CCS development for a low carbon future

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Abstract

Giving the challenge of mitigating the effects of climate change and so reducing carbon emissions, this study highlights the possible technological trajectories in a future climate regime and particularly the role of carbon capture and storage. This research is developed with TIAM-FR, a bottom-up optimization model describing the world energy system expressed by regions and sectors in great detail of current and future technologies.

Keywords – **Energy system, Long-term modeling, Technological choices, Climate policy, CCS.**

I. INTRODUCTION

Challenges for energy and climate change involve evolution of the world energy system, especially of the technological mix permitting to satisfy the energy demands. Over the past decade and while in May 2013 CO_2 concentration in the atmosphere reached the symbolic record high of 400 ppm, Carbon Capture and Storage (CCS) has increasingly been dealt as a possible, not to say an expected, solution to achieve CO_2 emissions mitigation objectives and switch to a low-carbon system. Indeed, despite of persistent controversies, in terms of i) a significant and uncertain costs that this technology requires, ii) a too low level of investment and progress as regards a plausible large scale deployment of the technology but also of infrastructures (i.e. transport, shared platform, for example), iii) support of incentives by comparison with other options, as renewables, or iv) the risks of storage for environment and human health that question the social acceptability and the appropriate place of CCS within the portfolio of GHG abatement strategies, CCS technologies are still presented as a solution to reach ambitious climate target. For example, in the 2DS scenario of IEA [1], CCS contributes for 14 % of annual CO_2 emissions reduction between 6DS and 2DS scenarios. So achieving the 2DS (limiting average global temperature increase to 2°C) will require contributions from all sectors and application of a portfolio of technologies such as renewables or CCS. It is true that CCS is the only technology that can capture at least 90% of the emissions from the world's largest CO_2 emitters. This is particularly important in a world where coal and gas are not yet an outdated and disappearing sources of energy. The aim of this study is to analyze different paths of CO_2 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_2 mitigation targets in line with, on the one hand, an ambitious global target by 2050 according to the UNFCCC ultimate objective

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(limiting the global increase in temperature to 2°C) and, on the other hand, the IPCC recommendations (AR4 and AR5) [1] and regional assumptions by 2050 according to the group of countries (industrialized, fast developing or developing). These scenarios provide a framework for understanding the climate context of the future regime which is expected to be decided in 2015 (COP 21 in Paris). Our analysis mainly focuses on the effects of these environmental constraints on global and regional CO_2 emissions and the evolution of the energy system with particularly the development of CCS technologies.

II. MODELING APPROACH

In the database of IPCC, 55 models were identified and classified in 5 main families as Figure 1 shows [2]. These energy models follow particularly two approaches: top-down and bottom-up (without considering the most recent development of hybrid models). These two types of models tend to produce different outcomes for the same problem, because they handle various manners; inter alia, the adoption of technologies and the decision-making behavior of economic agents. Top-down models use aggregated data in order to examine interactions between the energy sector and other sectors of the economy, and to analyse the overall macroeconomic performance of the economy. This is done by endogenizing behavioral relationships, and this past behaviour can be extrapolated into the future, which makes top-down models suitable for predictive purposes on the short and long term.

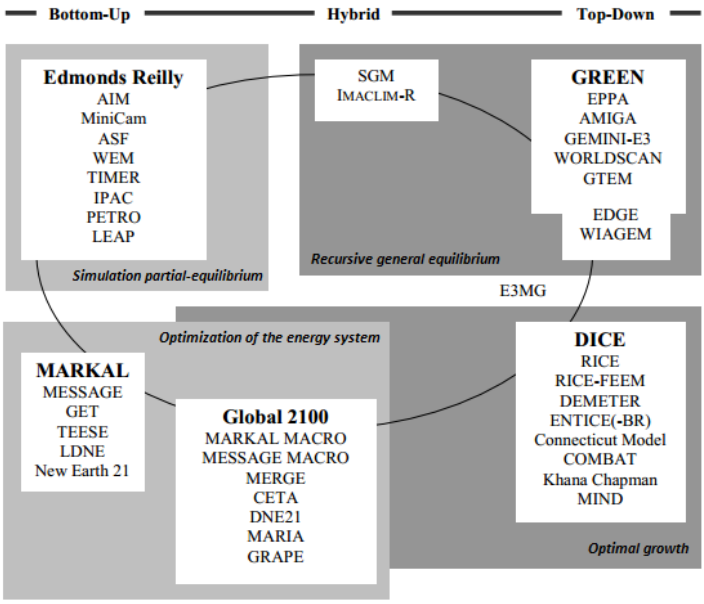


Fig.1, Landscape of the models in the IPCC database (ibid.)

