Trading woody biomass and negative emissions under a climate mitigation scenario

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Abstract

Bio-energy has the potential to be a key mitigation option if combined with carbon capture and sequestration (BECCS) because it can generate both electricity and negative emissions. Unfortunately, the uneven distribution of biomass endowment among world countries makes it difficult to produce energy from BECCS in regions with high energy demand and low abatement opportunities. Trading biomass is definitely a possibility to match demand and supply at global level. This paper examines the multifaceted aspects of woody biomass trade in climate mitigation policy scenarios using the integrated assessment model WITCH. The policy tool is a carbon tax that starts in 2015 at 7 USD/tCO_2 and reaches 490 USD/tCO_2 in 2100. Results show that the woody biomass market would start in 2040 with 107 EJ/yr traded and a value of almost 4,500 USD Billions by 2100. Then, comparing the carbon tax scenario with and without trade, we found that with trade emissions are 20% lower by 2100. At the global level, the share of BECCS in the energy mix would raise from 19% to 26% by 2100 while the share of coal with CCS would decline from 4% to zero by 2100. Then, we present a sensitivity analysis with four carbon tax trajectories of some key variables such as the international price of woody biomass, volume and value of the biomass market. Finally, we simulate a cap-and-trade scheme with a stabilization target of 550 ppm CO_2-eq at 2100 in order to study the implications of biomass trade on the carbon market.

Key words: BECCS, woody biomass trade, IAM, negative emissions, joint production

JEL codes: Q23, Q56, F18

1. Introduction

The policy aspiration of not exceeding a global temperature rise of 2°C, compared to preindustrial levels, is likely to require atmospheric concentrations below 450 ppme (IPCC AR4, WG I, Ch 10, Table 10.8 Meehl et al.,). Current CO_2 concentration is more than 390 ppm[1] and without a concrete action this level is assumed to reach 720 ppm by 2100. One way to reduce emissions is by substituting zero—negative—emissions energy for fossil fuels.

In this context, bio-energy has the potential to be a key mitigation option if combined with carbon capture and sequestration (BECCS) because it can generate both electricity and negative emissions (Obersteiner et al., 2001). For these peculiar characteristics, many studies show that BECCS is a critical technology to achieve low CO_2 concentration targets: it allows to cut emissions deeper and to increase the "when" flexibility of climate policy (Azar et al., 2006, 2010; Clarke et al., 2009; Edenhofer et al., 2009, 2010; van Vuuren et al., 2011).

Unfortunately, the uneven distribution of biomass endowment among world countries makes it difficult to produce bio-energy in regions with high energy demand and low abatement opportunities. For example, numerous studies show that Latin America and Sub-Saharan Africa have a large potential compared to other regions of the world (Berndes et al., 2003; Rokityanskiy et al., 2007; Smeets et al., 2007; Heinimö and Junginger, 2009; Chum et al., 2011). Physical trade of biomass could definitely bridge this disparity.

Several integrated assessment model (IAMs) have already included trade of biomass (van Vuuren et al., 2007; Edenhofer et al., 2010; Magne et al., 2010; Popp et al., 2011). However, these studies have focused on the energy sector and did not explore the role of trade itself. Other studies have analyzed which might be the best biomass trading option between physical trade, trade of electricity and trade of emissions permits either using case studies or energy models for only some regions of the world (Schlamadinger, Faaij and Daugherty, 2004; Hansson and Berndes, 2009; Laurijssen and Faaij, 2009).

In this paper we combine these different approaches of the literature in a single framework to extend the analysis on woody biomass trade in a climate mitigation policy scenario using the IAM WITCH (Bosetti et al., 2006, 2007, 2009).

The paper is organized as follows. Section 2 describes the method and scenarios used for the analysis. In section 3 we illustrate the international trade of woody biomass in a carbon tax scenario. Then, comparing the same carbon tax scenario with and without trade we assess how it affects the optimal abatement level. Finally, we simulate a cap-and-trade scheme with a stabilization target of 550 ppm CO2-eq at 2100 in order to see how the biomass market interacts with the carbon market and its effect on the stabilization policy cost. The final section provides a brief summary of the findings and concluding remarks.

2. Methodology

This section describes methods and scenarios used to develop woody biomass trade in the WITCH model.

Biomass supply is obtained from the GLOBIOM model (Havlík et al., 2011). The supply curves consist of woody biomass coming from conventional plantations and short rotation forests for each region. They have been constructed using land use change restrictions that guarantee carbon neutrality. As a result, we treat woody biomass as zero-emissions energy, without leakage effects.

