Climate policy impacts on energy system: a long-term analysis with the TIMES Integrated Assessment Model (TIAM-FR)

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ABSTRACT

This paper analyzes technological options to mitigate CO₂ emissions and reach the 2°C objective expressed to UNFCCC since COP15, through global and regional climate objectives. The first aim of this paper is to evaluate the impact on global CO₂ mitigation possibilities according to carbon constraints scenarios and the level of development of different regions. An important result consists in the necessary participation of developing countries in the international climate policy. The second main aim of the study is to study the evolution of the energy system for developed and developing countries. While CCS technologies deployment appears as a necessary solution for fast developing countries (especially China), developing countries (and in a lower manner developed countries) need to invest in renewable energies. But in both cases, countries face economical aspects of their energy transition, such as costs, large scale deployment, traditional energy sector core activities and objectives.

Keywords: Energy system, Long-term modelling, TIAM-FR, Climate policy, CCS technologies, Renewables energies and technological choices

1. INTRODUCTION

Strategies for reaching the long-term collective goal of limiting global average temperatures increases to 2°C above pre-industrial levels requires a transformation of the world energy system. In this paper, different pathways are analyzed for achieving a low-carbon economy and climate goals expressed in the Copenhagen Accord.

The evolution of the energy system differs between regions, and high differences in the deployment of (new) cleaner technologies can be observed. Utilizing a global energy system model, we evaluate emission policies in terms of their impact on global and regional energy systems, and their effectiveness to reduce emission and achieve global warming objectives. The model is furthermore used to analyze technological and economic plausibility of strategies deployed to reduce GHG emissions.

2. TIAM-FR PRESENTATION

The analyses carried out in this study are based on the TIAM-FR (the French version of the TIMES Integrated Assessment Model) developed under the Energy Technology Systems Analysis Program (ETSAP) of IEA. TIAM-FR is a technology-
rich, bottom-up energy system model. The model depicts the world energy system with a detailed description of different energy forms, resources, processes/technologies and end-uses. Links between commodities and technologies are described via a Reference Energy System, and thousands of technologies are used to model the different sectors of the energy system (energy procurement, conversion, processing, transmission, and end-uses). The model jointly considers the extraction, transformation, distribution, end-uses, and trade of various energy forms and materials.

TIAM-FR is a geographically integrated model in which the world is represented using 15 regions on the time horizon from 2005 to 2100. This study investigates changes in the energy system until 2050. The model aims to supply energy services at minimum global cost by simultaneously making decisions on equipment investment, equipment operation, primary energy supply, and energy trade. Costs considered in the model includes investment costs, operation & maintenance costs, costs of imported fuels, incomes of exported fuels, the residual value of technologies at the end of the horizon, etc.

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. Indeed, the model considers GHG emissions from fuel combustion and processes, carbon capture and sequestration technologies, and mitigation technological options for CH\textsubscript{4} and N\textsubscript{2}O. The model can thereby be used to analyze atmospheric GHG concentrations and temperature changes [1].

3. SPECIFICATION OF SCENARIOS

The development of the energy system was evaluated according two environmental scenarios and a baseline business as usual (BAU) scenario without any emission constraints. Furthermore, the impact of environmental scenarios was analyzed in terms of changes of the global and regional energy systems.

The Reg_Targ regional scenario represents the lower CO\textsubscript{2} mitigation targets by 2020, as expressed in the Copenhagen January 2010 Agreement by Europe, the United States of America, Australia, Canada, Japan, China and India. Targets by 2050 were assumed according to international convergence in term of CO\textsubscript{2} emissions reductions, literature, or expressed political ambitions. Note that the scenario is regional in that it assumes that only the previously described countries are bounded by the climate constraint. These targets, and the corresponding level of CO\textsubscript{2} emissions, are expressed in the Table 1.

