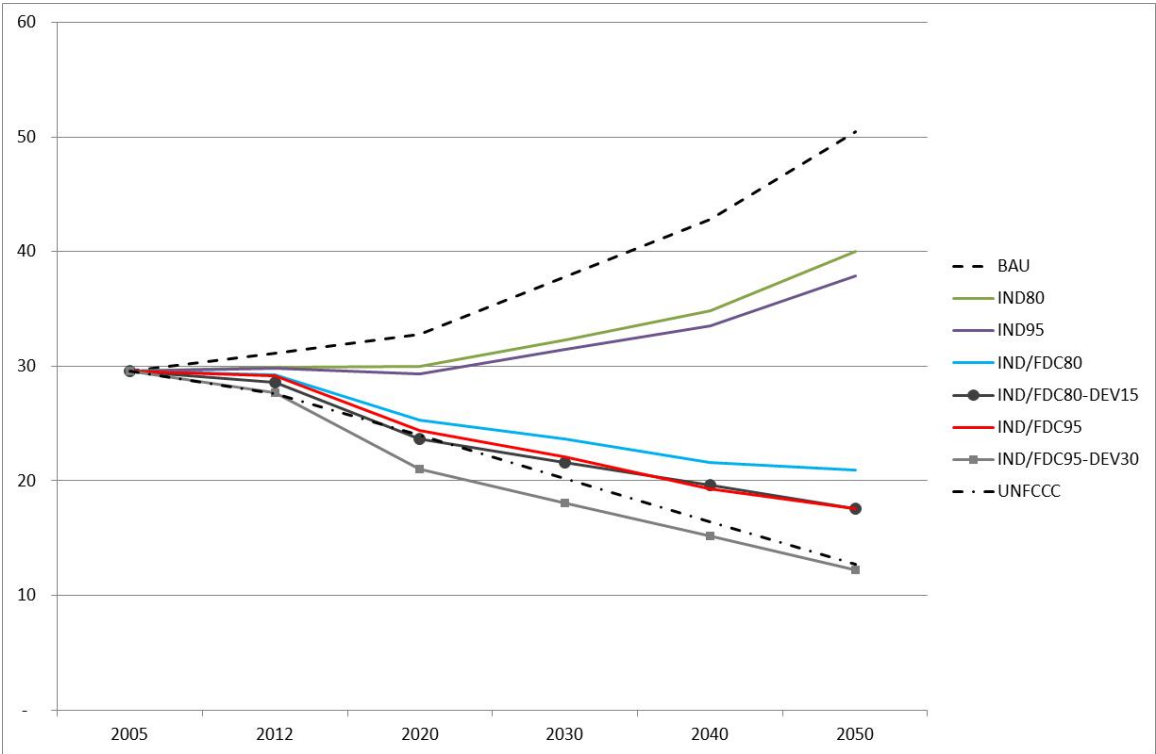


comparison with the BAU level. This questions the fair determination of the contribution by developing countries. Their participation is essential to reach an ambitious target but industrialized and fast developing countries must assume their responsibility for CO<sub>2</sub> emissions and contribute to the height of their ability. Especially, considering the fact that in 2050, contributions to the fight against the climate change, in terms of CO<sub>2</sub> mitigation, appears almost equally distributed by groups of countries in the UNFCCC scenario (Figure 5).