On the contrary, bottom-up models usually focus on the energy sector exclusively, and use highly disaggregated data to describe energy end-uses and technological options in detail. Thanks to these models, we can make forward-looking energy scenarios to explore pathways of possible futures. The optimization model TIAM-FR is one of these bottom-up models, for an “engineering approach”. More precisely, TIAM-FR is the French version of the *TIMES Integrated Assessment Model*, the global multiregional model from the TIMES family models. The generator of model TIMES (an acronym of "The Integrated MARKAL-EFOM System") was developed by ETSAP (*Energy Technology Systems Analysis Program*), under the aegis of the International Energy Agency (IEA). TIMES, the successor of two bottom-up energy models MARKAL and EFOM, was developed by combining the peculiarities of each of these models, and by coming to bring new specificities such as a module climate or a representation of the technologies with flexible inputs/outputs.

TIAM-FR is based on a detailed description of energy transformation technologies, allowing supplying an estimation of the dynamics of the long-term sector. The model incorporates all the chain of the energy process by taking into account extraction, refining, conversion, transmission, distribution and end-uses. Moreover, 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 optimization problem formulation in TIMES models consists of three types of entities [3]: (1) decision variables: endogenous quantities to be determined by the optimization; (2) objective function: express the criterion to be minimized or maximized, and (3) constraints: equations or inequalities involving the decision variables that must be satisfied by the optimal solution. 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 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 (Fig.2). Each economic sector is described by means of technologies, each characterized by its economic and technological parameters [4].

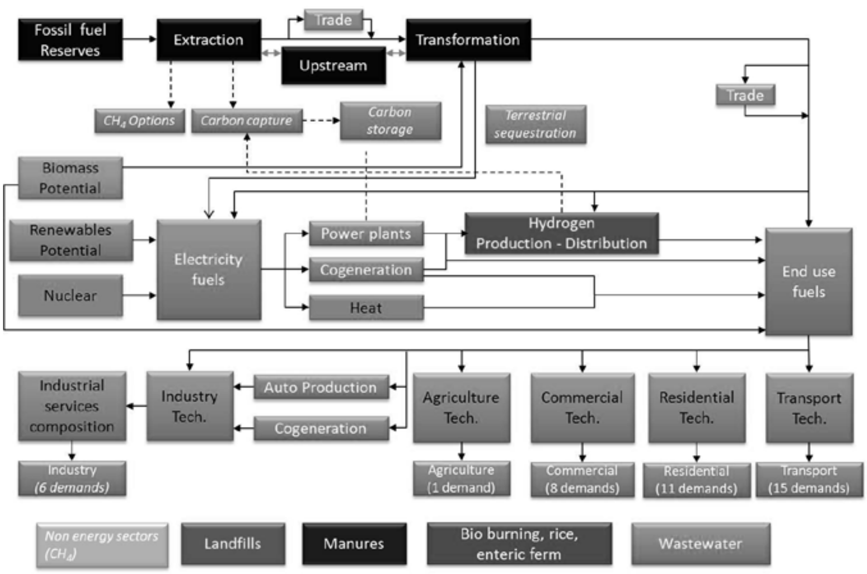


Fig.2, Synthetic view of the reference energy system (RES)

TIAM-FR is geographically integrated and offers a representation of the world energy system under a 15 regions disaggregation: 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. In this analysis, three groups of countries/regions are distinguished according to their level of development and their growth:

1. Industrialized countries – **IC**: AUS, CAN, EEU, JPN, USA and WEU;
2. Fast developing countries – **FDC**: CHI and IND;
3. Developing countries – **DC**: AFR, CSA, FSU, MEX, MEA, ODA and SKO.

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_2, CH_4, and N_2O 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_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.