### Table 1: Cop 15 targets for CO\textsubscript{2} emissions

<table>
<thead>
<tr>
<th>Regions</th>
<th>Year ref.</th>
<th>Year target</th>
<th>Targets</th>
<th>Reduc. type</th>
<th>Level CO\textsubscript{2} (Gt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEU-EEU</td>
<td>1990</td>
<td>2020</td>
<td>20%</td>
<td>Emi. Reduc.</td>
<td>1.54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2050</td>
<td>80%</td>
<td></td>
<td>0.80</td>
</tr>
<tr>
<td>USA</td>
<td>2005</td>
<td>2020</td>
<td>17%</td>
<td>Emi. Reduc.</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2050</td>
<td>83%</td>
<td></td>
<td>0.97</td>
</tr>
<tr>
<td>AUS</td>
<td>2000</td>
<td>2020</td>
<td>5%</td>
<td>Emi. Reduc.</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2050</td>
<td>90%</td>
<td></td>
<td>0.28</td>
</tr>
<tr>
<td>CAN</td>
<td>2005</td>
<td>2020</td>
<td>17%</td>
<td>Emi. Reduc.</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2050</td>
<td>83%</td>
<td></td>
<td>0.79</td>
</tr>
<tr>
<td>JPN</td>
<td>1990</td>
<td>2020</td>
<td>25%</td>
<td>Emi. Reduc.</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2050</td>
<td>80%</td>
<td></td>
<td>0.79</td>
</tr>
<tr>
<td>CHI</td>
<td>2005</td>
<td>2020</td>
<td>80%</td>
<td>CO\textsubscript{2} intensity</td>
<td>6.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2050</td>
<td>10%</td>
<td>Emi. Reduc.</td>
<td>4.12</td>
</tr>
<tr>
<td>IND</td>
<td>2005</td>
<td>2020</td>
<td>20%</td>
<td>CO\textsubscript{2} intensity</td>
<td>2.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2050</td>
<td>10%</td>
<td>Emi. Reduc.</td>
<td>0.20</td>
</tr>
</tbody>
</table>

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

The Glob\textsubscript{50}, global scenario assumes that world CO\textsubscript{2} emission in 2050 should be 50% less than that of the 2000 level. The scenario is thus in line with the consensual 2°C objective expressed at COP15 (IPCC, AR4). All regions are bounded by the climate constraint but they are not constraint at a beforehand determinate level of CO\textsubscript{2} emissions. Regarding this carbon constraint, world emissions of CO\textsubscript{2} could not be higher than 11 Gt.
4. RESULTS

The analysis of the results focuses on the impact of the climate change scenarios on:
- CO₂ emissions levels by regions and sectors.
- Electric mix: the use of fossil fuels and the future technological investments (renewables, carbon capture and storage).

Environmental objectives

Graph 1 presents CO₂ emissions trajectories for the different scenarios and regions. The Glob_50 and Reg_Targ scenarios, respectively result in a decrease of CO₂ emissions by 2050, of 38 Gt and 28 Gt in comparison to the BAU scenario. Thus, the two emission scenarios resulted in highly different levels of emission reductions.

Graph 1: CO₂ emissions by region and scenario

The level of CO₂ emissions of developed countries in 2050 was quite the same in the two climate scenario, i.e. around 5 Gt of CO₂. It is higher in 2020 in the global scenario, 11 Gt of emitted CO₂ against 10 Gt of CO₂ emitted in the target scenario. This let us think that developed countries are engaged in coherent pathways to reach the global climate ambition of 2°C. The question will be their capability to reach their environmental ambition. This is also the case for China and India with a 2020 and 2050 contribution to the CO₂ goal more or less equal for the regional and global scenarios. This confirms an important point of the global climate policy: the world could not reach an acceptable level of CO₂ emission without the participation of developing countries [2][3].

Technological challenges

CCS technologies were found to be highly deployed for reaching the climate targets (see graph 2). CCS was found to be particularly important to response to carbon constraint for fastest developing countries, like China, whatever the scenario.