In WITCH, woody biomass is mixed with coal in power plants (co-firing). Each region *n* chooses the optimal mix of coal and biomass on the basis of their availability at any time period *t* and their relative cost. Both integrated gasification combined cycle (IGCC) technologies and traditional power plants using pulverized coal (PC)[2] are used for co-firing. Since IGCC power plants are equipped with CCS, biomass energy with CCS (henceforth BECCS) yields negative net emissions. We assume that all IGCC power plants equipped with CCS have the same level of efficiency in all countries. However, the cost of storing CO_2 underground varies in different regions according to the estimated size of reservoirs.

The total quantity of woody biomass[3] consumed in IGCC (*WBIOigcc)* and PC power plants (*WBIOigcc)* is equal to the domestic production of woody biomass (*WBIOs*) for each region *n* at any given time *t*:

$$WBIOd_{n,t} = WBIOigcc_{n,t} + WBIOpc_{n,t} \quad (1)$$

$$WBIOd_{n,t} = WBIOs_{n,t} \quad (2)$$

With trade, the domestic consumption of woody biomass (*WBIOd*) is equal to the domestic production plus the net import of woody biomass from the international market ($NIPwbio_{n,t}$). We do not impose any restriction to the amount of biomass tradable in the market. The only constraint is that at each time *t* each country *n* cannot produce more than its woody biomass endowment ($E_{n,t}$) from GLOBIOM:

$$WBIOd_{n,t} = WBIOs_{n,t} + NIPwbio_{n,t} \quad (3)$$

s.t. $WBIOs_{n,t} \leq E_{n,t}$

In addition, we assume that the energy needed for trade is irrelevant so we do not account for it and for emissions associated to trade.

In exporting regions, domestic production of woody biomass is greater than domestic consumption, thus $NIPwbio_{n,t}$ is negative. While, importing regions have positive $NIPwbio_{n,t}$.

The equilibrium of the international market requires that the imports and exports are equal at each time period:

$$\sum_n \mathrm{NIPwbio}_n = 0 \;\; \forall t \quad (4)$$

Woody biomass is valued at the international market price $pwbio_t$ in all regions. The importer will also pay the transportation cost ($ctra_n$).[4]

Then, the domestic production cost of woody biomass ($cwbio_{n,t}$) and the value of net imports are included in the budget constraint of the economy:

$$
\begin{aligned}
Ynet(n,t) = & \frac{GY_{n,t}}{\Omega_{n,t}} \\
& -\sum_{q} Pq_{n,t}\, Vq_{n,t} \\
& -cwbio_{n,t} WBIOs_{n,t} \\
& -pwbio_{t} NIPwbio_{n,t} \\
& -ctra_{n} NIPwbio_{n,t}
\end{aligned}
\tag{5}
$$

Finally, we simulate four price trajectories of carbon using a tax on all GHG emissions as a policy tool. The first three trajectories start at 7 and 36 USD/tCO_2 in 2015 and then grow at the constant rate of 5% per year. We name these scenarios t1, t2 and t3. Concentrations are endogenous and lead to a temperature increase of 3°C, 2.4°C, 2.2°C respectively, in 2100, with respect to the pre-industrial level.[5] The last price trajectory (t550) is endogenously determined by imposing a target to radiative forcing equal to 3.7W/m^2 which is equivalent to a temperature increase of 2.5°C and a concentration target of 550 ppme in our climate model (Figure 1). Carbon taxes are uniform globally and tax revenues are recycled lump-sum domestically. In addition, we assume that the owner of the power plant producing energy with BECCS received a subsidy equals to the carbon tax per each ton of "avoided" CO_2.

For the last session, we use a policy scenario in which GHGs concentrations are forced to remain below 550 ppm CO_2-eq at the end of the century. The global pattern of emissions imposed is the result of a cost-benefit solution of the model under the assumption of a world social planner.