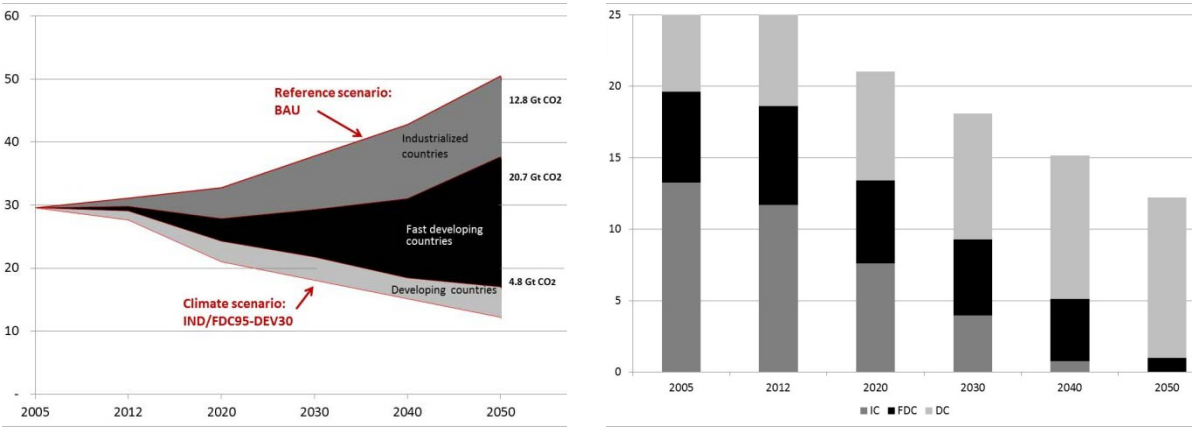
**Figure 5: Contribution by group of countries to the CO<sub>2</sub> mitigation effort in the UNFCCC and BAU scenarios (Gt CO<sub>2</sub>)**

What is the situation in the long-term? Consider the long-term scenarios of regional objectives by 2050, implemented according to international convergence and expressed ambitions.



**Figure 6: CO<sub>2</sub> emissions in long-term regional scenarios (Gt CO<sub>2</sub>)**

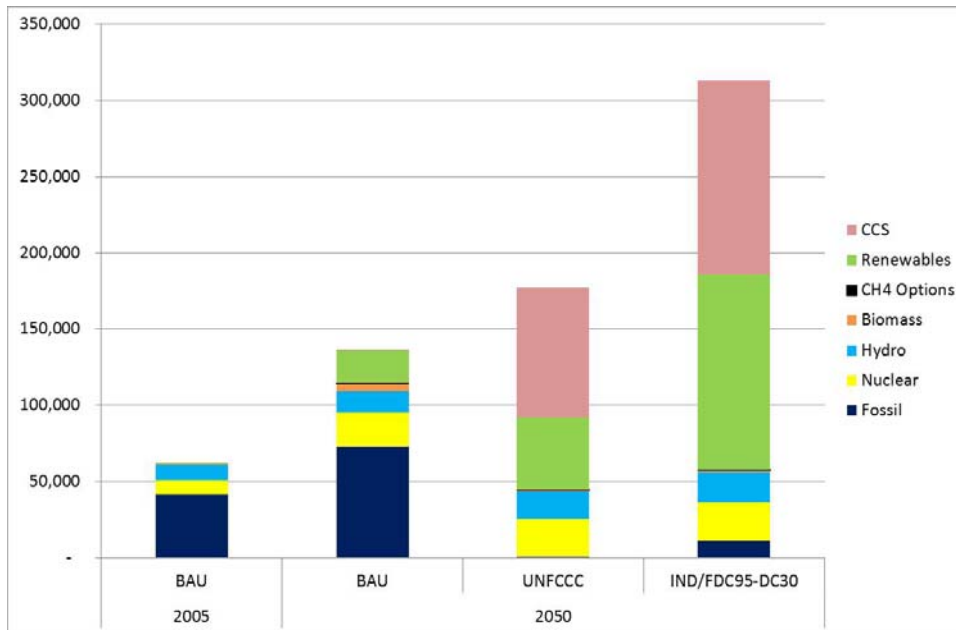
The aim of the next negotiations between Parties until the Twenty-first Conference of Parties (COP 21) which will be held in Paris in 2015 is to reach an international agreement involving as many countries as possible, in order to reduce CO<sub>2</sub> emissions sufficiently and stay in line with the ultimate 2°C objective of the UNFCCC. As highlights the Figure 6 and confirming the previous mid-term results, to be ambitious, the future climate regime cannot only be based on industrialized countries (*IND80* and *IND95*), nor on the latter associated with the fast developing countries, even if their joint commitments are particularly strong as in the *IND/FDC95* scenario with a 95% reduction of their CO<sub>2</sub> emissions by 2050 compared with 2005 level. The UNFCCC objective is reached in the very constrained case implemented in the *IND/FDC95-DEV30* scenario where developing countries contribute to the climate policy of CO<sub>2</sub> mitigation with a CO<sub>2</sub> emission reduction commitment of 30% to 2050 compared to their *business as usual* 2050 level. It is interested to note that *IND/FDC80-DEV15* and *IND/FDC95* follow almost the same trajectory of CO<sub>2</sub> emission decrease. This induces the fact that the mitigation constraint of industrialized and fast developing countries can be released with the participation of developing countries. However, this should not encourage industrialized and fast developing countries to reduce their ambition and not assume their responsibility in climate change.



