Supplementary material

Life cycle impact assessment of *Miscanthus giganteus* for a sustainable household heating in Serbia

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1. Modified Ecoinvent and Agri-footprint processes used in LCA of Miscanthus, wood logs, lignite briquettes and sensitivity analysis (future scenario)

In order to construct a system that coincides with potential Miscanthus briquettes supply chain in the Republic of Serbia, several modifications were made in processes integrated in SimaPro inventory bases, such as Ecoinvent and Agri-footprint. All modifications are summarized in Table 1 of this document.

In cases where electricity is used as an input only electricity produced in the Republic of Serbia is considered. Although existing in Ecoinvent 3 database, process "Electricity, high voltage {RS}| market for | Alloc Def, U" was modified since, according to authors of this publication, share of certain electricity sources did not match the real case. Modification made for this process are:

1) Electricity, high voltage {RS}| electricity production, hydro, pumped storage | Alloc Def, U 0,011637379 kWh ≈1.16 %;
2) Electricity, high voltage {RS}| electricity production, hydro, reservoir, alpine region | Alloc Def,U 0,035400908 kWh ≈3.54%;
3) Electricity, high voltage {RS}| electricity production, hydro, run-of-river | Alloc Def, U0,185872222 kWh ≈18.59 %;
4) Electricity, high voltage {RS}| electricity production, lignite | Alloc Def, U 0,547143023 kWh ≈54.71 %;
5) Electricity, high voltage {RS}| electricity production, natural gas, at conventional power plant | Alloc Def, U 0,008541836 kWh ≈0.85 %;
6) Electricity, high voltage {RS}| electricity production, oil | Alloc Def, U 0,003537763 kWh ≈ 0.35 %.

1.1. Miscanthus

In Miscanthus Life cycle, instead of using "Electricity, medium voltage {GLO}, market for" for herbicide production and for briquetting, Electricity mix for Republic of Serbia was chosen (discussed above).

1.2. Wood logs

1. In Wood logs life cycle, in process named "Heat, central or small-scale, other than natural gas {RoW}| heat production, mixed logs, at furnace 30 kW", only low voltage electricity produced in Republic of Serbia is used, while electricity produced from other countries is set to zero. Only "Transport, freight, lorry >32 metric ton, EURO3 {GLO}| market for | Alloc Def, U" is considered, while all other Transports are excluded. For transporting 1 kg of Cleft timber for 100 km we have: 0,001t*100km=0,1tkm.
2. Considering inputs of cleft timber, modifications are made according to [1]: "The most dominant forest species in Serbian forest is beech (47%), followed by oak (25%) and other hardwood species (17%). Regarding softwood species, 2% represents pine, 5% spruce and 3% fir. Other softwood and some hardwood species account for a mere 1%":
    1) "Cleft timber, measured as dry mass {RoW}| hardwood forestry, beech, sustainable forest management | Alloc Def, U" = 0.47 kg per 1 kg of "Cleft timber, measured as dry mass {GLO}| market for | Alloc Def, U";
    2) Share of 1 % from "other softwood and some hardwood species" is assigned to oak:

"Cleft timber, measured as dry mass {RoW}| hardwood forestry, oak, sustainable forest management | Alloc Def, U" = 0.26 kg per 1 kg of "Cleft timber, measured as dry mass {GLO}| market for | Alloc Def, U";

   3) Inputs for other hardwood species are assigned to birch: "Cleft timber, measured as dry mass {RoW}| hardwood forestry, birch, sustainable forest management | Alloc Def, U" = 0.17 kg per 1 kg of "Cleft timber, measured as dry mass {GLO}| market for | Alloc Def, U";
   4) Since no input for fir was found in database, 3% of fir was divided to spruce and pine:
      a) "Cleft timber, measured as dry mass {RoW}| hardwood forestry, pine, sustainable forest management | Alloc Def, U" = 0.04 kg per 1 kg of "Cleft timber, measured as dry mass {GLO}| market for | Alloc Def, U";
      b) Cleft timber, measured as dry mass {RoW}| hardwood forestry, spruce, sustainable forest management | Alloc Def, U = 0.06 kg per 1 kg of "Cleft timber, measured as dry mass {GLO}| market for | Alloc Def, U";
   5) "Cleft timber, measured as dry mass {RoW}| cork forestry | Alloc Def, U" is set to zero, like all other "Cleft timber" inputs.

