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Research paper

Contribution of global GHG reduction pledges to bioenergy expansion

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A B S T R A C T

With growing concerns about climate change, countries are increasing efforts to reduce dependency on fossil energy sources, the major source of CO_2, by replacing them with cleaner energy sources including bioenergy. In this context, the global bioenergy market has grown massively during the last few decades. In addition, under the aegis of the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, 162 countries have already submitted their intended nationally determined contributions (INDCs) to mitigate climate change, including greenhouse gas emissions pledges and action plans. Hence, the effect of these GHG restrictions on the bioenergy sector in the new expected global decarbonized energy system needs to be addressed. In this study, we estimate what role the international climate agreement could play in bioenergy sector expansion using the bottom-up energy system optimization model, TIAM-FR, a TIMES family model from ETSAP/IEA. As results, GHG restrictions promoted global bioenergy supply over the time horizon 2010–2050. In 2050, global biomass supply reaches 131–138 EJ under these climate scenarios, which is more than double biomass supply in the BAU scenario (60 EJ). In final bioenergy consumption, in 2050, only 3–5 EJ is consumed as biofuel in transport sector while 60 EJ of biomass is consumed for different uses in other sectors and more than 40% of total supplied biomass produces heat and electricity.

1. Introduction

The rapid economic development in emerging countries and the growing population have driven a sharp increase in fossil energy consumption and global GHG emissions. According to IEA statistics [1], the share of fossil energy in the global TPES (Total Primary Energy Supply), which refers to coal, gas, and oil products, was over 80% in 2011. The high consumption of fossil energy products during the last decades has accumulated CO_2 emissions in the atmosphere and brought about global warming. Concerns about climate change issues have encouraged countries around the world to mitigate GHG emissions together. At the 21st conference of parties (COP 21), held in Paris, France in December 2015, a new international climate agreement was signed to keep the global average temperature rise well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C. As of 22 August 2016, 162 parties have already communicated GHG emission reduction commitments to UNFCCC, including action plans until 2020 or 2030 [2]. The key solution to reduce GHG emissions and fossil energy dependencies is a diversification of the energy mix, but, during recent decades, the share of bioenergy in TPES has remained stable at 10%. However, the development of bioenergy transformation technologies has had a significant and more efficient impact on the bioenergy supply pattern. Between 1990 and 2011, the primary solid biomass supply including municipal and industrial waste dropped from 99.02% (37.6 EJ) to 93.37% (51.3 EJ) and was replaced by liquefied and gasified bioenergy sources such as ethanol, biodiesel, and biogas, whose share increased from 0.98% (400 PJ) to 6.63% (3.6 EJ) [1]. The phenomenon is particularly remarkable in the transport sector, where liquid biofuel consumption reached 2.45 EJ (7% of total gasoline and diesel consumption) in 2011 compared to 250 PJ (1.3% of total gasoline and diesel consumption) in 1990. These statistics indicate the transition from the use of traditional bioenergy with relatively low energy efficiency, for example, direct combustion of woods and crops, to modern bioenergy with increased energy efficiency, such as wood pellets, liquid and gasified biomass for electricity generation, transport fuels, etc. [3]. With the recent COP 21 decision to limit the global average temperature increase below 2 °C or 1.5 °C, the bioenergy sector is expected to expand further. In the IPCC SRREN (Special Report on Renewable Energy Sources and Climate Change Mitigation) [4], primary bioenergy supply reaches in the rage of

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25–300 EJ y^{-1} by 2050 for the tight climate mitigation scenarios (Cat.I+II: < 440 cm^3 m^{-3}) and 20–265 EJ y^{-1} for the less tight scenarios (Cat. III+ IV: 440–600 cm^3 m^{-3}). The GEA (Global Energy Assessment) scenario [5], which implies global CO_2 emissions reductions from energy and industry to 30–70% of 2000 levels by 2050, assesses 80–140 EJ of bioenergy supply by 2050. However, these studies did not imply climate mitigation scenario from INDCs. Only the recent version of WEO (World Energy Outlook)2016 from IEA analyzed potential deployment of bioenergy applying INDCs scenario. WEO 2016 projects 72 EJ y^{-1} of primary bioenergy supply by 2030 [6] with new policy scenario, which implies INDCs targets, and 96.7 EJ y^{-1} by 2040 with 2 °C scenario. Apart from WEO study, there are no other global studies that assess the relationship between bioenergy and current INDCs' GHG emissions reduction levels in an expected decarbonized energy system to explore different bioenergy pathways for the future. The aim of this paper is to discuss how the recent global GHG pledge will affect the bioenergy sector in a long term. 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. Our study involves the estimation of global bioenergy potential corresponding to the structure of TIAM-FR model.