**Figure 7: Contribution by group of countries to the CO<sub>2</sub> mitigation effort in the IND/FDC95-DEV30 scenario (Gt CO<sub>2</sub>)**

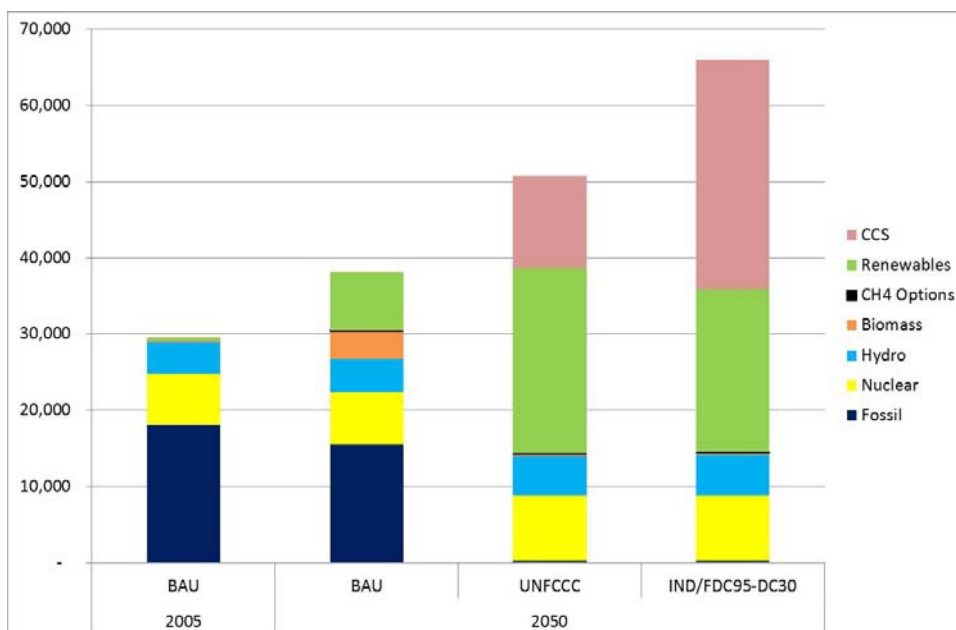
It clearly appears that the contribution of CO<sub>2</sub> reduction, in this case, is particularly supported by fast developing countries, i.e. China and India. From 10 Gt of emitted CO<sub>2</sub> in 2005, developing countries should to limit the increase of their CO<sub>2</sub> emissions in 2050 to 11 Gt in the *IND/FDC95-DEV30* scenario, against 16 Gt in the *BAU* scenario. Even if the CO<sub>2</sub> emission reduction from fast developing countries is more important than the one from industrialized countries, 21 Gt of avoided reduction for FDC in 2050 by comparison with the 2050 BAU level against 13 Gt for IC, it is important to consider the fact that the energy system of the latter has to be completely carbon-free in 2050 in this climate scenario.

