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Modelling biomass with CCS in the WITCH model

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SUMMARY The present report describes the advancements related to GEMINA Work Package 6.2.3 reviewing mitigation issues which have been incorporated into different versions of the WITCH model.

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Introduction

The use of biomass is a prerequisite for generating power while producing negative emissions. Co-firing with fossil fuels such as coal is an important mitigation option that can fit into current the energy system without requiring major modifications. In fact, in addition to offering high conversion efficiency (>36%), biomass co-firing with coal requires relatively small changes at the power plants, and in ensures fuel flexibility. Globally, experience with biomass (or waste) co-firing with coal comes from about 150 power plants, either as pilot tests or in commercial use (IEA Bioenergy, 2007). If biomass is fed into IGCC power plants equipped with a technology for capturing and storing emissions (CCS), it can yield negative emissions, making it possible to achieve the very low stabilization targets that require technologies capable of removing CO2.

Introducing the woody biomass supply curves derived by GLOBIOM into WITCH first required a regional matching between the two different aggregations considered in these models. While a perfect matching is evidently not possible, it was guaranteed that the supply curves of main producer areas in GLOBIOM were consistently attributed to WITCH regions.

Table 1. Regional matching

<table>
<tr><th>WITCH regions</th><th colspan="2">GLOBIOM Regions</th></tr>
<tr><td rowspan="2">LACA</td><td>BRAp</td><td>MEXp</td></tr>
<tr><td>RCAMp</td><td>RSAMp</td></tr>
<tr><td>CAJAZ</td><td>CANp</td><td>JPNp</td></tr>
<tr><td>CHINA</td><td colspan="2">CHNp</td></tr>
<tr><td>KOSAU</td><td>CORp</td><td>RJANp</td></tr>
<tr><td>MENA</td><td colspan="2">MENAp</td></tr>
<tr><td>SASIA</td><td colspan="2">RSASp</td></tr>
<tr><td>India</td><td colspan="2">NDEp</td></tr>
<tr><td>EASIA</td><td colspan="2">RSEAp</td></tr>
<tr><td>SSA</td><td colspan="2">SSAFp</td></tr>
<tr><td>US</td><td colspan="2">USAp</td></tr>
<tr><td>TE</td><td>USSRp</td><td>RoWp</td></tr>
<tr><td>New Europe</td><td colspan="2" rowspan="2">EU27p*</td></tr>
<tr><td>Old Europe</td></tr>
</table>

* The Globes EUp27 region was splited into New and Old Europe regions in WITCH

The final aim of this exercise envisaged the use of second generation bioenergy for electricity generation. Accordingly, the original information provided by GLOBIOM required two additional modifications before it could be actually implemented in WITCH. First, it was necessary to obtain the carbon content contained in these supply curves; second, it was needed to obtain their energy content.

For the first step, and as that the data originally provided by GLOBIOM was expressed in m3, we converted it into Kg. The coefficient used for this aim equals 400Kg/m3. This number was chosen following the paper by Senelwa et al (1999) who studied fuel characteristics of biomass from 12 short rotation species.