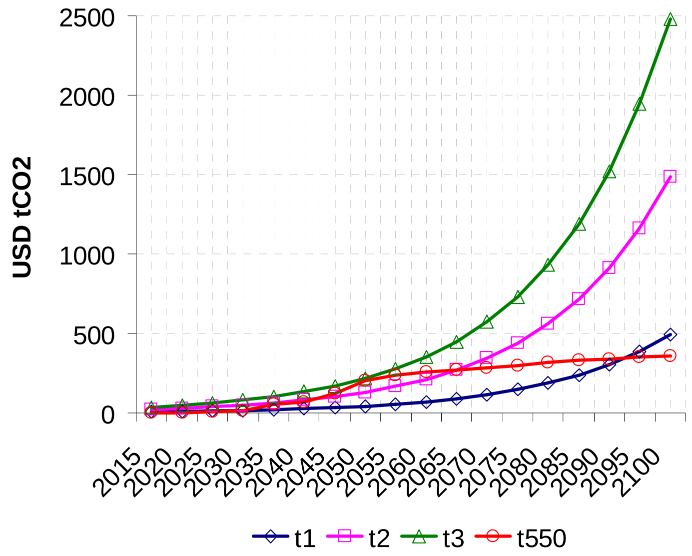


Figure 1 Carbon taxes

3. Results

In this section, we first describe the international trade of woody biomass in the carbon tax scenario (t1) that starts with 7 USD/tCO_2 in 2015 and reaches 495 USD/tCO_2 in 2100. Then, comparing the same scenario with and without woody biomass trade we discuss the positive effects of trade. In particular, we show how bridging the disparity of woody biomass potential reduces GHGs emissions creating a cleaner energy mix. We also provide a qualitative and quantitative analysis of the joint production of energy and negative emissions when bio-energy coupled with CCS. Finally, we discuss whether is better to trade physical biomass instead of carbon credits associated to the use of bio-energy and its effects on the stabilization cost.

3.1. The international trade of woody biomass

The international price of woody biomass emerges in WITCH endogenously as an outcome of a non-competitive Nash game among all regions. Figure 2 shows both the international price of biomass and the path of the subsidy per kwh for stored tCO_2. Their paths are similar. The CO_2 content of woody biomass is more valuable than the energy content driving the demand of biomass. Hence, woody biomass trade flows are mainly driven by the demand of negative emissions instead of the demand of the energy input.

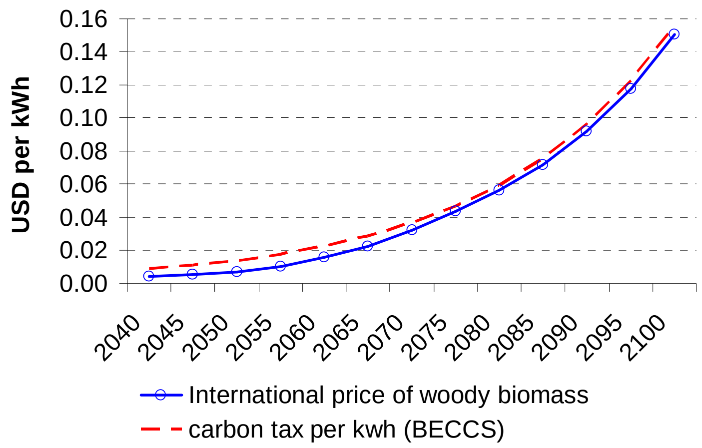
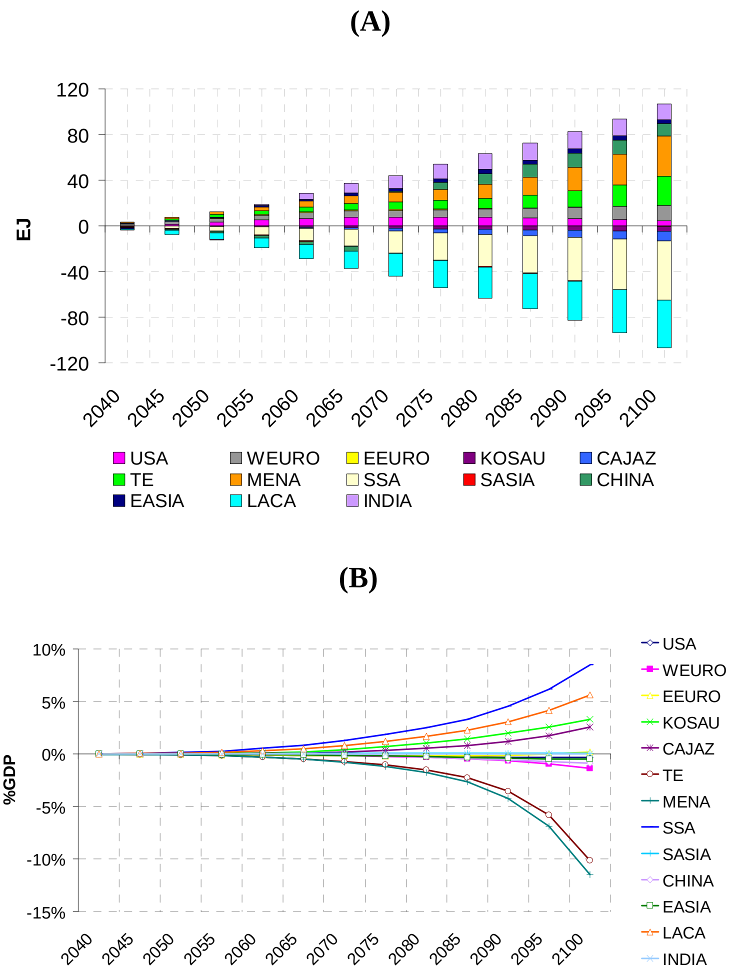


