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Biochar Pellet Carbon Footprint

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Life cycle assessment of Biochar was performed in this study using SimaPro software, aiming at the evaluation of the carbon footprint of biochar. Product Category rules have been developed. Data have been collected in a demonstrative slow pyrolysis plant, which is present at the University of Perugia and from field tests. The technical standard followed is ISO/TS 14067. Biochar, used as a soil amendment can improve soil health and fertility, soil structure, nutrient availability, soil-water retention capacity and is also a mechanism for long term Carbon storage in soils. Carbon sequestration in soils can be seen not only as a strategy to mitigate the global climate change, but also as a source of profit for companies via Carbon Credits. LCA is a useful tool to estimate the Carbon balance through all the Biochar life cycle. The feedstocks considered in this study is miscanthus, a perennial herbaceous energy crop. The functional unit is one ton of dry matter of initial feedstock (that is miscanthus biomass). The final carbon footprint is equal to -737 kgCO2eq/t of feedstock dried.

1. Introduction

There is an urgent need to develop strategies for mitigating global climate change. Promising approaches to reducing anthropogenic greenhouse gas (GHG) emissions often include energy generation from climate neutral renewable resources. However, pyrolysis of biomass with biochar applied to soil offers a direct method for sequestering carbon and generating bioenergy (Lehman 2007). Because carbonizing biomass stabilizes the carbon that has been taken up by plants, sustainably produced biochar applied to soils may proactively sequester carbon from the atmosphere, while also generating energy. Pyrolysis with biochar applied to soil offers potential solutions to the current climate and energy concerns. This is an example of polygeneration technology useful to build agroenergy districts (see Manos et al. 2014). However, to avoid unintended consequences of a new technology or mitigation strategy, it is necessary to conduct analyses of potential life-cycle impacts of biochar pyrolysis systems, as it would be undesirable to have the system actually emit more GHG than sequestered or consume more energy than it is generated. Because of its “cradle-to-grave” approach and transparent methodology, life cycle assessment (LCA) is an appropriate tool for estimating the energy and climate change impacts of pyrolysis-biochar systems. In this paper, LCA is used to estimate the full life-cycle GHG emissions balance. Roberts et al. 2010 analysed the LCA of biochar made from different sources: crops residues (corn stover) and bioenergy crops (switchgrass). The results show that the net GHG emissions for stover and other yard wastes range from -793 to -885 kgCO_2/t dry biomass. For switchgrass the net GHG emissions are comprised between -442 and +36 kgCO_2/t dry biomass, the difference depends from the land use model adopted. In Ibarrola et al. 2012 it is reported a carbon abatement due to biochar, that ranges from 0.07 tCO_2eq (for cardboard, used as raw material for the production of biochar) to 1.25 t CO_2eq per tonne of feedstock (for wood waste), being biochar used for soil and crop enhancement purpose in field. There are no data available on LCA of biochar produced from miscanthus, this represents the scientific value added of the work. The approach adopted was to monitor miscanthus growth and production in experimental fields, describing also cultivation practices and reporting inputs and outputs in a field registry. Pyrolsis mass and energy balances are calculated based on previous work on an Integrated Pyrolysis Regenerated Plant available at the University of Perugia. The obtained biochar has been pelletized in a small scale machine, measuring electricity consumption. All these measures have been used to derive data to insert in the software SimaPro, version 8.

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2. Material and methods

2.1 Experimental fields

Five experimental fields situated in different sites throughout Umbria territory were realized during 2007 and 2012 by the Biomass Research Centre, University of Perugia:

- Trestina, field established in collaboration with private farmer (the energy crops tested were: sorghum, hemp, kenaf);
- Pietrafitta field, established in collaboration with local agency (the energy crop tested was: black locust) see Cotana et al. 2006 and Bidini et al. 2005;
- Beroide field, established in collaboration with a private farmer (the energy crops tested were: poplar clones);
- Montelabate field, established in collaboration with a private farmer (the energy crops tested were: Jerusalem artichoke, black locust, poplar clones);
- Casalina field, established in collaboration with Perugia University experimental farm (the energy crops tested were: Jerusalem artichoke, poplar clones, sunflower, sorghum, miscanthus, Arundo donax and cardoon).

Figure 1: Miscanthus fields in the experimental farm of the University of Perugia

2.2 Integrated Pyrolysis Regenerated Plant (IPRP)

The Integrated Pyrolysis Regenerated Plant (IPRP) technology is mainly composed of a Gas Turbine (GT) fuelled by gas obtained by slow pyrolysis of biomass and/or wastes in an externally heated reactor. The energy required to sustain the pyrolysis process is provided by the exhaust gases of the GT and by combustion of pyrolysis process products, such as volatiles (tars) and solid (char).