1.3. Lignite briquettes

In process "Heat, central or small-scale, other than natural gas {RoW}| heat production, lignite briquette, at stove 5-15 kW", modification is made in input process "Lignite briquettes {GLO}| market for | Alloc Def, U":

Transport by transoceanic tanker and barge tanker are excluded. Only three Transportation Processes considered are:

1) Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, U
2) Transport, freight, lorry, unspecified {GLO}| market for | Alloc Def, U
3) Transport, freight train {Europe without Switzerland}| market for | Alloc Def, U

Values of tkm for these included Transportation processes are allocated from aforementioned excluded processes and other excluded Transportation processes, which are using the same transportation vehicles but referred to regions outside the Europe.

Modified process "Electricity, high voltage {RS}| market for | Alloc Def, U" is also used as an input.

1.4. Sensitivity analysis

For sensitivity analysis, process "Electricity, high voltage {RS}| market for | Alloc Def, U" is modified. Instead of high voltage electricity imported from from Bulgaria, Hungary and Romania, Renewable energy sources are considered to have 20% share:

1) Electricity, high voltage {RoW}| electricity production, geothermal | Alloc Def, U
   0,0619574071919004 kWh ≈ 6 %;
2) Electricity, high voltage {RoW}| electricity production, wind, 2.3MW turbine, precast concrete tower, onshore | Alloc Def, U
   0,0619806819504248 kWh ≈ 6 %;
3) Electricity, high voltage {RoW}| heat and power co-generation, wood chips, 6667 kW | Alloc Def,U
   0,082625392761550 kWh ≈ 8 %.

Table S1. Modified Ecoinvent and Agri-footprint processes used in LCA of Miscanthus, wood logs, lignite briquettes and sensitivity analysis (future scenario):

<table>
<tr><th></th><th>Prosess name:</th><th colspan="3">Modification applied:</th></tr>
<tr><td rowspan="2">Miscanthus</td><td>“Glyphosate {RER}| production | Alloc Def, U”</td><td colspan="2">“Electricity, medium voltage {RS}| market for | Alloc Def, U”</td><td>1.2 kWh kg^{-1}</td></tr>
<tr><td>Briquetting</td><td colspan="2">“Electricity, medium voltage {RS}| market for | Alloc Def, U”</td><td>7.7 kWh h^{-1}</td></tr>
<tr><td rowspan="8">Wood logs</td><td>“Heat, central or small-scale, other than natural gas {RoW}| heat production, mixed logs, at furnace 30 kW”</td><td colspan="2">“Electricity, low voltage {RS}| market for | Alloc Def, U ”</td><td>0.014 MJ MJ^{-1}</td></tr>
<tr><td rowspan="7">Cleft timber, measured as dry mass {GLO}| market for | Alloc Def, U</td><td colspan="2">Transport, freight, lorry >32 metric ton, EURO3 {GLO}| market for | Alloc Def, U</td><td>0.1 tkm kg^{-1}</td></tr>
<tr><td colspan="2">Cleft timber, measured as dry mass {RoW}| cork forestry | Alloc Def, U</td><td>0 kg</td></tr>
<tr><td colspan="2">Cleft timber, measured as dry mass {RoW}| hardwood forestry, beech, sustainable forest management | Alloc Def, U</td><td>0.47 kg kg^{-1}</td></tr>
<tr><td colspan="2">Cleft timber, measured as dry mass {RoW}| hardwood forestry, oak, sustainable forest management | Alloc Def, U</td><td>0.26 kg kg^{-1}</td></tr>
<tr><td colspan="2">Cleft timber, measured as dry mass {RoW}| hardwood forestry, birch, sustainable forest management | Alloc Def, U</td><td>0.17 kg kg^{-1}</td></tr>
<tr><td colspan="2">Cleft timber, measured as dry mass {RoW}| softwood forestry, pine, sustainable forest management | Alloc Def, U</td><td>0.04 kg kg^{-1}</td></tr>
<tr><td colspan="2">Cleft timber, measured as dry mass {RoW}| softwood forestry, spruce, sustainable forest management | Alloc Def, U</td><td>0.06 kg kg^{-1}</td></tr>
<tr><td rowspan="4">Lignite briquettes</td><td rowspan="4">“Heat, central or small-scale, other than natural gas {RoW}| heat production, lignite briquette, at stove 5-15 kW”</td><td rowspan="3">Lignite briquettes {GLO}| market for | Alloc Def, U</td><td>Transport, freight, light commercial vehicle {GLO}| market for | Alloc Def, U</td><td>9.23077E-05 tkm</td></tr>
<tr><td>Transport, freight, lorry, unspecified {GLO}| market for | Alloc Def, U</td><td>0.007471795 tkm</td></tr>
<tr><td>Transport, freight train {Europe without Switzerland}| market for | Alloc Def, U</td><td>0.00225641 tkm</td></tr>
<tr><td>Lignite briquettes {RoW}| production | Alloc Def, U</td><td>Electricity, high voltage {RS}| market for | Alloc Def, U</td><td>0.09 MJ MJ^{-1}</td></tr>
<tr><td rowspan="3">Future scenario</td><td rowspan="3">Briquetting</td><td rowspan="3">“Electricity, medium voltage {RS}| market for | Alloc Def, U”</td><td>Electricity, high voltage {RoW}| electricity production, geothermal | Alloc Def, U</td><td>0.0619574071919004 kWh</td></tr>
<tr><td>Electricity, high voltage {RoW}| electricity production, wind, 2.3MW turbine, precast concrete tower, onshore | Alloc Def, U</td><td>0.0619806819504248 kWh</td></tr>
<tr><td>Electricity, high voltage {RoW}| heat and power co-generation, wood chips, 6667 kW | Alloc Def, U</td><td>0,082625392761550 kWh</td></tr>
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2. Soil Organic Carbon