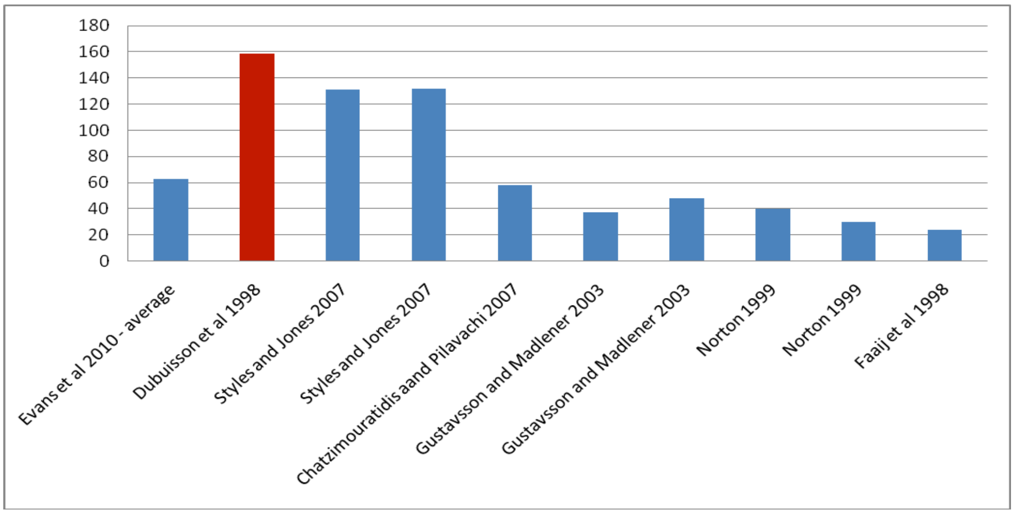
The values for these species range from 388Kg/m3 to 485Kg/m3, the average value equals 443Kg/m3. Once the data was translated into KG it was then possible to obtain its corresponding carbon content. The coefficient used here equals 0.5, that is, we assumed that 50% of wood is carbon. This is by far the most used number in the literature. While some studies contest it (Lamlom and Savidge 2003, Thomas and Malczewski 2007), the ranges of variation presented are, nonetheless, small: 48.4%-51% for the latter and 46.27%-49.97% or 47.21%-55.2% for the former, depending on tree characteristics. Finally, the coefficient used to convert woody biomass cubic meters into GJ Energy was directly provided by IIASA and equals 7.5GJ/m^3.

CONVERSION COEFFICIENT FACTOR

Correctly accounting for greenhouse gas emissions is a crucial element in a biomass power production analysis. A very common assumption asserts that this type of biomass is carbon neutral, in the sense that emissions resulting from combustion had been previously compensated by forest carbon sequestration. Central to this assumption is, however, land use change emissions resulting from an increase of short rotation forests areas. In fact, if bioenergy plantations were to march into previous natural forests, major initial land use emissions occurring at this phase could compromise woody biomass carbon neutrality. Accordingly, the curves derived by GLOBIOM for this study were constructed under land use change restrictions that guarantee it. As a result, woody biomass is treated in WITCH as a carbon neutral energy. Notwithstanding this, fertiliser use, farming management, harvesting and transportation imply additional emissions resulting from fossil fuel usage. A rather recent study (Evans et al. 2010) provides a survey on life cycles assessment for electricity production using woody biomass energy sources (see figure 1). While this study covers a large number of different electricity generation technologies it leaves outside the one considered in our analysis, i.e., co-combustion with coal. Accordingly, we follow Dubuisson and Sintzoff 1998 who provides final carbon emission factors for short run coppices (SRC) used to produce electricity with this type of technology. While the life cycle assessment undertaken in this study covers the all process involving this type of bioenergy, from cultivation to fuel pre-treatment and final conversion, it is produced building upon Belgium SRC's. To take this into account we performed a sensitivity analysis.

Figure 1: Life cycle emissions (gCO2/kWh).

Sources: Evans et al. 20101 and Dubuisson er al 1998



CO-FIRING OF WOODY BIOMASS AND COAL IN THE WITCH MODEL

The supply curves of second generation biomass from GLOBIOM were introduced into the WITCH model as step functions describing biomass marginal costs associated with different quantity classes.

Biomass can be currently co-fired in coal-fired power plants at a 10% fuel share on energy basis (NETBIOCOF, 2006) and there are only few examples with higher shares (20%). Because of the lack of information on how this share is likely to evolve in the far future, given the long-time horizon of the model and its optimization nature, we decided not to impose any exogenous constraint on the share of co-firing. Both feedstock (coal and biomass) can be used to feed coal power plants and each region *n* chooses the optimal mix on the basis of coal and biomass availability at any time period *t*, and their relative cost. Both IGCC technologies (equation 1) and traditional power plants using pulverized coal (equation 2) can be used for co-firing:

$$ELIGCC(n,t) = \sum_{cl} WBIO\_IGCC(cl,n,t) * (\mathrm{XSI\_COAL\_IGCC(n,t)} - 0.05) + COAL\_IGCC(n,t) * \mathrm{XSI\_COAL\_IGCC(n,t)} \quad (1)$$

$$ELPC(n,t) = \sum_{cl} WBIO\_PC(cl,n,t) * (\mathrm{XSI\_COAL\_IGCC(n,t)} - 0.05) + COAL\_PC(n,t) * \mathrm{XSI\_COAL\_IGCC(n,t)} \quad (2)$$