III. Climate Analysis

In late January 2010, at the end of the fifteenth Conference of the Parties (UNFCCC - COP 15), some countries pledged their commitment to the United Nations Framework Convention on Climate Change as part of the Copenhagen Agreement to mitigate GHG 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. 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_2 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. Tackling the problem of global climate change requires a high level of international cooperation. After decades of negotiations, the challenge is (once again) to get countries to converge towards a global, multilateral agreement to keep their sights on the ambitious targets to limit GHG emissions. This is the ultimate aim of the Conference of Parties due to take place in Paris in 2015 (COP 21). Even though the deadline for the implementation of this agreement is imminent, we propose to discuss the key points of these ambitious objectives for 2015 and provide a framework for understanding the future climate regime that has to be decided. In order to analyze possible alternative development paths of the system and discuss the future climate regime, we investigated in this study two environmental target scenarios on different regions of the world over the period 2005-2050. A baseline Business as Usual (BAU) scenario without any emission constraints was first calculated. 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. The first climate scenario is a global scenario compatible with the UNFCCC ultimate objective of limiting temperature change to 2°C, where all countries are involved to contribute to this global mitigation target. The second climate scenario is based on assumptions on the 2050 targets based on each country's announced political ambitions, expected ambitions or required contributions [5]. So, more precisely:

1. **BAU**: World reference scenario without any explicit policy measures on GHG mitigation;

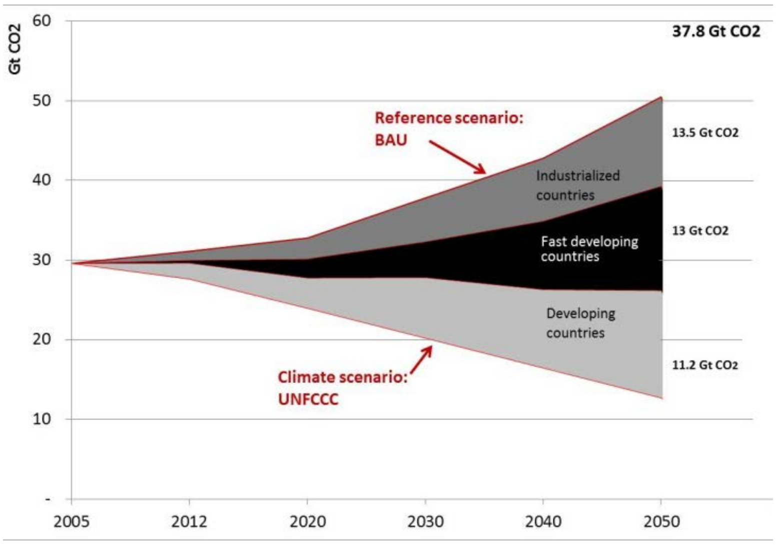
2. **UNFCCC**: World climate scenario in line with limiting temperature change to 2°C in 2100, i.e. a 50% reduction of the world CO_2 emissions by 2050 by comparison with 2000 [1];

3. **IND/FDC95-DEV30**: with an optimistic GHG emission reduction commitment to 2050 for industrialized countries (**IC**) and fast developing countries (**FDC**), i.e. a 95% reduction of their CO_2 emissions by 2050 by comparison with 2000, and with a CO_2 emission reduction commitment of 30% to 2050 compared to a business as usual scenario for developing countries (**DC**).

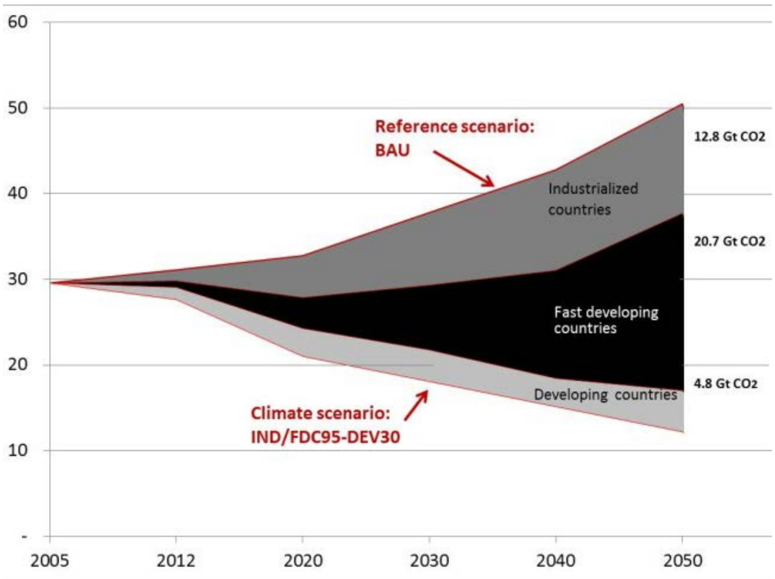
In the *UNFCCC* scenario, the main contributors in 2050[2] are IC with a reduction of their CO_2 emission in 2050 by 13.5 Gt by comparison with BAU, followed by FDC with a reduction of 13 Gt and by DC with 11.2 Gt of avoided CO_2.