Figure 2: Integrated Pyrolysis Regenerated Plant (IPRP)

The average characteristics of biochar are shown in the paper of Paethanom et al. 2013. Char is made of 70% carbon, 3% hydrogen and 0.6% nitrogen. Ash content is about 7%. Some pelletization tests of biochar have been published by Hu et al. 2015 and Peng et al. 2015. From these publications a mix to be pelletized made of 5% binder (mainly corn starch), 5% sawdust and 90% biochar was found to be optimal.

Figure 3: Milled char to be pelletized (left) pelletized biochar (right)

2.3 Pelletizing tests

Pelletizing tests have been performed at the Laboratories of the Biomass Research Centre, University of Perugia using biochar produced from local biomasses. The results are applied to miscanthus assuming that the different biomass doesn't affect pelletizing process. The machine is produce by Smartec and the model is PLT 100. The main features are the following: product mass flow about 40 kg/h, pellet diameter about 6 mm, engine power about 4 kWe, machine weight 100 kg.

Figure 4: Pelletizing machine (Smartec PLT 100)

3. Biochar Carbon Footprint Calculation

For the calculation of biochar footprint Product Category Rules (PCR) were drafted according to the product category rules for "Charcoalization Products of wood and Bamboo" prepared by the Taiwan Eco-Materials Industry Development Association.

Table 1: Product category rules for the carbon footprint of pelletized biochar

Stage	Rule	Description
Scope and Functional Unit	Scope of the study	Calculate PCF of biochar (expressed in kg CO2eq/t feedstock dried), based on ISO 14067
	System boundary	The following phases are considered: cultivation, transformation, packaging, distribution and use
	Functional unit	The functional unit considered is 1 ton of dry matter of feedstock.
	Allocation	Allocation is particularly important in the pyrolysis process. System Expansion is the approach to be chosen
	Time reference	Cultivation operation are refferred to the growing season 2011, while the time reference for biochar action in soil is supposed to be at least 100 years.
	Cut-off on LCA processes	The threshold of 1% is chosen
Product definition	Biochar	Biochar in this analysis is defined as the solid product of a slow pyrolysis process to be pelletized and used as soil amendment
Data collection & quality	Cultivation	The following processes are comprised: fertilization, harvest, weeding, irrigation, haying and baling, ploughing
	Pyrolysis	Pyrolysis data are taken from the Integrated Pyrolysis Regenerated Plant (IPRP) of the University of Perugia
	Use	It is assumed that the biochar is pelletized, packed and then spread in the soil. Data on pellettization are collected through experimental tests
Carbon Footprint calculation	Software	Simapro software is used to design process tree, and calculate PCF, the method used is IPCC 2013
	Norm	ISO TS 14067
Results communication	Label	A carbon footprint label is designed for the package

In table 1 a draft of a possible PCR table is reported, following the methodology reported in Fantozzi et al. 2015. In the biochar use stage the action as a carbon sink in the soil is considered. An application of 5 t/ha of biochar is assumed. Dealing with allocation, the most important case can be found for the pyrolysis process.

As it has been already discussed in Bartocci et al. 2016, the useful products are three: biochar, electricity and heat. Fort the last one heat produced with methane is considered as an avoided product, while for electricity generated through pyrolysis, electricity coming from the Italian grid is considered as and avoided product. The functional unit used in this study is equal to 1 ton of dry matter of feedstock (that is miscanthus biomass).

4. Results

4.1 Cultivation: mass and energy balances

From the monitoring activities of the experimental fields, presented in section 2, it has been derived an average productivity of 66 t of biomass per hectare. The moisture at harvest is about 40%, so the total dry matter harvested is about 39.6 t d.m./ha. Total volatiles are about 83.55 %d.b., ashes are about 4.03 % d.b., fixed carbon is about 12.42% d.b. The Higher Heating Value of biomass is 17,280 kJ/kg. The following processes have been considered in the cultivation phase: miscanthus rhizome production, ploughing, rhizome planting, fertilizing, irrigation, mechanical weeding, haying and baling, biochar spreading in soil (once pelletized). The quantity of biochar applied to soil was supposed to be about 5 t/ha. Carbon storage activity was estimated, through the data reported by Hammond et al. 2011.

4.2 Transformation: mass and energy balance

Data on the materials that compose the IPRP plant are proposed in table 2. This materials are used for more than one year in the biochar supply chain. For this reason it is assumed to take one fifteenth of the plant every year, assuming a duration of the plant of 15 years.