As it can be seen from equation (1) and (2), we assumed a 5% lower conversion efficiency compared to coal. We included a cost penalty of 20% for investment costs, which increases with the share of woody biomass (equation 4 and 5):

$$K\_IGCC(n,t) = (1 - DELTA(t,n) * K\_IGCC(n,t) + I\_IGCC(n,t) / (1 + \\ 0.2 * \sum_{cl} WBIO\_IGCC(cl,n,t) / (\sum_{cl} WBIO\_IGCC(cl,n,t) + COAL\_IGCC(n,t)) / INICOSTS(n,t) / 1000 \tag{4}$$

$$K\_PC(n,t) = (1 - DELTA(t,n) * K\_PC(n,t) + I\_PC(n,t) / (1 + \\ 0.2 * \sum_{cl} WBIO\_PC(cl,n,t) / (\sum_{cl} WBIO\_PC(cl,n,t) + COAL\_PC(n,t)) / INICOSTS(n,t) / 1000 \tag{5}$$

Following Dubuisson and Sintzoff (1998) biomass produces positive emissions, about CO2 emissions 12 Kg/GJ, which is accounted for into the emission equation. The cost of biomass is paid out of the budget constraint:

$$\begin{aligned} Ynet(n,t) = & \frac{TFP(n,t)\left[\alpha(n)\cdot\left(K_C{}^{1-\beta(n)}(n,t)L^{\beta(n)}(n,t)\right)^{\rho} + (1-\alpha(n))\cdot ES(n,t)^{\rho}\right]^{1/\rho}}{\Omega(n,t)} \\ & - \sum_f \left(P_f(n,t)X_{f,extr}(n,t) + P_f^{\text{int}}(t)X_{f,netimp}(n,t)\right) \\ & - P_{CCS}(n,t)CCS(n,t) \\ & - \sum_{cl} WBIO\_PC(cl,t,n) * CL\_WBIO(cl) \\ & - \sum_{cl} WBIO\_IGCCC(cl,t,n) * CL\_WBIO(cl) \end{aligned} \tag{6}$$

List of Variables:

ELIGCC = Electricty Generated Using IGCC Power Plants

ELPC= Electricty Generated Using Traditional Coal Power Plants

I_SC = Investments In Coal Power Plants

I_SIGCC = Investments In Igccl Coal Power Plants

K_SC = Capital In Traditional Coal Power Plants

K_SIGCC = Capital In Igccl Coal Power Plants

INICOST = Investments Cost Power Plant

XSI_COAL_IGCC = Thermal Efficiency Of The Coal IGCC Power Plant

XSI_COAL_PC = Thermal Efficiency Of The Conventional Coal Power Plant

ST_COAL = Stechiometric coefficient – COAL

$\sum_{cl} WBIO\_IGCC(cl)$ = Woody Biomass in IGCC power plants

$\sum_{cl} WBIO\_PC(cl)$ = Woody Biomass in PC power plants

$CL\_WBIO(cl)$=cost level of woody bio USDperGJ DOLLAR 2000

WITCH includes baseline projections for land-use emissions as well as estimates of global potential and costs of reducing emission from deforestation (Eliasch 2008). However, there is no competition with short-rotation crops for woody biomass because supply curves in GLOBIOM were generated under the assumption of

Some selected results from baseline and stabilisation scenarios are reported in Figure 2,3 and Table 2.