Contributions to the fight against the climate change, in terms of CO_2 mitigation, appear almost equally distributed by groups of countries in the *UNFCCC* scenario. This questions the fair determination of the contribution by DC. Their participation is essential to reach an ambitious target but IC and FDC must assume their responsibility for CO_2 emissions and contribute to the height of their ability. The end-period UNFCCC objective is also reached in the other very constrained case implemented in the *IND/FDC95-DEV30* scenario where DC contribute to the climate policy of CO_2 mitigation with a CO_2 emission reduction commitment of 30% to 2050 compared to their *business as usual* 2050 level. It is interesting to note that in the *UNFCCC* scenario, the mitigation corresponds to a reduction by 84% of CO_2. In this case, the climate stress is transferred to FDC with a contribution of 20.7 Gt of avoided CO_2. This is also advantageous for IC, with a slightly reduced effort. But this also expresses that the flexibility of the IC countries is smaller due to structural reasons (their energy mix, etc.).

2 If we consider the less costly approach, TIAM-FR aiming to satisfy energy demand minimizing the total discounted cost of the system.



a) Between BAU and UNFCCC scenarios



b) Between BAU and IND/FDC95-DEV30 scenarios

Fig.3, Contributions to CO_2 emissions reduction by groups of countries

It clearly appears that the contribution of CO_2 reduction, in this case, is particularly supported by FDC. From 10 Gt of emitted CO_2 in 2005, DC should to limit the increase of their CO_2 emissions in 2050 to 11 Gt in the *IND/FDC95-DEV30* scenario, against 16 Gt in the *BAU* scenario. Even if the CO_2 emission reduction from FDC is more important than the one from IC, 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.

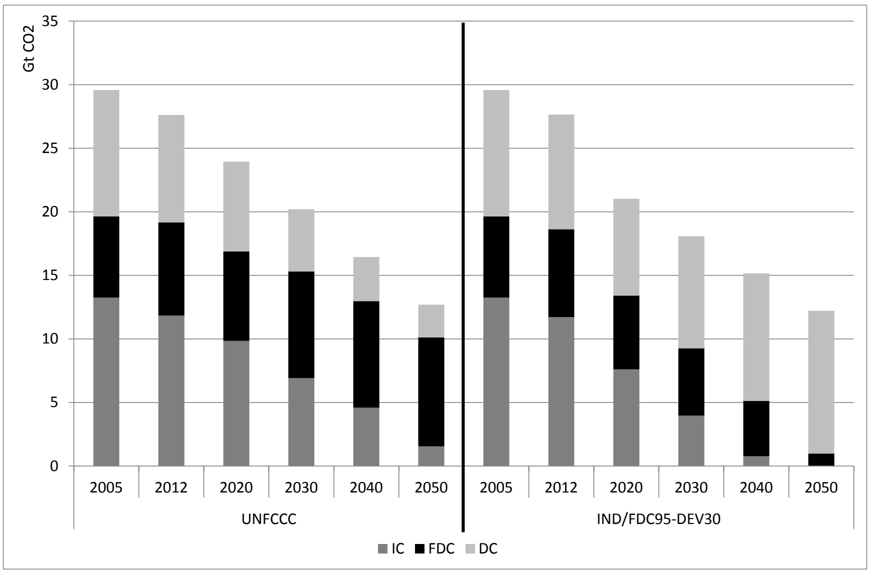


Fig.4, Evolution of CO_2 emissions reduction by groups of countries in UNFCCC and IND/FDC95-DEV30 scenarios

IV. THE DECISIVE ROLE OF THE CARBON CAPTURE AND STORAGE TECHNOLOGIES (CCS)

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. CCS technologies are still presented as a solution to reach ambitious climate target. The purpose of this analysis conducted in TIAM-FR is to estimate the CCS deployment in next decades, by considering the useful primary energy for the electricity production and the necessary storage capacity. 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%).

