Life cycle energy and environmental assessment of generating electricity from Short Rotation Woody Crops of *Eucalyptus globulus*

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Abstract

Through the use of biomass in combustion, operating coal plants have an opportunity to reduce their environmental impact. In order to asses such impact reduction, a Life Cycle Assessment (LCA) has been conducted on a coal-fired power plant able to co-fire *Eucalyptus globulus* from Short Rotation Woody Crops (SRWC). Besides comparing the production and emissions of the two fuels in both scenarios, we also consider the consequences regarding land use, assuming that production of *E. globules* from SRWC competes with maize production. However, to ensure comparability with other studies, we also conducted the LCA neglecting land use change. In this case, co-firing has better environmental and energetic performance. If land use change impacts are considered, then most positive impacts of co-firing are reduced, but the scenario still compares favorably to the combustion scenario.

Keywords: SRWC, co-firing, combustion, land use change, environmental impact.

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1. Introduction

Nowadays, the worldwide emerging demand for energy originates environmental concerns, namely regarding the use of fossil fuels. In this context, the XXI century is envisioned to become the age of renewable biomass resources (Vega *et al*., 2010). Growing concerns about energy security, global increases in carbon dioxide emissions, local and regional air pollution, sustainability of natural resources, increasing demand for biodegradable products, and need to revitalize rural economies has made the development of sustainably produced biomass as a feedstock for bioenergy, a critical priority in Europe, and also in Portugal (COM, 2005).

Coal made possible an easy access to electricity, along with its benefits. However, the chemical make-up of coal, transportation and the older technologies used at most operating coal-fired power plants create significant environmental impacts. At the power plant, sulfur dioxide, nitrogen oxides, and particulate matter are released into the air. Additionally, because coal is a fossil fuel, its use results in the production of CO_2.

In an effort to reduce the environmental impacts associated with electricity production, owners and operators of coal-fired power plants considered adding biomass to their fuel mix. There were around 100 co-firing units in Europe, by the end of 2007. Currently, the number increased, and most co-fired plants import large quantities of biomass from abroad, according to the European Biomass Industry Association (EUBIA). Woody biomass grown specifically to produce energy reduces the net GHG produced per unit of electricity generated. Additionally, because of its low sulfur content, relative to coal, biomass can reduce power plant sulfur dioxide (SO_2) emissions. Biomass also contains less ash than coal, thus decreasing the amount of solid waste generated. Likewise, because biomass is more volatile than coal and usually contains lower amounts of fuel-bound nitrogen, co-firing may result in lower nitrogen oxide (NO_X). Other impacts associated with production and using coal, such as mining emissions, will also be reduced (Mann and Spath, 2001). Beyond the climate change mitigation, and the aim to achieve the goals of Kyoto Protocol, it also contributes to the reduction of energy dependency and thus, the increased security of supply. Indeed, there are disadvantages of co-firing, namely, since biomass is a poor fuel by comparison to coal, because it contains oxygen (O_2) and a substantial amount of moisture. Besides this, it can be expensive, although will depend on subsidies at present. Even more important is the fact that unsustainable production SRWC would erode the climate-related environmental advantages of bio-energy (Vis *et al*, 2008).

Biomass used as feedstock to bioenergy can come from a variety of sources including forests, agricultural crops and dedicated woody crops. Short rotation forestry refers to the growing of trees in extremely dense stands, harvested at 3-4 years intervals and regenerated from the stools, which are expected to survive 4 rotations, at least. As a rotation crop, it is harvested at specific intervals, to provide a regular and constantly renewable supply of biomass. The development and deployment of woody biomass resources has several advantages over agricultural sources. Woody biomass is available year-round from multiple sources, so end users are not dependent on a single source of material. The net energy ratios associated with bioenergy from woody biomass are large and positive, meaning that considerably more energy is produced from these systems than is used in the form of the fossil fuels to produce the biomass and generate electricity (Keoleian and Volk, 2005). Several studies show that SRWC will be the single most important source of biomass. The size of the worldwide contribution of SRWC in the future will be strongly influenced by factors such as land availability, environmental considerations, yield and socioeconomic conditions that will vary from region to region.

2. Method

2.1 LCA Tool

We use Life Cycle Assessment to analyze the environmental impact. We used the aggregation methods *Eco-indicator 95* and 99 in the SimaPro 7.2 software. SimaPro 7.2 was developed by the National Reuse of Waste Research Programme and Pré Consultants of the Netherlands, and is widely used in assessing environmental performance. It consists of a data base of inputs and outputs from several processes and production of materials. Therefore, the assessment of environmental impacts consists in the sum of impacts from each step of its life cycle. Impacts are then added by environmental themes. Even though the conclusions of the *Eco-indicator 95* and *Eco-indicator 99* are often similar, it is important to use both, as they present different themes and a different conception.