Figure 2: Primary energy mix with (left) and without (right) bioenergy in the power sector (550 ppme)

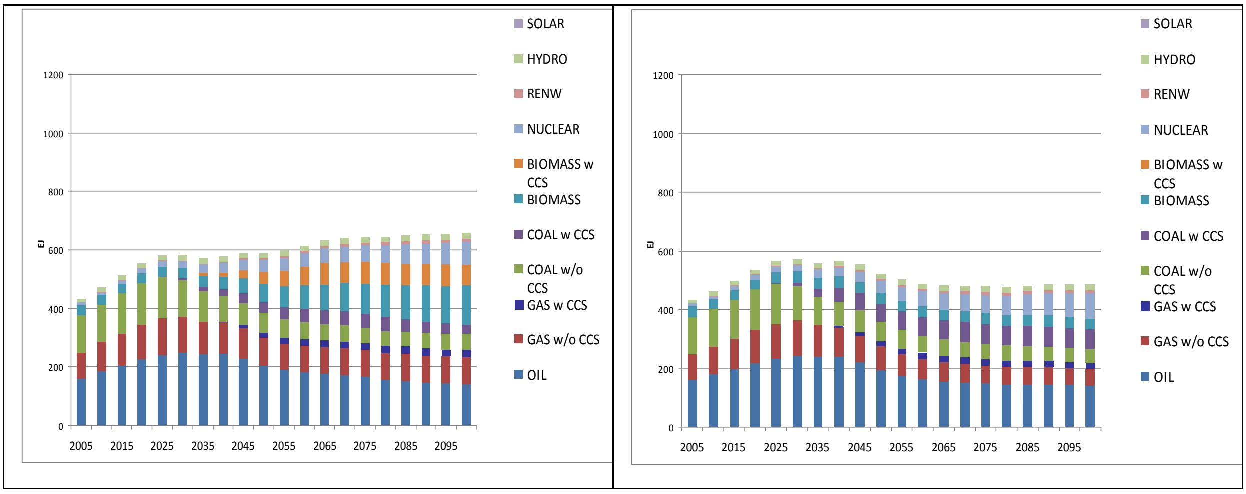


Figure 3: Sensitivity on life cycle emissions. Primary energy mix with (left) and without (right) life cycle emissions (450 ppme)

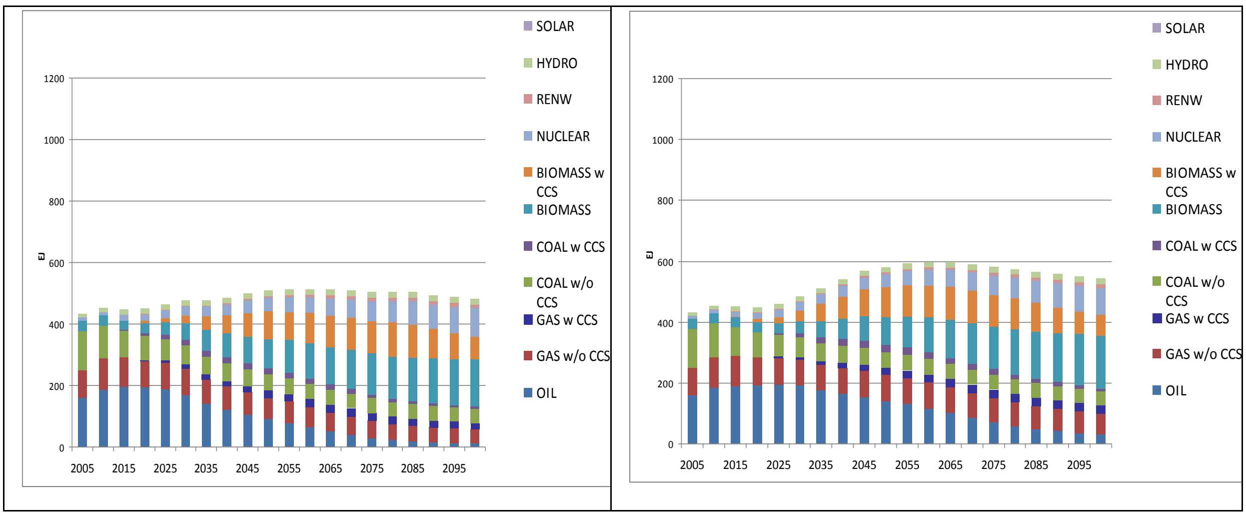


Table 2: Policy costs – discounted gross world product percentage change compared to BaU

550	550 w/o bioenergy	550 w/o life cycle emissions	450	450 w/o life cycle emissions
-1.47%	-2.32%	-1.47%	-4.37%	-3.20%

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