Figure 2. Woody biomass international price and carbon tax, scenario t1

The trade of woody biomass starts in 2040, when the carbon tax is high enough to drive the demand of carbon negative technology. In 2100 the market volume reaches 107 EJ/yr more than the half of the biomass consumed globally the same year. Finally, the value grows through time reaching 4,468 USD Billions in 2100 almost 1.3% of the gross world product (Figure 3).



Notes: WEURO: Western Europe; EEURO: Eastern Europe; KOSAU: Australia, South Africa and South Korea; CAJAZ: Canada, Japan and New Zealand; TE: Transition Economies; MENA: Middle East and Northern Africa; SSA: Sub-Saharan Africa; SASIA: South Asia; EASIA: East Asia; LACA: Latin America and the Caribbean.

Figure 3. Woody biomass trade volume (EJ) (A) and woody biomass traded value in USD Billions (B), carbon tax scenario t1

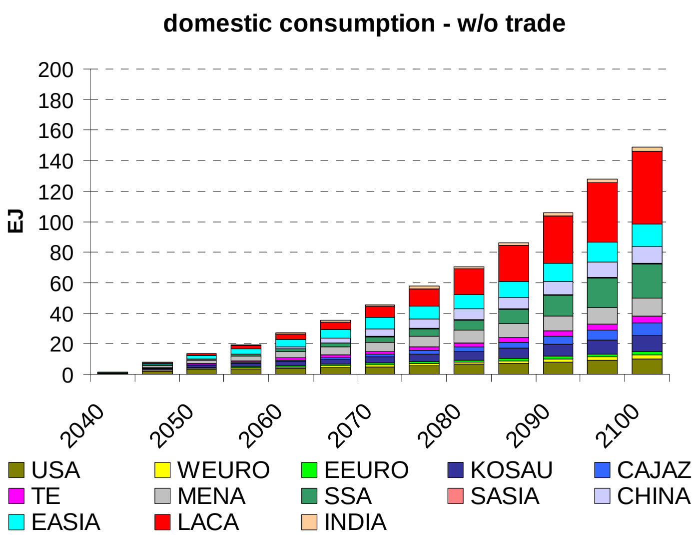
Latin America (LACA) and Sub-Saharan Africa (SSA) are the two main exporters, covering the 90% of total supply in 2100. While demand of biomass is more heterogeneous. Middle East and Northern Africa (MENA) and Transition Economies (TE) represent together its 60% by 2100. Trading dynamics can be explained by the initial endowment, energy demand and biomass production cost. The two largest exporters are indeed the countries with the largest biomass potential and lowest production costs. While, importers are regions with either high biomass cost (e.g. TE) or low biomass potential (MENA) and high demand of clean energy.

3.2. Trade effects on the optimal abatement level

Biomass trade bridges the disparity between demand of a clean energy source from regions with low abatement opportunities and supply of biomass from regions with high potential and low production costs. With trade, importing regions would reduce their emissions switching from fossil fuels to bio-energy and also sequestering emissions with CCS.

The first effect of the trade is an increasing amount of biomass used at the global scale from 140 EJ/yr to 190 EJ/yr by 2100 (Figure 4). The regional distribution of the domestic consumption and production varies significantly comparing the scenario without trade to the one with trade. Importers would keep almost invariant their domestic production and increase their consumption importing. While, exporters would both decrease their domestic consumption and increase their production substantially in order to satisfy the international demand.