Indeed, emission reduction is achieved through technology and fuel substitutions. The optimization results are notably the structure of the energy system, i.e. type and capacity of the energy technologies for example. In 2005, in *BAU* scenario, the world power mix is dominated by fossil fuels, followed by nuclear and hydro, with respectively 66%, 16% and 11% of the electricity generation. Renewables represents less than 2% of the world production. Their share increases in 2050 to 20% in the *BAU* scenario to the detriment of fossil (54%) and hydro (10%), even if their level increases in 2050. The role of nuclear power remains stable on the time horizon (Figure 8).



**Figure 8: World electricity production in 2005 and 2050 in BAU, UNFCCC and IND/FDC95-DEV30 scenarios (PJ)**

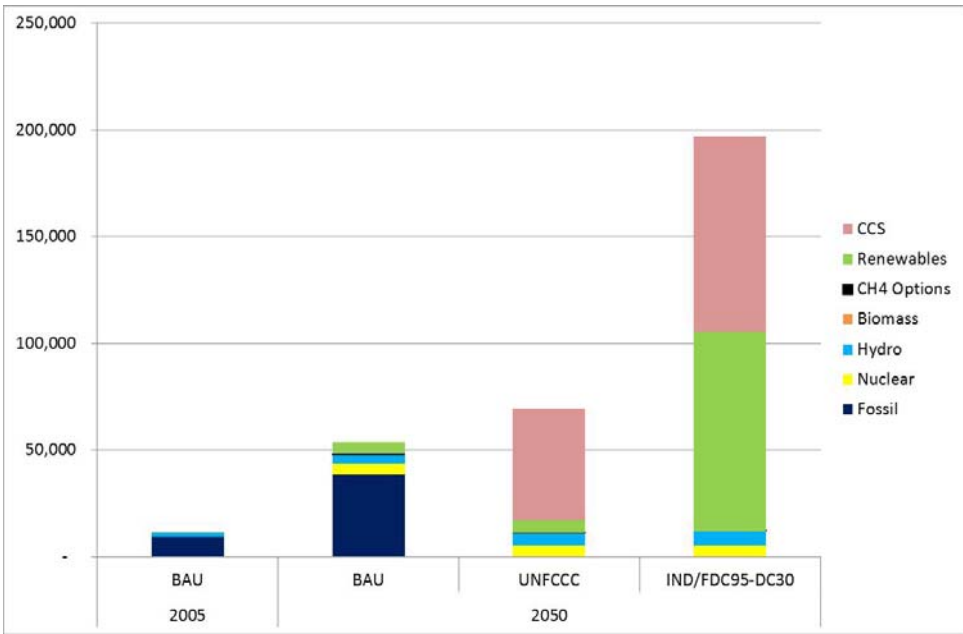
In 2050, in climate scenarios, electricity based on fossil fuel drastically decrease in favor of renewables and CCS (carbon capture and storage). Renewables represent 28% and 41% of the power generation in *UNFCCC* and *IND/FDC95-DEV30* scenarios respectively and CCS, 48% and 41% respectively. It is interesting to note the fact that, even if in 2050 the level of CO<sub>2</sub> emission is the same in *UNFCCC* and *IND/FDC95-DEV30* scenarios, the electricity mix clearly appears different. This is due to, of course, the initial structure of the regional energy system and the distribution of the contribution to the CO<sub>2</sub> emissions mitigation.



**Figure 9: Electricity production in 2005 and 2050 in BAU, UNFCCC and IND/FDC95-DEV30 scenarios (PJ), in industrialized countries**

In industrialized countries, fossil based electricity is replaced by CCS and renewables (Figure 9). Even if the hydro and nuclear electricity increases by 2050, their shares decreases in the power mix with, respectively in UNFCCC and IND/FDC95-DEV30, 17% and 13% for nuclear and 10% and 8% for hydroelectricity. The higher is the climate constraint, the higher is the development of CCS. In both case renewables are deployed. The competition between low-carbon options is then between renewables and CCS.

In UNFCCC scenario, renewables represents 48% of the power generation of Industrialized countries, and in IND/FDC95-DEV30, 47% of the one of fast developing countries (Figure 10) including geothermal, wind and solar and then, intermittent solutions. This large penetration of intermittent options raises the question of the reliability of the network and of the needed large investment in storage technologies.

