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Power system and Carbon capture under Climate policy: A water impact analysis with TIAM-FR

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1- Introduction

An increasing body of literature assesses the attainability of stringent CO_2 mitigation targets (e.g. van Vuuren *et al*., 2007), depending on a wide range of different reduction options, and the technology 'readiness' of advanced technologies, in particular the industrial scale of carbon capture and storage (CCS)and the combination of bio-energy, carbon capture and geologic storage (BECCS). Introducing CCS to abate emissions appears more and more as incontrovertible to reduce future CO_2 emissions in line with the consensual limit of 2°C temperature increase (IPCC, 2007b). This all the more if we consider that fossil fuels will remain the dominant sources of energy over the next decades and that, as a result, CO_2 emissions will drastically increase to reach unsustainable levels. Furthermore, among the technological options to mitigate CO_2 emissions, BECCS is gaining increasing attention, as this alternative offers a unique opportunity for a net carbon removal from the atmosphere while fulfilling energy needs (Herzog *et al*., 2005;Azar*et al*., 2006;van Vuuren *et al*., 2007; Katofsky *et al*., 2010).

The aim of this study is to analyze alternative development paths of the energy systeminvestigating different constraints on the use of CCS and BECCS, under climate policy context. This analysis is conducted using the global multiregional TIAM-FR optimization model. Water needs of the processes have been implemented in this version of the model (Bouckaert *et al*., 2012). So we also analyze the increase pressure by the development of carbon capture technologies (fossil and biomass) on the water resources and discuss the plausibility of technological choices in terms of water availability.

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The paper is organized as follows: section 2 describes the methodology used for the analysis and the constraints scenarios. Section 3 presents the results of the long-term modeling, and the final section concludes with a discussion on the CCS option.

2- Model and scenario analysis

TIAM-FR is the French version of the TIMES Integrated Assessment Model, a widely used, linear programming TIMES family model developed under the IEA's Energy Technology Systems Analysis Program (ETSAP). TIAM-FR is a bottom-up energy system model. It depicts the world energy system with a detailed description of different energy forms, technologies and end-uses constituting the Reference Energy System (RES). The RES network links these commodities to several thousand existing and future technologies characterized by their economic and technological parameters in all sectors of the energy system (agriculture, industry, commercial, residential and transport; taking into account conversion and the electricity sector). The system includes the extraction, transformation, distribution, and trade of various energy forms and materials, and their end-uses.

TIAM-FR is driven by end-use demand and aims to supply energy services at minimum global cost by simultaneously making decisions on equipment investment and operation, primary energy supply, and energy trade (Loulou and Labriet, 2007).TIAM-FR is geographically integrated in 15 global regions and covers the time horizon from 2005 to 2100; nevertheless, this study investigates until 2050. The structure of the energy system is given as an output,i.e. future investments, type and capacity of the energy technologies, energy consumption by fuel, emissions, energy trade flows between regions, detailed energy system costs, and marginal costs of environmental measures such as CO_2 mitigation targets.

Through its integrated climate module, the model makes it possible to analyze and make assumptions on atmospheric GHG concentrations and temperature changes. It integrates CO_2, CH_4 and N_2O emissions from each fuel combustion and process. TIAM-FR integrates several carbon capture and sequestration technologies derived from fossil or bioenergy resources. In the power sector, the model considers two capture technologies for bioplants: pre-combustion for the biomass gasification process, and post-combustion for the direct combustion process. Biomass co-firing in coal power plants has also been implemented in TIAM-FR, with and without carbon capture technologies (Ricci and Selosse, 2011).

In the model, biomass is characterized by manifold sources - industrial waste, municipal waste, landfill gas, bioenergy crops, and solid biomass resources – and the fact that it is not traded between regions. The maximum amount of available biomass for each region is determined exogenously according to IEA data. The global potential is estimated at 234 EJ per year in 2050. In literature, biomass potential varies greatly given the different assumptions on land use, yield development, food consumption and other criteria of sustainability such as water scarcity and loss in biodiversity (van Vuuren *et al*, 2009). This potential varies between 100 EJ and 400 EJ per year over the period 2050-2100.