In this section results presented in Table 3 and Table 4 of the main manuscript are explained in a greater detail.

2.1. Calculation of Miscanthus aboveground residual biomass

After the maximal Miscanthus growth season in summer until February, when crop is harvested, decrease in Miscanthus yield due to loss of leaves and upper parts of the plant is estimated around 35% [2]. This implies that maximal Miscanthus yield can be around 46.15 t. By subtracting Miscanthus yield at harvest from maximal Miscanthus yield, 16.15 t of biomass is obtained. In other words 16.15t of Miscanthus biomass stays on the soil. This amount of biomass is further drying on the field. From the beginning of Miscanthus biomass decrease till the harvest, water content of biomass drops from 55% to 33.5% [2]. At the moment of harvest 10.92 t (66.5% d.m.) of residual biomass can be obtained. This value is further considered as mass of aboveground residual biomass.
This result is in correlation with the result obtained by Hamelin et al. and Olsen et al., who obtained around 10.88t of d.m. ha^{-1} yr^{-1} from 4-20 years old Miscanthus plantation [3].

2.2. Calculation of Miscanthus belowground biomass

According to Hamelin et al., the bellowground biomass is estimated as 16% of the total above ground biomass (harvest + aboveground residue)"[3]. Considering average Miscanthus yield of 23.5 t, the mass of belowground biomass is 5.5 t:
(23.5 t + 10.92 t= 34.42, where 16 % is 5.5 t).

Same model is used for calculation aboveground residual biomass and belowground biomass from maximal and minimal Miscanthus yield.

2.3. Carbon content of above and belowground biomass

C-content of above and belowground biomass is calculated considering 0.483 t C per t d.m. Miscantus biomass [4].

2.4. Direct and indirect N_2O emissions from Miscanthus cultivation

Considering mass of the above and belowground Miscanthus biomass and methodology presented by IPCC, calculation of direct and indirect N_2O emissions from Miscanthus cultivation is done.
N content in aboveground biomass is calculated according to IPCC formula: 0.01 kg of N emitted per kg d.m.[5]. N content in belowground biomass is calculated according to IPCC formula: 0.005 kg of N emitted per kg d.m. [5].
N_2O-N_{dir}: direct N_2O emissions are calculated according to IPCC formula: $N_20\text{-}N = [(100kg + [a+b]) \bullet 0.01]$, where 100 kg is the amount of N fertilizer used annually on chernozem experimental field, 0.01 is emission factor recommended by IPCC;

N_2O_{dir}: Conversion of N_2O-N emissions to N_2O for reporting purposes is performed by using the following equation: N_2O-N_{dir} • 44/28 [5];
***Indirect* N_20 emissions** are calculated according to IPCC formula: $N_2O_{(ATD)}$-N = (100kg +0.1) • 0.01, where 100 kg is the amount of N fertilizer used, and 0.1 and 0.01 are values recommended by IPCC. Considering conversion for reporting purposes, same as for direct emissions (• 44/28), indirect N_20 emissions are 0.08 kg;

2.5. Calculations of CO_2 eq total emissions

For calculation of CO_2 eq total emissions, GWP of N_2O is taken to be 298 times higher than of CO_2.
CO_2 eq total emissions are calculated as **X** + **Y**,
where X represents CO_2 eq emitted along whole annual Miscanthus life cycle (field operations, briquetting, transport) which are around 1.2 t ha^{-1} yr^{-1} and Y represents CO_2 eq, from N_2O transformation; Value of **X** is given in Table 2 of the main manuscript, and values of **Y** are given in Table 3 of the main manuscript.

2.6. Carbon sequestration potential from Miscanthus cultivation

Calculations of carbon sequestration potential from Miscanthus cultivation are mostly based on model given by Matthews and Grogan [6].
Gross soil C sequestration potential is also calculated as **Gross CO_2 emission reduction**, considering C mass of 12 g and CO_2 mass of 44 g;

References:

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