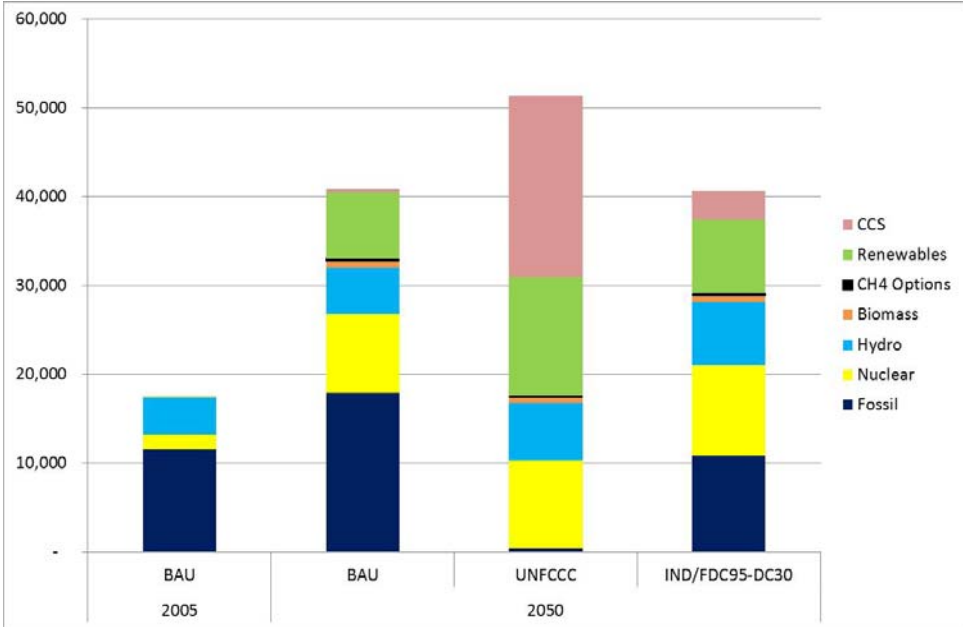


**Figure 10: Electricity production in 2005 and 2050 in BAU, UNFCCC and IND/FDC95-DEV30 scenarios (PJ), in fast developing countries**

The first considered option in fast developing countries, i.e. China and India in this study, is the CCS development. This can be explained by the importance of fossil power plants, and particularly coal plants in China. In IND/FDC95-DEV30 scenario where the contribution to carbon mitigation is particularly important, investment in the deployment of CCS is no longer sufficient and renewables are expected to be largely developed. In UNFCCC scenario, the power production by plants with carbon capture technology represents 75% of the total electricity generation. Note that these power plants are not only based on fossil fuel but also on biomass. This allows benefit from negative emissions, the biomass combustion being considered as neutral. In IND/FDC95-DEV30 scenario, the power production by plants with carbon capture technology represents 47% of the total electricity generation, the same as the renewables production of electricity.

Note that the higher level of electricity production in the climate scenarios can be explained by a substitution between fossil fuels and electricity in other sectors, like transport.

In developing countries (Figure 11), the power mix is dominated by fossil, 66%, and hydro, 24%, in 2005 in the BAU scenario. In 2050, in UNFCCC scenarios where the weight of the climate constraint is high, electricity based on fossil fuel drastically decrease (representing only 1% of the power mix) in favor of CCS (40%), renewables (26%). Nuclear represents 19% of the electricity production but this level is similar to that in BAU scenario in the same period.



**Figure 11: Electricity production in 2005 and 2050 in BAU, UNFCCC and IND/FDC95-DEV30 scenarios (PJ), in developing countries**

In IND/FDC95-DEV30 scenario, the power mix is similar to that of the BAU scenario. Fossil fuels still dominates the mix, although their share represents only 27% in IND/FDC95-DEV30 scenario (against 44% in BAU), followed by nuclear with respectively 25 and 22%. The climate constraint, less strong than in UNFCCC scenario, involves an increase of hydroelectricity, the use of CCS, but in a lesser extent than in UNFCCC with 8% of power generation, and a larger development of renewables. The portfolio of developed options to meet the climate challenge appears more diversified and in a more plausible extent in terms of achievement. But for that, the challenge is considerable for other regions as fast developing countries and the solutions needed to develop in order to reach an ambitious target staying in line with the 2°C objective are still in challenging state, especially in this extent of development.