The environmental constraints also lead to an increase deployment of renewable technologies, especially in developing countries in the global scenario where there are constrained for their CO₂ emissions.

Graph 2: World electricity mix

Developed countries also invest in renewables technologies to reach climate targets (whatever the global policy or their COP 15 commitments). In China and India, the deployment of renewables is slowed by investment in CCS technologies. Note that carbon constraint involves an increase of nuclear power in developed and developing countries.

Carbon Capture and Storage technologies deployment

According to industry leaders such as Alstom Power, China is expected to be a major market for CCS technologies [4]. Graph 3 highlights the same CCS as an important market opportunity. In the global environmental scenario, 16 Gt of carbon
need to be sequestrated in 2050 if the power generation comes from coal plants.

Graph 3: CCS and BECCS deployment

However, this ignores the highly development costs to make CCS available at large scale of commercialization and unresolved safety problem. Obtain the social acceptability will be a challenge for the large scale commercialization of CCS technologies.

To highlight this point, a constraint was constructed regarding deployment of coal in China. The constraint was constructed in line with Chinese energy policy to accompany its environmental target. In this scenario, the share of coal in the electric mix from fossil was limited to no more than 50%. The constraint for China was incorporated into the Glob_50 and Reg_Targ scenarios, but note that developed and developing countries are not directly impacted by this change in the constraints.

Graph 4: CCS and BECCS deployment

Results according to the climate scenario highlights the reduced investment in CCS technologies to reach climate policy for fast developing countries, and here, more specifically China (see graph 3). With this new constraint, China sequestrates 4.2Gt of CO₂ in the global scenario in 2050. However, as a consequence of the constraint, an increased development of renewables energies to generate electricity was noted. However, the deployment of renewable energies may be limited in China, thus forcing a high deployment rate of CCS in China [5].

5. CONCLUDING REMARKS

Environmental stakes requires global constraints and CO₂ mitigations are required from developed countries and developing countries (including fast developing countries like China and India) for global climate constraints to be reached. Post-COP15 policies thus require CO₂ mitigations from developed countries and developing countries. The question is to determine the possible and fair level of CO₂ mitigation for regions [4], considering that climate strategies impact on impacts energy systems, and that the action potential differs between regions.

For each region, costs and the most promising technologies to reach climate targets are different. Regional differences exists in terms of the existing energy system, infrastructure, technological potential (renewable energies, CCS, etc.), future economic development, and priorities.

For addressing the problem of global climate change, CCS technologies are expected to be deployed. However, are the required large scale investments in CCS technologies feasible, and can they be deployed to the considered levels? In order to face stringent carbon constraints, CCS technologies need to be installed on an industrial scale, but potential, effectiveness and cost aspects are still highly uncertain. Large scale adoption
of this technology is not yet economically feasible, and commercialization is likely to take time due to high costs and safety problem (leak back into the atmosphere and social acceptability).

This study also highlights that even if international cooperation is needed to face the energy-climate problem, it is not only countries that must act, but technological progress must also be realized.

The pool of existent and future technologies need to be extended and the mitigation potential of the technologies need to be realized. This not only concerns CCS technologies, but also non-fossil technologies, like wind, solar, biomass, etc. Like for CCS technologies, the potential of deployment of renewables is still uncertain. Notably, in the case of intermittent renewables power and their variability, the question remains still remains if a power system can introduce a larger share of renewables without any changes whatsoever? Deployment of renewables energies face traditional energy sector objectives, such as reliable electricity supply [6]. The electricity network will need to be reinforced to ensure stability, thus adding to the cost of renewables. Energy-climate goals to be addressed are reduction in energy-related greenhouse gas emissions (and environment protection more widely), energy security, energy service cost minimization (for both business and residential consumers), and energy service accessibility [6]. These objectives imply not only behavioral changes in consumption (changes we have not evocated here because of a technological focus), but also further technological development. Investments will be required to make a low carbon society feasible.

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7. REFERENCES