(A)



(B)

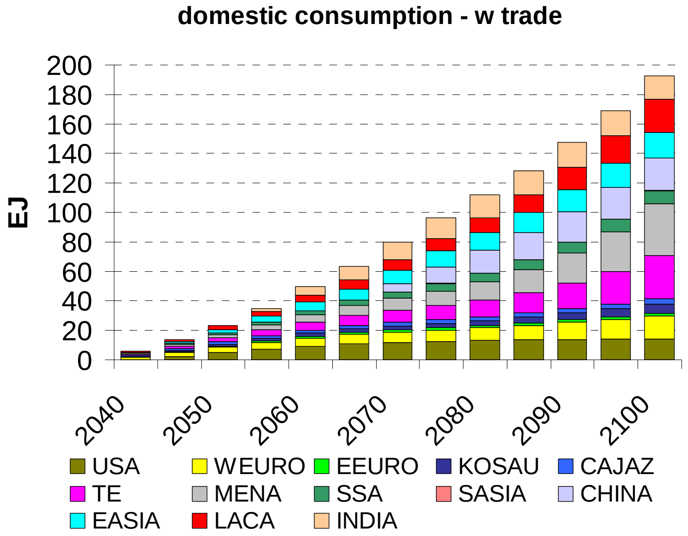


Figure 4. Domestic consumption of woody biomass combined with CCS without (a) and with (b) woody biomass trade

Figure 5 and Figure 6 show how production and consumption of the main actors in the market change with and without trade in 2070 and 2100.

For importing regions, in 2070, the amount of biomass produced domestically (red bar and black diamond) is almost unchanged while the total consumption (red and green bar) increases with imports. For instance, the 65% of biomass consumed in the USA is imported; this percentage increases to around 80% in Transition Economies and West Europe and reaches 90% in India and 100% for Middle East and Northern Africa. The latter has no domestic biomass endowment (yellow circle), so the only way to use this technology is via the international market. In 2100, they increase not only imports but also their domestic production using almost all the biomass available at the national level in order to satisfy a voracious demand (Figure 6).

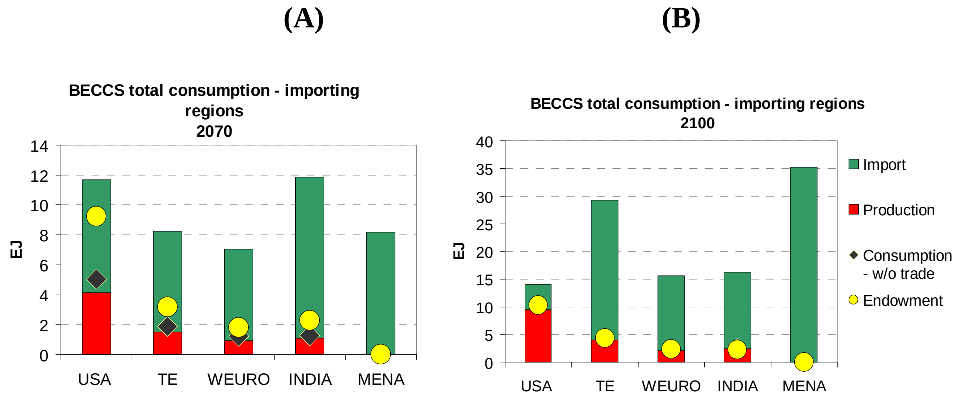


Figure 5. Domestic consumption of woody biomass combined with CCS in 2070 (A) and 2100 (B) – importing regions.

For exporting regions, in 2070 they consume domestically the same amount of biomass (black diamond and red bar) with and without trade; while, the production increases from 8 EJ/yr to 27 EJ/yr in Latin America and from 4 EJ/yr to 24 EJ/yr in Sub Saharan Africa. In 2100 the picture changes significantly. They use almost all their biomass potential (yellow circle) and in order to increase their export they drop their domestic consumption by 60% and 50% respectively with respect to the scenario without trade.