To highlight the importance of water impact in the evolution of energy system and discuss the plausibility of future technological options, particularly in climate policy context, water footprints of the different processes have been implemented in the model. So water consumption and withdrawal have been indicated for all processes (Bouckaert *et al*, 2012).

So, to analyze possible alternative development paths of the future energy system we investigated alternative scenarios according to different assumptions concerning:

- Climate policy, regarding to regional et/or global CO_2 emissions mitigation targets;
- Cumulated carbon storage capacities;
- Development of BECCS technologies;
- Water availability.

3- Results

The analysis of the results focuses on the effects of the various constraints (environmental, resources and technological) on the power mix and on the future technological investments. The water impact of the latter, in terms of water needs, is also analyzed, insofar as the water withdrawals and consumptions for energy production are assessed by the model.

The climate policy scenarios investigated highlight the importance of technology improvements and lead to a noticeable expansion of renewable energy and CCS technologies in the power sector, fossil and/or BECCS according to technological constraints. In a general manner, CCS from fossil fuel is mainly deployed in fast developing countries that are well endowed with coal. The remaining fossil fuel use is indeed in combination with carbon capture and storage. BECCS is highly distributed in developing countries, even though biomass resources are widely available in all regions.

The assumptions according to carbon storage capacities and BECCS investments involve different sets of mitigation options across regions, with varying shares of renewable energy, CCS, gas, and biomass. The water analysis allow us to discuss the dependence between water and the energy production system and, by the way, to put in perspective the technological solutions to climate and environmental constraints.

4- Conclusion

The use of fossil and biomass emerges as a response to carbon constraint, especially for fast developing countries and developing countries. The capture and storage of CO_2 offers the potential for near-zero CO_2 emissions from fossil-based power plants and negative CO_2 emissions from biomass-based power plants. A major issue related to the deployment of CCS and BECCS is their economic viability. If they are to become significant, economic incentives will be required. The role of CCS and BECCS in mitigating climate change partly depends on their ability to reduce costs and, by consequence, their commercialization on an industrial scale in the marketplace (technology learning),as well as sustained Research, Development & Demonstration. In addition, covering the distance to CO_2 capture and storage sites will involve developing and financing infrastructure for transporting CO_2. Moreover, safety problems and social acceptability must also be considered in terms of risks and concerns for long-term CO_2 geological storage. A regulatory system is required to supervise the selection of appropriate sites, long-term ownership and liabilities, and a monitoring program to detect problems. For example, in the case of carbon leaking back into the atmosphere, methods should be developed to stop or control CO_2 releases.

Concerning biomass energy, being directly tied to forests, food and other ecosystems, its use induce environmental and social impacts, both positive and negative. That the reason why biomass has to be sustainably produced. When accompanied by incentives, BECCS appears as an option to satisfy climate constraints and, at the same time, as fulfilling energy demands (consistent with Obersteiner *et al*, 2001). The potential for fossil and biomass exists but regulatory barriers have to be discussed and removed as knowledge gaps are filled. The increasing need to limit CO_2 emissions and the current limits of alternative technologies constitute assets in this sense. For example, renewable options should in no way be excluded from the debate, but they need to be thought out in terms of the structural costs of investments in the power network required to integrate intermittent energies. Therefore, a complete and complex chain of processes and procedures has to be thought through and determined in the design of future energy policies.

The global community has also to recognize that climate change will affect freshwater availability (IPCC, 2007a). In this context, another important issue, less developed in the energy system literature, consists in the increase pressure these technologies involve on the water resources. It is important to understand and estimate the dependency between water and energy systems, particularly according to the possibility of reduced water availability in the future due to climate change and the increased energy and water demands. This could have important implications for policy makers (Siddiqi and Diaz Anadon, 2011).

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