The paper is organized as follows: Section 2 describes the methodology used for the analysis and the climate scenarios. Section 3 presents the model results for the longer term projection. The final section concludes with a discussion on the deployment potential of bioenergy.

2. Materials and methods

The evaluation of bioenergy avenues is performed through long-term scenario analysis for the period 2010–2050 with a bottom-up energy system optimization model, TIAM-FR, developed by the MINES ParisTech's Centre for Applied Mathematics [7]. Prior to the scenario analysis, we modified the current TIAM-FR structure, which comprised an aggregated level on biomass resources, and re-estimated the global bioenergy potential to correspond to the newly introduced structure. Secondly, we analyzed global GHG reduction scenarios based on INDCs communications and a 2 °C limit in the global temperature increase to observe the effects of GHG emission pledges on the bioenergy sector.

2.1. The TIMES integrated assessment model (TIAM-FR)

TIAM-FR is the French version of the world *TIMES Integrated Assessment model*, the global multiregional model from the TIMES family developed under the Energy Technology Systems Analysis Program (ETSAP) at the International Energy Agency (IEA) [8–10]. This model is based on a bottom-up approach and a technology-rich representation of the energy system to estimate how it will change and evolve in the long term. On the supply side, the reserves and resources of hard coal, lignite, conventional and unconventional oil and gas, including their supply costs, are presented for each world region. The energy conversion technologies for current and future energy systems, from extraction through primary energy supply and secondary energy supply to the end-uses, are detailed with technico-economic parameters. Regarding bioenergy conversion technologies, more than 100 technologies are integrated in TIAM-FR model over the entire regions and sectors. Summary of representative technologies are described in Appendix A.

On the demand side, 41 end-use demands (vehicle-km in the transport sector, tons of materials to produce in the industrial sector, lighting and water heating in the residential sector, etc.) for 5 energy-service sectors (agriculture, industry, commercial, residential, transport) are described based on socio-economic assumptions and on external projections of the growth of regional GDP, as well as population or the volume of various economic sectors over the entire time horizon (see Fig. 1 and Appendix B).

The model covers the time horizon from 2010 to 2050 divided into 5-year periods, and the world split into 15 global regions: Africa (AFR), Australia and 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). The regions are linked via the trading of energy and materials.

TIAM-FR is a linear programming model that aims to estimate an inter-temporal partial economic equilibrium on integrated energy markets assuming perfect markets and unlimited foresight over the time period, the described economic sectors and commodities [7]. The objective function is to minimize the discounted global energy system cost over the entire model horizon until 2050 under demand, environmental, and technological constraints. The net present value of the model is calculated based on (equation (1)) for each region.

$$NPV = \sum_{r=1}^{R} \sum_{y \in YEARS} (1 + d_{r,y})^{REFYR-y} \times ANNCOST_{r,y} \quad (1)$$

Where NPV is the net present value of the total cost for all regions over the calculation period; $ANNCOST_{r,y}$ is the total annual cost in region r and year y; $d_{r,y}$ is the discount rate; REFYR is the reference year for discounting; YEARS is the set of years and R is the set of regions (15 regions).

The results of the optimization are the structure of the energy system for each region, i.e. type and capacity of the energy technologies, energy consumption by fuel, development of emissions, energy trade flows between the regions and the resulting transport capacities required, and detailed energy system costs, plus information on the marginal costs of environmental measures, etc.

2.2. Bioenergy resource potential: methods

In the TIAM-FR model, biomass supply is characterized by manifold sources - bioenergy crops, solid biomass, industrial and municipal wastes, and land fill gas. Due to this aggregation level, current classification does not allow us to classify crop-specific or solid biomass types according to different technology progress or strategy/policy on biomass uses. We thus modified this structure by reformulating the extraction phase of biomass resources and the corresponding energy chain. In this study, we focus on bioenergy crops and solid biomass.

In the case of energy crops, which are aggregated into one commodity, the supply side was detailed based on a land-based approach due to possible land competition between different crops. In the literature, several studies have estimated global land availability for bioenergy production [11–17]. Overall, the estimated land availability varies depending on the approach, such as biomass flows and crop production, and on assumptions regarding land type, evolution of crop productivity, food demand projections, sustainability criteria such as water, and biodiversity issues. Furthermore, each study features a different geographical coverage, none of which comply with the TIAM-FR model. Hence, our study had to estimate its own bioenergy potential to implement into the