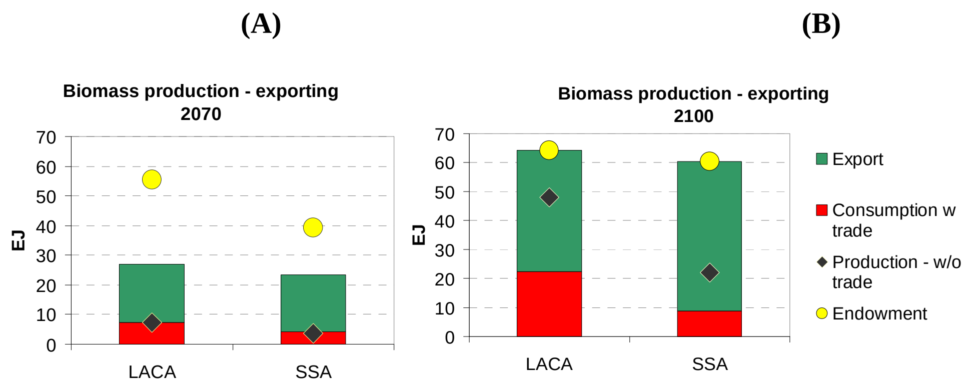
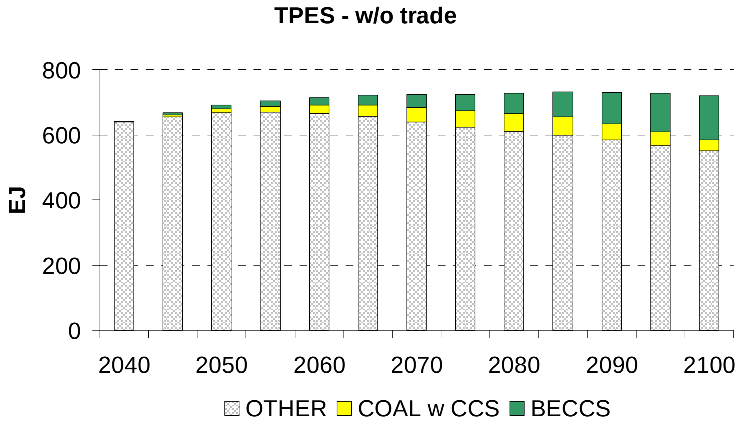


Figure 6. Domestic production of woody biomass combined with CCS in 2070 (A) and 2100 (B) – exporting regions.

The second effect of the introduction of woody biomass trade is a change in the energy mix. The share of BECCS on the total primary energy supply increases from 19% to 26% while the share of coal with CCS decreases from 4% to 0.1% by

2100. This is the result of both the substitution effect between the two technologies and the competition for the same carbon sequestration sites (Figure 7). In particular, the trade anticipates the peak in the use of coal with CCS to 2070, ten years earlier than the scenario without trade. Finally, the use of nuclear collapses in importing countries (Figure 8 – A) and grows in exporting countries (Figure 8 – B); however, at the global level it remains almost unchanged. Nuclear represents the closest substitute to BECCS because it is a large scale, virtually carbon free technology.

(A)



(B)

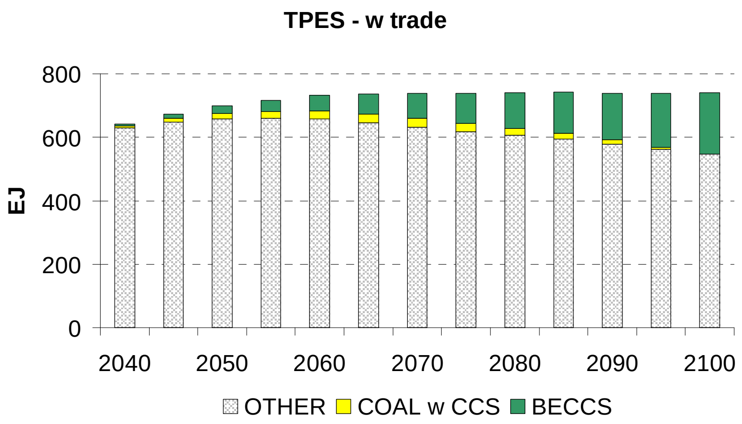


Figure 7. Global primary energy supply without (a) and with (b) woody biomass trade