In 2050, in climate scenarios, electricity based on fossil fuel drastically decrease in favor of renewables and CCS (Fig.5). 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_2 emission is the same in *UNFCCC* and *IND/FDC95-DEV30* scenarios, the electricity mix clearly appears different.This is due to the initial structure of the regional energy system and the distribution of the contribution to the CO_2 emissions mitigation.

In IC, fossil based electricity is replaced by CCS and renewables. 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 competition between low-carbon options is then between renewables and CCS.

In FDC, the development of CCS technologies is very strong. This can be explained by the importance of fossil power plants, and particularly coal plants in China. In *UNFCCC* scenario, the power production by plants with carbon capture technologies represents 75% of the total electricity generation. While in the *IND/FDC95-DEV30* scenario the production with CCS represents 47% of the total electricity generation, because the contribution to carbon mitigation is particularly important.

In DC, the power mix is dominated by fossil (66%) and hydro (24%) in the BAU scenario in 2005. In *UNFCCC* scenario, electricity based on fossil fuel drastically decrease (only 1% of the power mix) in favor of CCS (40%) and renewables (26%). In *IND/FDC95-DEV30* scenario, where the climate constraint is less strong than in *UNFCCC* scenario, the CCS power generation represents just 8%. Fossil fuels, nuclear and hydro represent respectively 27, 25 and 22%.

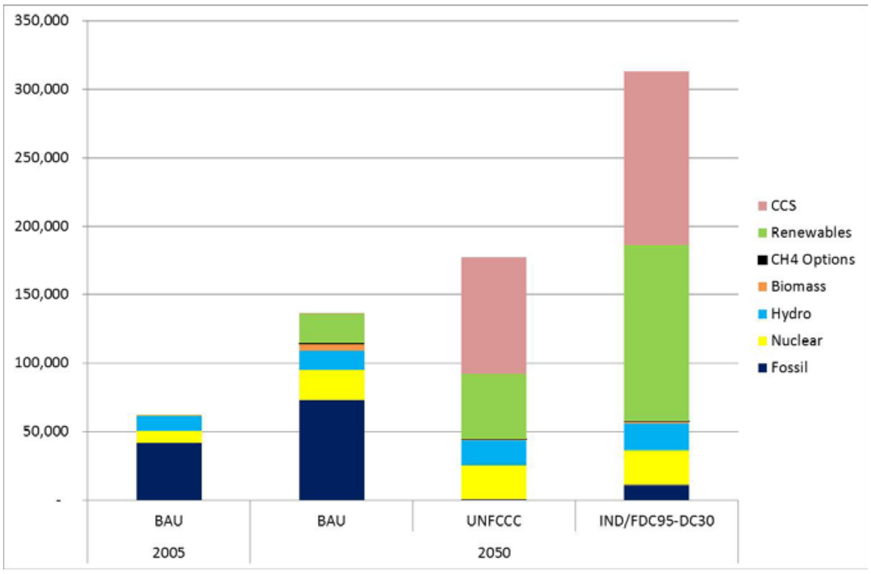


Fig.5, World electricity production in 2005 and 2050 in BAU, UNFCCC and IND/FDC95-DEV30 scenarios (PJ)

The Table 1 summarizes the part of CCS electricity in the power mix in 2050 for all scenarios. To sum up, the CCS development in FDC is very strong due to the importance of fossil power plants in these countries, particularly coal plants in China. The higher is the climate constraint, the higher is the development of CCS. IC are exceptions because the importance of fossil fuels is less strong than FDC, so renewables are expected to be largely developed.

TABLE 1, SHARE OF CCS IN THE POWER MIX IN 2050

% CCS	IC	FDC	DC
BAU	0	0	1
UNFCC	24	75	40
IND/FDC95-DC30	46	47	8

CCS technologies are presented as a decisive solution to reach ambitious climate target as shows the share in 2050 of CCS in the power mix in the table 1. The maintaining question is to know from which sources is generated electricity with carbon capture and storage? The Fig.6 brings us an overview on this interrogation.