**Conclusion**

The previously cited scenarios are analyzed to explore the effects of a possible international coordination on main environmental and economic indicators. The impacts of different commitment levels under post-Copenhagen and/or global long-term climate policies can thereby be discussed and provide some understanding on the stakes and issues. The main focus is, in a first part, on the ambition of the various climate policies regarding CO2 emissions at global and regional level. In a second part, we discuss the impact of international climate change strategies to the energy system, and particularly on the electricity generation. In this context, discussions investigate long-term

solutions, such as the development of CCS technologies or renewables, in response to a constraint that influences the energy mix. The aim is to assess the plausibility of its fulfillment and to highlight the challenges, as the storage question.

A strong climate policy in line with the 2°C objective (representing the UNFCCC consensus) requires a global contribution, whether countries are industrialized or developing, or especially fast developing or emerging. After many years of discussion, ambitious targets require commitment to meet the recommended 2°C limitation in temperature increases. However, it is primarily up to industrialized countries to keep their promise of helping countries develop a record of adapting to the impacts of climate change, and nothing is certain as regards the possible level of CO<sub>2</sub> emission reduction that developing countries will be able to attain or, even, accept to reduce. In terms of cost, a larger contribution from developing countries is less expensive than strong emission mitigation in industrialized countries, as expressed by the decision to allow flexible mechanisms under the Kyoto Protocol (i.e. develop GHG emissions mitigation projects where the carbon abatement cost can be lower). But this is not sufficient. Could we reach an ambitious, and necessary, climate target without the participation of developing countries? The results highlights the fact that, no, this is not possible. However, do developing countries have the capacity to implement policies to reduce emissions given that their priority is development and energy supply? What are the technological possibilities considering the state of development of their energy systems and the evolution of their needs? CCS and renewables appears as low-carbon solutions but a strong climate constraint requires a high (too high) level of deployment. In addition, the carbon having to be sequestered, the question arises sites and more specifically their potential, location (onshore, offshore), transport (development of a network, strategy to pool resources, etc.), acceptability social due to possible risks of leaks, etc. So many questions that increase the list of challenges to solve. But with this, the climate challenge is also a political challenge to determine who and how high above, contribute to the reduction of CO<sub>2</sub> emissions.

A key feature of the Copenhagen agreement and of the future accord is the participation of the United States of America and non-Annex I countries, especially China, as they represent a large share of global CO<sub>2</sub> emissions. China and the USA are the largest global emitters of CO<sub>2</sub> and, as concerning developing countries, without their participation in a climate agreement the latter cannot really ensure achieving stabilized CO<sub>2</sub> concentration and global temperatures. Industrialized countries must provide tools and resources to meet the challenges. If they do not, developing countries, which are the most affected by climate change and the most vulnerable, will not be able to commit to reducing their own GHG emissions. However, it is imperative that these countries promptly consider such mitigation policies, especially China, India and Brazil, because in the near future they will represent the biggest share of global emissions. For example, in 2008 China surpassed Germany in terms of economic wealth, and the United States in terms of emissions of carbon dioxide (CO<sub>2</sub>). Indeed the impact of these countries' CO<sub>2</sub> mitigation targets on global CO<sub>2</sub> emissions is essentially long term.

So, at the end, no country can mitigate climate change on its own. International cooperation is needed to tackle the energy-climate problem. However, not only must countries act, but technological progress must also find an adequate response to countries' ambitions to expand the pool of available (or not) technologies and their mitigation potential. This not only concerns CCS

technologies, but also non-fossil energies, like wind, solar, biomass, etc. Thus the question of technological plausibility is also a critical factor for the future international climate regime.