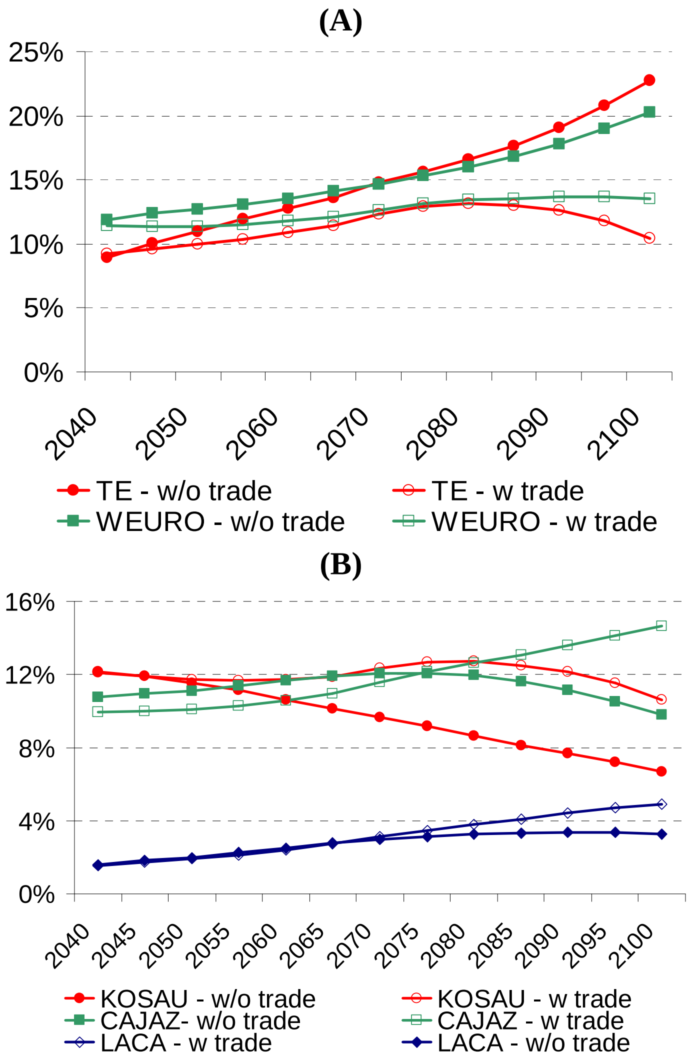
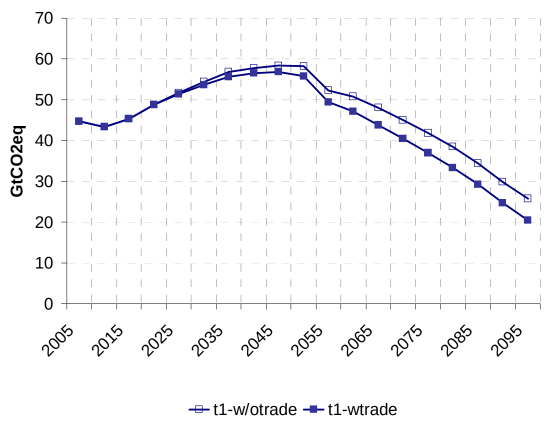


Figure 8 Share of nuclear on the total primary energy supply – importing regions (A) and exporting regions (B)
Note: The share of nuclear in the total primary energy supply of MENA and SSA is almost zero.

The introduction of trade – proving new abatement opportunities - shifts the marginal cost curve to the right: for the same carbon tax there is a reduction in emissions per unit of output. In particular, using biomass from the international market in power plant with CCS, importers reduce the carbon intensity of their energy system not only substituting fossil fuels with bio-energy but also storing CO_2 with CCS.

Comparing the same carbon tax scenario with and without trade, we found that carbon intensity of energy and the energy intensity of the output decrease by 6% and 17% respectively at the global level. The trade offers an emission reduction of 20% by 2100 (Figure 9 - A). In particular importing countries – namely Western EU, USA, Transition Economies, Middle East and North Africa and India - decrease their emissions by 50% by 2100. The reduction in the total GHG emissions is mainly due to an increase in the "negative" emissions produced by BECCS which increase by 22% comparing to the scenario without trade (Figure 9 – B).

(A)



(B)

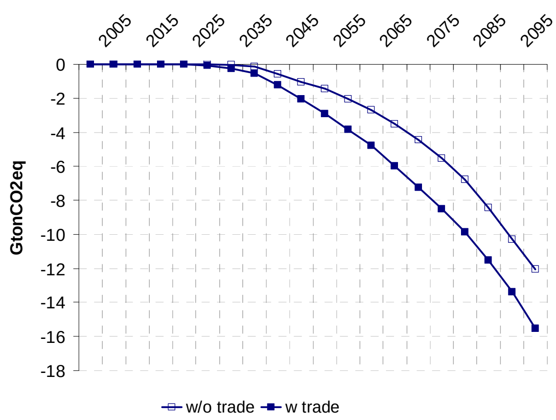


Figure 9. GHGs emissions (A) and negative emissions (B) from BECCS without and with trade, carbon tax scenario t1

3.3. Sensitivity analysis

[to be completed]

3.4. The woody biomass market vs. the carbon market **(to be completed)**

In this last session we introduce the trade of woody biomass in cap-nd-trade scenario with a stabilization target of 550 ppm CO2-eq at 2100 in order to see how the two trades interact.