First of all, it is interesting to note that the production of power plants with CCS is not only based on fossil fuel but also on biomass. In both scenarios, electricity generation by gas-fired power plants represents the biggest part of the total electricity generation with CCS. In *UNFCCC* scenario, it represents 83%, and 79% in *IND/FDC95-DEV30* scenario. Moreover, it is necessary to note that is a good economic point. Indeed, in the *Annual Energy Outlook 2014,* according to U.S. Energy Information Administration, the LCOE (Levelized Cost of Electricity) in 2019 of a natural gas-fired plant with CCS is 85.5 $/MWh, while it's 137.3 $/MWh for a coal plant with CCS.

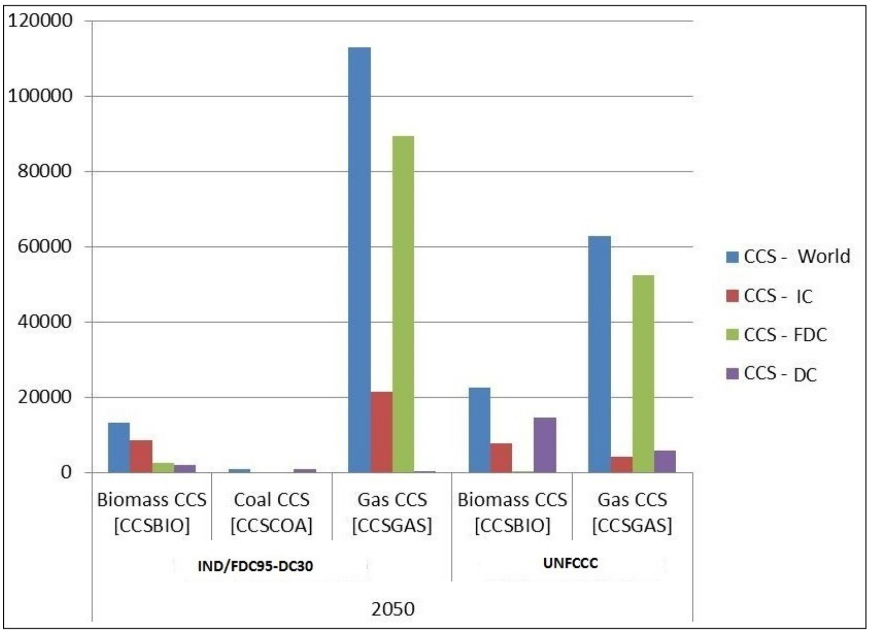


Fig.6, World electricity production with CCS in 2005 in UNFCCC and IND/FDC95-DEV30 scenarios (PJ)

It's normal to observe a biomass CCS development stronger for *UNFCCC* scenario than *IND/FDC95-DEV30* scenario, because the climate constraint of 50% reduction of the world CO_2 emissions by 2050 by comparison with 2000 is strong. This allows benefit from negative emissions, the biomass combustion being considered as neutral.

Even if carbon capture already works and has been clearly demonstrated at pilot scale, carbon dioxide is not currently captured at full commercial scale plants. More research to reduce the cost and for the next generations of technologies is required. There are currently three basic types of CO_2 capture: pre-combustion processes, post-combustion processes and oxyfuel with post-combustion.

We realized a finer study to determine which technology should be developed in the conditions of these two scenarios, and in which type of countries.

As we saw previously, the development of CCS technology associated with coal plants is tiny with regard to the other technologies (Fig.7). In *UNFCCC* scenario, there are two technologies which develop mainly, the Bio crop gasification with CCS and the Natural Gas Combined Cycle (NGCC) with CO_2 removal from flue gas, so post combustion processes. In *IND/FDC95-DEV30* scenario, NGCC with oxyfueling, i.e. use oxygen rather than air for combustion of fuel, is the other technology which is developed besides both quoted previously.

In FDC, where the development of CCS is very strong, CCS technologies with NGCC appear totally in front of biomass technologies. Furthermore, NGCC with oxyfueling explodes literally in *IND/FDC95-DEV30* scenario, thanks to a climate constraint less strong than *UNFCCC* scenario.