2.2 Estimating biomass in SRWC

In this study was made an effort to modeling *E. globulus* growth as SRWC, due to the fact that doesn't exist any publication about SRWC irrigated in the region that we aim to study, Ribatejo e Oeste (RO). Woody crops for energy proposes aren't yet implemented in Portugal in spite of a common growing interest from different sectors.

The simulation of *E. globulus* biomass production was developed using forest productivity models 3PG 2.5 and Globulus 3. We used two models to overpass the difficulty of 3PG in dealing with coppice. 3PG is a process-based model, requiring a restricted number of parameters easy to gather (Sands, 2004), combined with the empiric model Globulus (Tomé *et al.*, 2001).

The 3-PG model was developed by Joe Landsberg and Dick Waring (CSIRO – Australian Commonwealth Scientific and Research Organization), the Globulus model was developed by Margarida Tomé, Tânia Oliveira e Paula Soares (ISA - Superior Institute of Agronomy in Portugal).

2.3 Case study description

The main objective is the comparative analysis of electricity production in Sines and Pego coal-fired plants with a co-fired rate of 10% (on a heat input basis), where provide biomass, *E. globulus*, comes from a SRWC located in Ribatejo and Oeste (RO) (locations shown in Figure 1)

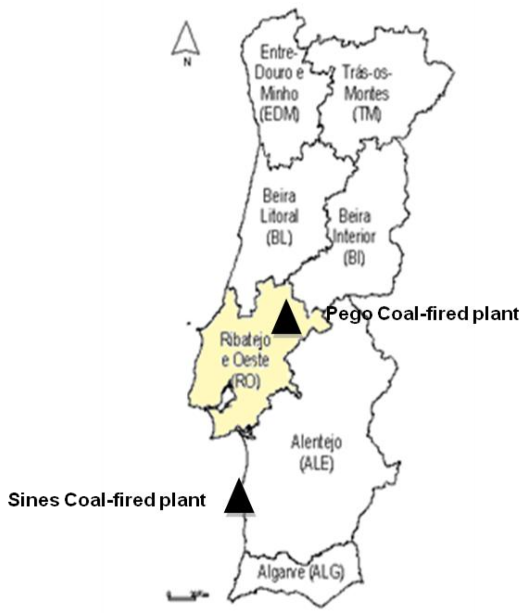

Figure 1 – Localization of the coal-fired plants in analysis and the agricultural region Ribatejo and Oeste.

The power plants efficiency, both pulverized coal boiler, is 39%. The distance from the SRWC is approximately 50 km for Pego and 200 km to Sines coal-fired plant. At the moment of transportation of the *E. globulus*, we assume moisture of 40%wt and at the power plant 20%wt. The Low Heating Value (LHV) calculated in the present study of *E. globulus*, at this moisture, was 13 MJ/kg. The LHV of bituminous coal is 27 MJ/kg. Attending to the site maize and *E. globulus* productivity on RO, respectively 13 ton/ha/year and 16 ton/ha/year, we assume that the consideration of land use change request a importation of 0,05 kg of maize produced in Argentina (ARG) to a 1 kWh_e produced at the plant. In Figure 2 is shown the LCA boundaries and the studied scenarios, the Function Unit (FU) is 1 kWh_e.

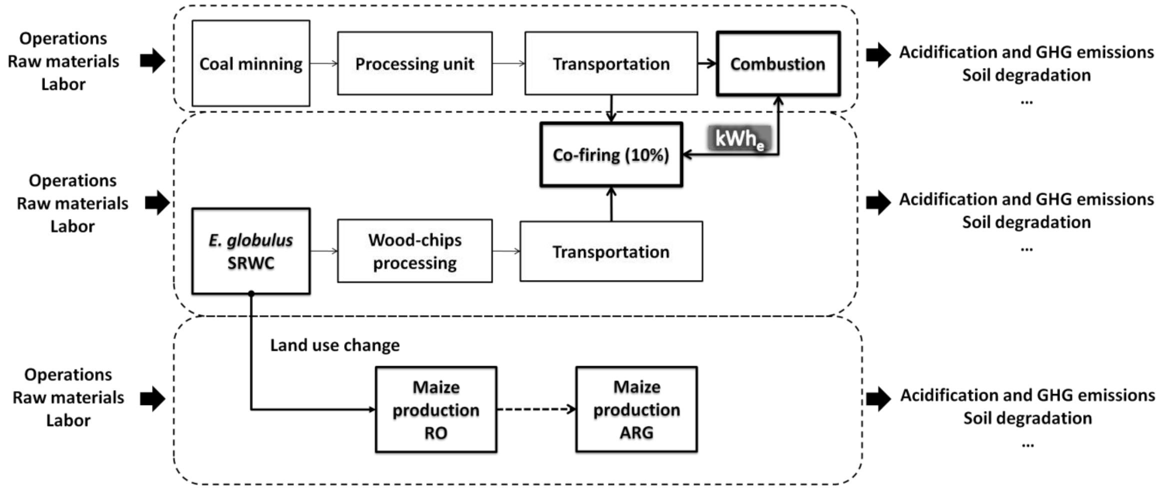

Figure 2 - LCA boundaries

In the conducted LCA, energy and raw materials requirements, emissions, effluents, and soil waste were quantified for each process, from resource extraction to final product use and disposal in both scenarios (combustion and co-firing 10%).