For this analysis, we assume that negative emissions from BECCS can be converted to carbon credits and either used in national inventory or sold in the carbon market. Indeed, when the trade of woody biomass is allowed, regions without cheap abatement opportunities within their boarders have two options to reduce their emissions. They can import either emissions permit or woody biomass that burned in their power plant equipped with CCS produces both energy and negative emissions. Hence, they will choose the option that provides more benefits.

In this scenario, the above discussed issue of joint production is even more marked than in the carbon tax scenario. In fact, BECCS output is not single-valued but it is a joint production of energy and negative emissions both sold in their own markets. In this case the trade of biomass has indeed a direct impact on the CO_2 price represented by the price of carbon permits.

Our results [to be completed]

Conclusion

This paper evaluates the potential of the trade of woody biomass in a climate policy scenario. Although numerous integrated assessment model (IAM) have introduced the trade of biomass, they focus only the energy sector and did not explore trade itself.

First, we have introduced the trade of woody biomass in the IAM WITCH. The international price of woody biomass emerges endogenously as an outcome of a non-competitive Nash game among all regions. Results show that the woody biomass market would start in 2040 with 107 EJ/yr traded and a value of 4,500 USD Billions in 2100. Volume and value are highly influenced by the carbon tax: when the tax is high, regions increase their demand of biomass in order to reduce their emissions both switching from fossil fuels to bio-energy and sequestering emissions with CCS. Latin America and Sub-Saharan Africa would cover 90% of total supply in 2100. While demand of biomass is more heterogeneous. Middle East and Northern Africa (MENA) and Transition Economies (TE) represent together its 60% by 2100.

Second, we have analyzed woody biomass trade effects on the optimal abatement level comparing the same carbon tax scenario with and without trade. We found that the trade offers a 20% reduction in GHGs emissions. In particular, importers would use BECCS to substitute fossil fuels reducing the carbon intensity of their energy system and producing negative emissions at the same time. At the global level, the share of BECCS in the energy mix would raise from 19% to 26% by 2100 while the share of coal with CCS would decline from 4% to zero by 2100 for a substitution effect and because the two technologies compete for the same carbon sequestration sites.

Third, we have simulated a cap-and-trade scheme with a stabilization target of 550 ppm CO_2-eq at 2100 with and without woody biomass trade [**to be completed**].

Finally, different climate and trading policies may distort the results above described. For instance, we do not assume any governmental support to promote domestic production of bio-energy such as subsidies and we have not set any domestic targets on renewable. In addition, we assume neither barriers nor social and political limitations in biomass trading. However, energy security and geopolitical issues exist and must be carefully considered.

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[1] Concentrations of all GHG are equal to about 430 ppme.

[2] For this study we use only biomass combined with IGCC.

[3] The coefficient used to convert woody biomass cubic meters into GJ Energy is equal to 7.5GJ/m^3.

[4] According to Hansson and Berndes (2009), we assume generic transportation costs of 0.00025 euro/GJ per kilometer equal for all regions. Transportation costs are measured using the average distance from the main port of each region weighted by regional biomass endowment. Main harbours were defined according to “World port rankings - 2009” at http://aapa.files.cms-plus.com/PDFs/WORLD%20PORT%20RANKINGS%202009.pdf. The distance for ship transportation is retrieved from Port to port distances at http://www.searates.com/reference/portdistance/. Last viewed on December 2011.

[5] This should be compared to the 4.1°C temperature increase in the Reference scenario.

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Appendix

List of variables

$WBIOd$ = total consumption of woody biomass

$WBIOigcc_{n,t}$ = Woody biomass used in integrated gasification combined cycle (IGCC) technologies with CCS

$WBIOpc_{n,t}$ = Woody biomass used traditional power plants using pulverized coal (PC)

$WBIOs_{n,t}$ = total production of woody biomass

$NIPwbio_{n,t}$ = net import of woody biomass

$NIPwbio_{n,t} > 0$ importing; $NIPwbio_{n,t} < 0$ exporting

$\frac{GY_{n,t}}{\Omega_{n,t}}$ = gross output

$\sum_q Pq_{n,t} Vq_{n,t}$ = sum of expenditure

$pwbio_t$ = international price of woody biomass

$cwbio_{n,t}$ = average cost production (woody biomass)

$ctra_n$ = transporation cost woody biomass