This study highlights the important role of CCS which currently is the only technology that can capture at least 90% of the emissions from the world's largest CO_2 emitters. Nevertheless the potential of deployment of CCS is highly connected to the potential of carbon storage, which makes the object of several studies, but also we can be interested in the primary energy required to answer these two scenarios.

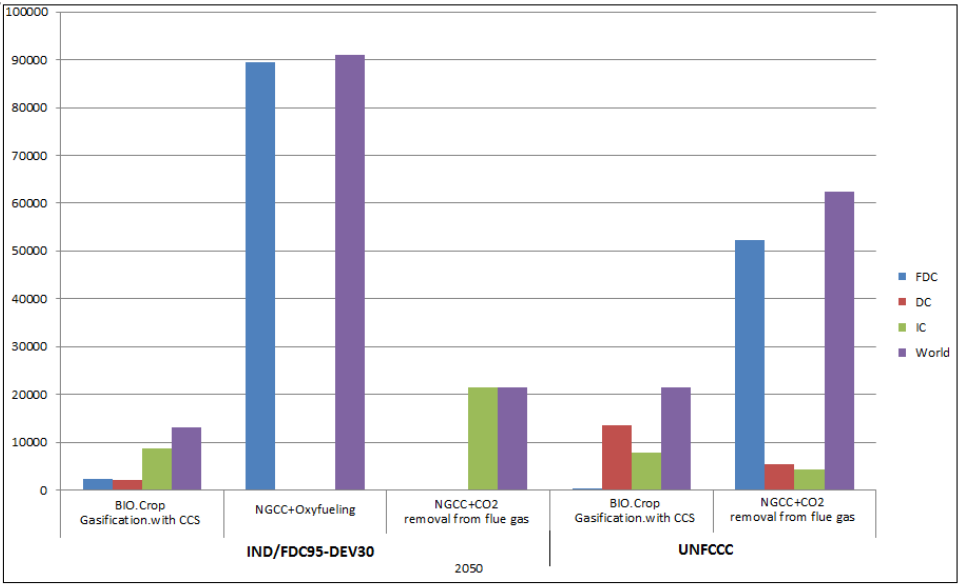
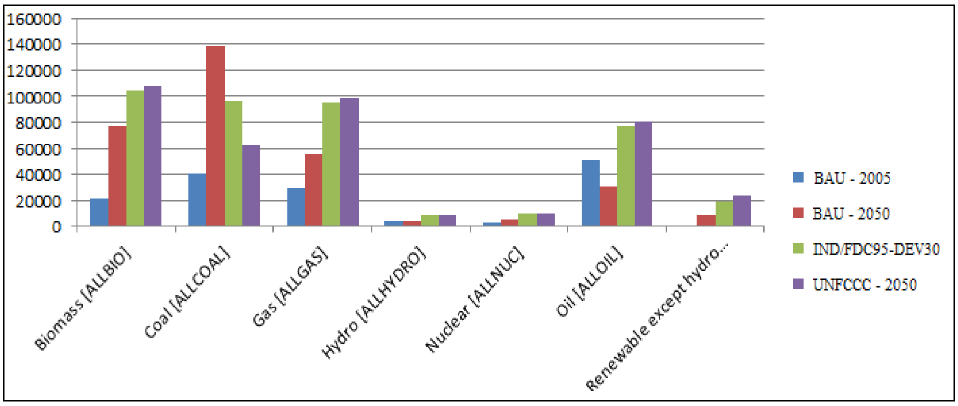


Fig.7, World electricity production with CCS technologies in 2005 in UNFCCC and IND/FDC95-DEV30 scenarios (PJ)