3. Result

3.1 SRWC production

The *E. globulus* cropping system boundary is shown schematically in Figure 3.

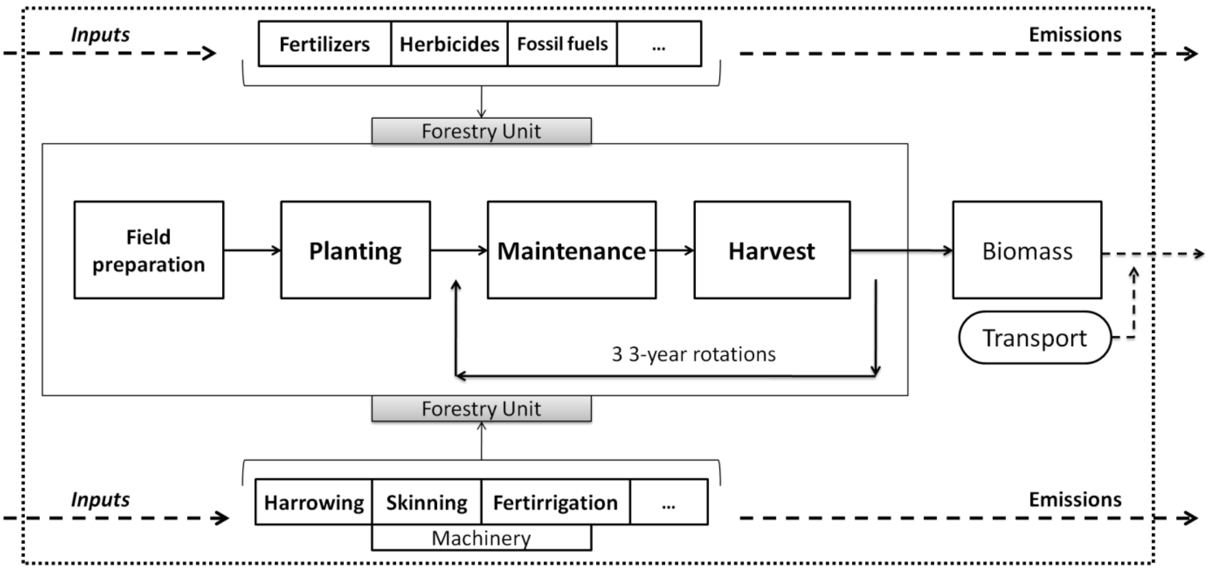

Figure 3 – Schematic representation of *E. globulus* production process and inputs.

E. globulus biomass crops are grown as a perennial with multiple harvest cycles (or rotations) occurring between successive plantings. The model base-case scenario assumes four three-year rotations and includes coppicing after the first year of growth and the removal of the *E. globulus* stool at the end of the final rotation. With a planting density of 3.000 plants/ha and an irrigation of 500 mm/ha/year on RO, the annual biomass productivity is about 16 ton/ha.

The environmental pressure of the *E. globulus* energy crop is described in Table 1. The findings of the study EEA, (2006) indicate that perennial energy crops, e.g. short rotation coppice, generally have lower environmental pressures than most annual plants.

Table 1 – Environmental pressures of SRWC eucalyptus. Source: EEA, 2006.

Aspect	Score (risk)	Reason
Erosion	Low to medium	Permanent crop, but leaves soil rather bare
Soil compaction	Low	Deep rooting, permanent crop
Nutrient leaching to ground and surface water	Low	Takes a lot of nutrients
Pesticide pollution of soils and water	Low	Very competitive
Water abstraction	Medium	Requires a certain soil moisture; suspected of altering hydrological regimes and reducing groundwater availability by transpiring large amounts of water in semi-arid conditions
Fire risk	Hight	Because of high oil content
Link to farmland biodiversity	Hight	Suppresses nearly all other plants
Diversity of crop types	Hight	Currently common in the south

We concluded that the most important environmental themes in SRWC *E. globulus* production are eutrophication, acidification, GHG, climate change and Ozone depletion. These themes are referred to the impact due to fertirrigation and machinery use.

3.2 Combustion *versus* co-firing

The final results are show in Table 2 and consist in the degree of difference impacts between co-firing and combustion by their comparison. The Avoid Impact (AI) was calculated in two cases: with and without consider the land use change.