## References

- Assoumou E., Maïzi N. (2011), "Carbon value dynamics for France: A key driver to support mitigation pledges at country scale", *Energy Policy*, Vol. 39, No. 7, pp.4325-4336.
- Bouckaert S., Selosse S., Dubreuil A., Assoumou E., Maïzi N. (2012), "Analyzing Water Supply in Future Energy Systems Using the TIMES Integrating Assessment Model (TIAM-FR)", *Journal of Systemics, Cybernetics and Informatics*, Vol. 10, No. 1, pp 89-94.
- den Elzen M. and Höhne N. (2008), "Reductions of greenhouse gas emissions in Annex I and non-Annex I countries for meeting concentration stabilisation targets. An editorial comment", *Climatic Change*, Vol. 91, pp.249-274.
- den Elzen, M.G.J., Hof, A.F., Roelfsema, M. (2011), "The emissions gap between the Copenhagen pledges and the 2°C climate goal: Options for closing risks that could widen the gap", *Global Environmental Change*, 21, 733-743.
- den Elzen, M.G.J., Hof, A.F., Roelfsema, M. (2013), "Analysing the greenhouse gas emission reductions of the mitigation action plans by non-Annex I countries by 2020", *Energy Policy*, 56, pp. 633-643.
- Dubreuil A., Assoumou E., Bouckaert S., Selosse S., Maïzi N. (2013), "Water modeling in an energy optimization framework - The water-scarce middle east context", *Applied Energy*, Vol. 101, No.33, pp. 268-279.
- Hof, A.F., Den Elzen, M.G.J., Roelfsema, M. (2013), "The effect of updated pledges and business-as-usual projections, and new agreed rules on expected global greenhouse gas emissions in 2020", *Environmental Science and Policy* 33, 308-319.
- IPCC (Intergovernmental Panel on Climate Change) (2007), *Climate Change 2007, Fourth Assessment Report (AR4)* Cambridge University Press, Cambridge.
- Krey, V., Riahi, K. (2009), "Implications of delayed participation and technology failure for the feasibility, costs, and likelihood of staying below temperature targets—Greenhouse gas mitigation scenarios for the 21st century", *Energy Economics*, 31: S94-S106.
- Loulou, R. and Labriet, M. (2008), "ETSAP-TIAM: the TIMES integrated assessment model. Part I: Model structure", *CMS*, 5, 7-40.
- Peterson, E.B., Schleich, J., Duscha, V. (2011), "Environmental and economic effects of the Copenhagen pledges and more ambitious emission reduction targets", *Energy Policy*, 39, 3697–3708.
- Remme U. and Blesl M. (2008), "A global perspective to achieve a low-carbon society (LCS): scenario analysis with the ETSAP-TIAM model", *Climate Policy*; Vol. 8, pp.60-75.

Ricci O., Selosse S. (2013), "Global and regional potential for bioelectricity with carbon capture and storage", *Energy Policy*, Vol. 52, No 61, pp 689-698.

Ricci O., Selosse S. (2013), "Regional impacts of post Copenhagen emission reduction pledges: prospective analysis with TIAM-FR", *Economics Bulletin*, Vol. 33, No. 1, pp. 764-77.

Selosse S., Assoumou E., Maïzi N. and Mazauric V. (2010), "Post-Kyoto policy implications on the energy system: A TIAM-FR long term planning exercise", 22<sup>nd</sup> World Energy Congress, Montreal, Canada, proceeding n°366.

Selosse S., Ricci O., Maïzi N. (2013), "Fukushima's impact on the European power sector: The key role of CCS technologies", *Energy Economics*, Vol. 39, September, pp. 305-312.

van Vliet, J., van den Berg M., Schaeffer M., van Vuuren D. P., den Elzen M., Hof A. F., Mendoza Beltran A. and Meinshausen M. (2012), "Copenhagen Accord Pledges imply higher costs for staying below 2°C warming", *Climatic Change*, 113, 551-561.