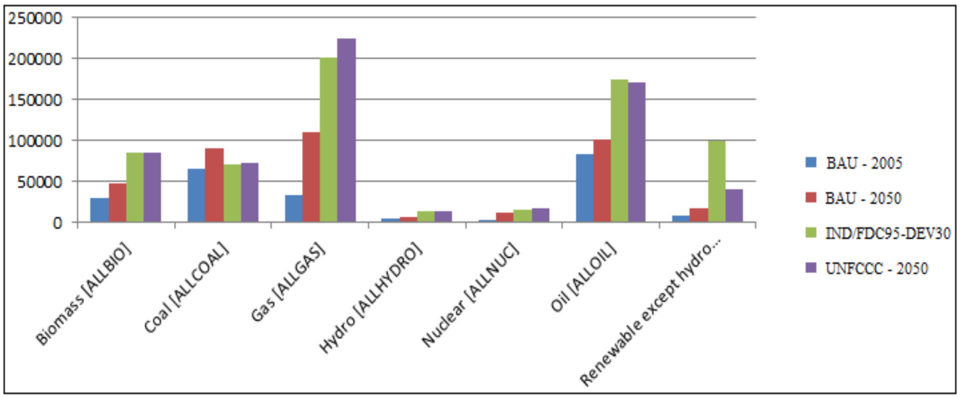
In industrialized countries, the explosion of the demand in primary energy for Biomass, Coal and Gas will be inevitable to be able to answer our increasing needs for energy without influence of the scenario. The demand in primary energy in oil should increase except for the BAU scenario. Concerning the demands in primary resources as hydraulic, nuclear power and renewables energies, they increase slightly in all scenarios with a little more for *UNFCCC* scenario. In BAU scenario, coal primary resource literally explodes in 2050, while they are the biomass and gas resources which benefit from the strong climatic constraint of *UNFCCC* and *IND/FDC95-DEV30* scenarios.

In developing countries, the demand in gas explodes in *UNFCCC* and *IND/FDC95-DEV30* scenarios, and to lesser extent in BAU scenario. In BAU scenario, the primary resources stay appreciably in the same level as on 2005, with a light increase nevertheless. It is interesting to note that the coal demand concerning *UNFCCC* and *IND/FDC95-DEV30* scenarios (and BAU) remains almost constant over the period, contrary in the other resources which increase more or less strongly.

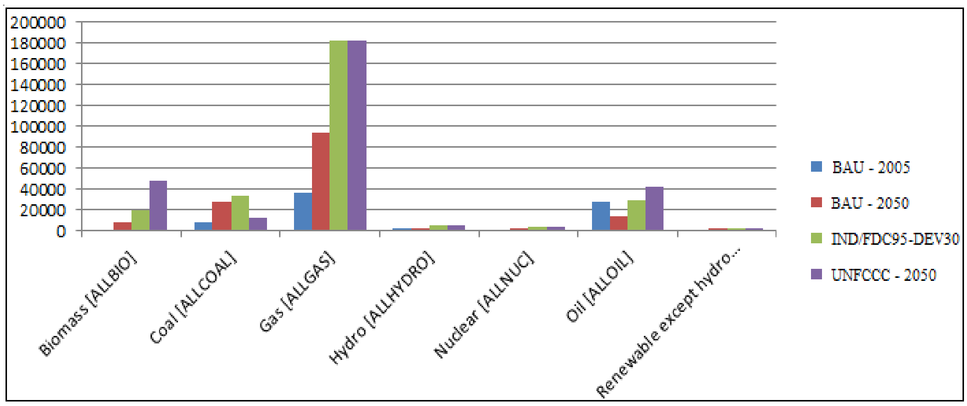
In fast developing countries, i.e. China and India, firstly, it’s surprising to notice that the coal demand is not exceptional in all scenarios. We can note as in developing countries, the explosion of demand in primary energy in gas resource, with a level reaching 180,000 PJ for *UNFCCC* and *IND/FDC95-DEV30* scenarios. Other resources progress a little like Biomass and Oil, whereas hydraulic power, nuclear and renewable energies stay with a sensitive level of 2005, rather low.



a) In industrialized countries



b) In developing countries



c) In fast developing countries

Fig.8, Primary energy in 2005 and 2050 in BAU, UNFCCC and IND/DEV95-DEV30 scenarios (PJ)

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.

V. CONCLUSION

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. 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_2 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? In this context, the USA stressed for example 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.

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_2 emissions sufficiently and stay in line with the ultimate 2°C objective of the UNFCCC. 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 CO_2 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. As highlights the results, to be ambitious, the future climate regime cannot only be based on industrialized countries, nor on the latter associated with the fast developing countries, even if their joint commitments are particularly strong 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 CO2 mitigation with a CO_2 emission reduction commitment of 30% to 2050 compared to their *business as usual* 2050 level. 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. Indeed, 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_2 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). 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?

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. 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_2 emissions.

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Les Cahiers de la Chaire

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