In this case study, co-firing of coal and biomass in existing coal-fired power plants provides the maximum 10% of Avoid Impact (AI), indeed the maximum is never recorded for any impact category (see Table 2).

Land use change occurs when land currently or capable to be used for feed or food crops is changed or utilized into bioenergy feedstock production. In the RO one of the main agricultural products is maize (INE, 2010). The demand for the previous land use (i.e. feed, food) remains, because the displaced agricultural production will move to other places where land use change could occur. In this study we assume that is capable of occur in ARG. To quantify the land use effects was determinate the Land Used Change Factor (LUCF), based on the LCA study (Teixeira *et al*, 2007), whose quantified the environmental impacts on the maize production in RO and on the imported from ARG. By consider the land use change it is possible to occur: an increase of AIs, a decreased of AIs and not verify AI. In this last situation, the impact of the co-firing is over combustion.

Table 2 – Avoid Impact in the most important environmental categories for the co-firing of coal and biomass in Sines and Pego coal-fired power plants, with and without consider the land use change. FU: 1 kWh_e

Method	Impact category	Unit	Sines		Pego	
			AI LUCF (%)	AI (%)	AI LUCF (%)	AI (%)
Eco-indicador 95	Greenhouse	kg CO2	8,29	9,13	8,43	9,29
	Ozone layer	kg CFC11	-1,44	-0,03	3,81	5,18
	Acidification	kg SO2	-18008	8,00	-32451	6,69
	Eutrophication	kg PO4	-2131835	2,51	-2234583	2,92
	Heavy metals	kg Pb	11,01	6,77	11,44	7,28
	Carcinogenic	kg B(a)P	9,57	5,00	10,45	5,99
	Summer smog	kg C2H4	6,18	5,12	8,08	7,05
	Winter smog	kg SPM	-14934	9,71	-33681	9,36
	Energy resources	MJ LHV	1,47	1,55	1,75	1,84
Eco-indicador 99 (H)	Carcinogenic	DALY	13,47	8,00	13,56	8,11
	Resp. organics	DALY	5,78	5,06	7,72	7,02
	Resp. inorganics	DALY	5,10	6,43	3,18	5,17
	Climate change	DALY	8,01	9,06	8,15	9,22
	Radiacion	DALY	6,43	7,67	8,21	9,31
	Ozone layer	DALY	-0,57	0,27	4,45	5,27
	Ecotoxicity	PAF.m2.yr	26,08	5,12	27,73	7,39
	Acidification/ Eutrophication	PDF.m2.yr	0,69	4,40	-1,05	3,61
	Fossil fuels	MJ surplus	2,51	3,12	4,72	5,33

Legenda de cores:

- AI increase
- AI decrease
- AI don't occur with our without LUCF
- Co-firing impact is bigger than combustion

Even though the propose of the study isn't compare the two power plants, it's important to refer the reason why Pego have in general a higher percentage of AI per impact category than Sines. This situation is related with a low distance between the power plant and the SRWC in the Pego scenario. The distance is also the reason why co-firing in Sines has more impacts in the ozone layer than combustion.

Discussion and Conclusions

Co-firing with coal provides numerous environmental benefits. Indeed, the maximum AI isn't recorded once associated with a reducing of the coal flow there is a increasing of fossil fuels, fertilizers and raw materials by the insertion of a biomass flow. While the upstream energy consumed in growing or processing and transporting biomass roughly balances the reduced consumption from mining, processing and transporting less coal. So, in a LCA context, co-firing system energy consumption of fossil fuels is lowered by 30%, for Sines, and 50% for Pego, compare to combustion, to produce the same energy in the power plant.

This studied have concluded that most, but not all, environmental impacts categories still have a positive consequence when concerning land use change. Therefore, it should always be acknowledged that the positive impacts on GHG emissions may carry a cost in other environmental areas, so that a much more careful analysis is needed to understand the trade-offs in any particular situation. In this condition appears the environmental categories winter smog, acidification and eutrophication. This applies particularly to maize production and transportation. In fact the trade-off of the production unit of RO to ARG, prejudice particularly the above citied categories. Hence the most important environmental themes in maize production are eutrophication, acidification and greenhouse gas emissions, plus winter smog when we considered the transportation of maize to Portugal.

These environmental categories are affected by site-specific features, the risk of eutrophication and acidification on ARG probably could not occur since ARG is a suitable place for production and the impact will depend on the environmental resilience of the ecosystem.

We also conclude, in a LCA context, that with or without considered the land use change co-firing biomass from a SRWC, localized above 50 a 200 km, offers a good opportunity to currently operating coal plants reduce their environmental impacts. Although if we think about others issues, e.g. like the evolution of the oil and maize prices, global food security, the need to reduce energy import dependency and reduce GHG emissions, it is not easy to draw simplified conclusions.

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