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Global and regional potential for bioelectricity with carbon capture and storage

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HIGHLIGHTS

- ► We assess the global and regional potential of BECCS in the power sector up to 2050.
- ► This analysis is conducted with the multiregional TIAM-FR optimization model.
- ► BECCS plays an important role in the electricity mix to achieve ambitious targets.

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ABSTRACT

Among technological options to mitigate greenhouse gas (GHG) emissions, biomass energy with carbon capture and storage technology (BECCS) is gaining increasing attention. This alternative offers a unique opportunity for a net removal of atmospheric CO_2 while fulfilling energy needs. Empirical studies using bottom-up energy models show that BECCS has an important role to play in the future energy mix. Most of these studies focus on global BECCS potential, whereas it is of interest to understand where this mitigation option will be deployed. This key issue will strongly depend on regions' biomass resources and possession of storage sites. The aim of this study is to assess the global and regional potential of BECCS up to 2050 in power generation. This analysis is conducted using the multiregional TIAM-FR optimization model. The climate policy scenarios investigated lead to a considerable expansion of renewable energy and CCS and BECCS technologies in the power sector. CCS from fossil fuel is mainly deployed in fast developing countries (India and China) and BECCS is highly distributed in developing countries, even though biomass resources are widely available in all regions.

1. Introduction

Fossil fuels (coal, oil and gas) will remain the dominant sources of energy over the next decades. And yet the end product of existing fossil fuel-based power generation processes being CO_2, CO_2 emissions will drastically increase and accumulate mainly into the atmosphere in unsustainable and practically irreversible levels. This can be explained by a very slow natural carbon sequestration processes, without forget the substantially lower (than in previous centuries) industrialization and deforestation terrestrial plants' potential for atmospheric CO_2 binding (Budzianowski, 2011). Carbon capture and storage (CCS) is a promising technology to achieve a sharp drop in emissions and reverse this trend (IEA, 2008) allowing to satisfy expected increasing electricity demand. It consists of capturing CO_2 from large stationary sources, transporting it and storing it in geological formations where it can no longer contribute to global warming.

CCS is mostly associated with the use of fossil fuels but it can also be combined with bioenergies (BECCS). This option is drawing increasing attention as it offers a unique opportunity for the net removal of atmospheric CO_2 at the same time as fulfilling energy requirements such as electricity, heat, hydrogen and biofuels (Obersteiner et al., 2001). Considering that biomass transformation or combustion is neutral, as biomass includes carbon entirely assimilated from atmospheric CO_2 during its growth via photosynthesis, BECCS can lead to "negative emissions" given sustainable biomass harvesting practices and the permanent geological storage of CO_2. A growing body of literature using bottom-up energy models shows that BECCS has an important role to play in the future energy mix. At low stabilization targets, models predict that the availability of BECCS decreases the cost of mitigation. In fact, when stringent targets are applied,

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negative emissions become a valuable option (Azar et al., 2006, 2010; Katofsky et al., 2010; Luckow et al., 2010; van den Broek et al., 2011; van Vuuren et al., 2007).

Most of these studies estimate the global potential of BECCS in reducing emissions assuming that all world regions act together under a common policy. What happens in a more realistic, second-best framework, where heterogeneous regions have different concerns in terms of environmental policies? Many countries made pledges to UNFCCC in January 2010 under the Copenhagen Accord to reduce their GHG emissions, and these should be taken into account. Moreover, it is worth trying to understand where BECCS will be deployed. This key issue will strongly depend on regional biomass resources and the existence of storage sites.

The aim of this study is to assess the global and regional potential of BECCS in the power sector up to 2050 assuming environmental policy scenarios based on the commitments announced by countries. This allows us to analyze how those commitments affect the future power mix and particularly the deployment of CCS technologies. This analysis is conducted with the global multiregional TIAM-FR optimization model, the French version of the TIMES Integrated Assessment Model developed under the Energy Technology Systems Analysis Program (ETSAP) of IEA. To analyze possible alternative development paths of the system we also investigated a global environmental scenario with distinct constraints on the use of CCS and BECCS technologies.

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

2. Methodology and climate scenarios

2.1. TIAM-FR

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, shown in Fig. 1, links these commodities to several thousand existing and future technologies characterized by their economic and technological parameters (investment cost, fixed and variable costs, availability factor, efficiency, lifetime, discount rate, etc.) 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.

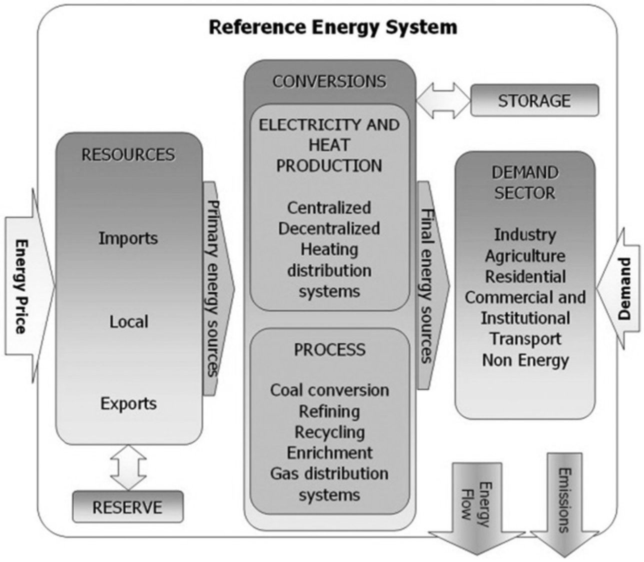

Fig. 1. Synthetic view of the reference energy system.

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). 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, detailed energy system costs, and marginal costs of environmental measures such as GHG mitigation targets.

TIAM-FR is geographically integrated in 15 global 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 Asian Countries (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). It covers the time horizon from 2005 to 2100; nevertheless, this study investigates until 2050.

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. CO_2 capture can be realized according to three modes: (1) a post-combustion mode by using a variety of processes such as reactive absorption or membranes, (2) a pre-combustion mode with conversion of fuel chemical energy into the form of H_2 followed by simultaneous low-cost carbon separation and (3) an oxyfuel mode characterized by the low cost of CO_2 separation, but necessitating a supply of O_2 (Budzianowski, 2011). In the power sector, the model, more specifically, considers the three modes for fossil fuel-based plants and two capture technologies for bio-plants and co-firing plants: pre-combustion for the biomass gasification process, and post-combustion for the direct combustion process (cost details in Appendix A1). Cumulated storage capacities assumed in the model TIAM-FR are 14,800 Gt of CO_2 with 12,600 Gt of CO_2 that can be stored in deep saline aquifers (Appendix B2).

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 (72 EJ come from bioenergy crops, 72 EJ from solid biomass resources and the rest from industrial waste, municipal waste and landfill gas). 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. This potential varies between 100 EJ and 300 EJ per year by 2050. However it will be close to 100 EJ if sustainable land use management policies are not implemented (van Vuuren et al., 2009; IPCC, 2011).