Table 2: Materials required to produce the IPRP plant

Material	Weight (kg)
Steel	17,547
Concrete	5,411
Copper	95
Cast Iron	8
Aluminium	208
Iron	580
Rockwool	33
Plastic	147
Total	24,029

From Bartocci et al 2016 it is inferred that for one hectare cultivated with miscanthus about 13 t biochar can be produced together with 14,000 MJ of electricity and 24,000 MJ of heat. The electrical energy required to pelletize one kilogram of biochar (as measured through experimental tests) is equal to: 0.05 kWh/kg. This value was compared with that provided in the software Simapro for the pellet production process.

4.3 Carbon Footprint calculation results

The total carbon footprint calculated resulted to be equal to -737 kgCO2eq/t of feedstock dried.

Table 3: Contribution of single phases to the PCF of biochar

Life cycle stage	Contribution (kg CO2eq/t feedstock dried)	Contribution (%)
Cultivation	199	-27
Pyrolysis	52	-7
Pelletizing	22	-3
Packaging	7	-1
Use in soil as a carbon sink	-368	50
Avoided use of heat	-251	34
Avoided use of electricity	-398	54
Total	-737	100

As it can be seen from table 3 the contribution of the cultivation phase, pyrolysis process, pelletization process and packaging process to the whole carbon footprint of biochar is limited, while of great importance is the carbon sink effect, that accounts for 50% of the positive effect of biochar. Avoided heat and electricity through pyrolysis CHP contribute also respectively 34 and 54% to the abatement of GHGs.

5. Discussion

The value of the carbon footprint of biochar found in this work is consistent with other results presented in literature, as it can be seen from figure 5. The final carbon footprint value (-737 kgCo2eq/t feedstock) is between the value of -442 kgCO2eq/t feedstock (calculated by Roberts et al. 2010 for switchgrass biochar) and the value of 1248 kgCO2eq/t (derived from some data proposed by Gaunt and Lehman 2008 for biochar produced from miscanthus pyrolysis). In the first case the value is lower than that proposed in this work, due to different procedures to calculate GHG emissions and land use change. In the second case the value is higher due to a more detailed evaluation of the benefits caused by biochar in soil (for example nitrogen fertilizer reduction and reduction in N_2O emissions from the soil).

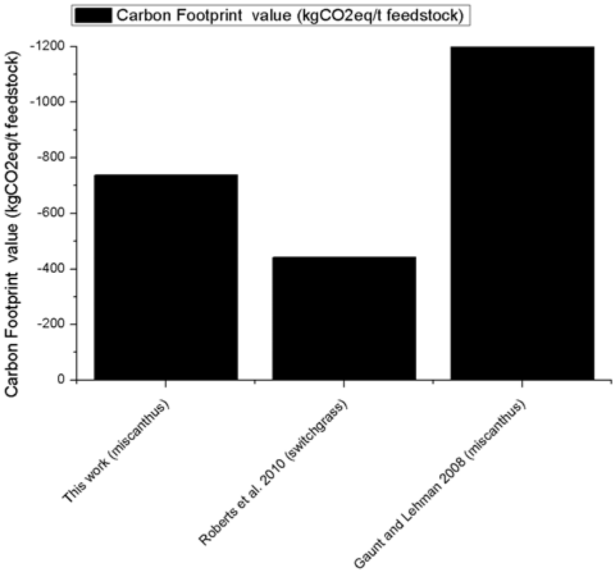

Figure 5: Comparison among different carbon footprint of biochar produced from perennial grasses

6. Conclusions

In this work miscanthus growth and production have been monitored in experimental fields, describing also cultivation practices and reporting inputs and outputs in a field registry. Pyrolsis mass and energy balances are calculated based on previous work on an Integrated Pyrolysis Regenerated Plant, available at the University of Perugia. The obtained biochar has been pelletized in a small scale machine, measuring electricity consumption. All these measures have been used to derive data to insert in the software SimaPro, version 8. The scientific added value of the paper is represented by the species of plants used to produce biochar (in fact LCA of biochar production from miscanthus was not studied before). The total carbon footprint calculated resulted to be equal to -737 kgCO2eq/t of feedstock dried. The contribution of the cultivation phase, pyrolysis process, pelletization process and packaging process to the whole carbon footprint of biochar are about -38%, while of great importance is the carbon sink effect, that accounts for 50% of the positive effect of biochar. Avoided heat and electricity through pyrolysis CHP contribute respectively for 34 and 54% of the GHG abatement.

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