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PULP AND PAPER

Industrial hemp or eucalyptus paper?

An environmental comparison using life cycle assessment

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Abstract
Background, aim, and scope Pulp and paper production is one of the most important Portuguese economic activities. Mostly based on eucalyptus (*Eucalyptus globulus*), nearly 70% of the pulp produced is exported, mainly to the European Union. The aim of this paper is to compare the environmental impacts of the production of Portuguese printing and writing paper based on eucalyptus with those from the production of paper from industrial hemp (*Cannabis sativa*).
Materials and methods We have used a life cycle assessment approach to compare both types of paper. The functional unit used was a ton of white printing and writing paper. Data was mostly derived from the Portuguese literature for eucalyptus and from scientific literature for hemp. The impact categories/indicators taken into account were global warming, photochemical oxidant formation (summer smog), acidification, eutrophication, and direct land use.
Results and discussion Industrial hemp presents higher environmental impacts than eucalyptus paper in all environmental categories analyzed. The main differences are in the crop and the pulp production stages. This is because hemp makes use of higher number of mechanical operations and larger amounts of fertilizer in the former and larger amounts of chemical additives in the latter.
Conclusions There is scope for improving industrial hemp paper production. We present some suggestions on how to reduce some of the environmental impacts identified for hemp, so that the pulp and paper industry can continue its progress towards a more environmentally friendly paper production.
Recommendations and perspectives New studies could be based on the alternatives presented throughout the paper for improving hemp paper. Further studies should incorporate analyses on water consumption, soil erosion, soil nutrient depletion, and impacts on biodiversity.

Keywords *Cannabis sativa* · *Eucalyptus globulus* · Eucalyptus · Hemp · LCA · Portugal · Pulp and paper

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1 Introduction

In Portugal, pulp and paper production is one of the most important industrial activities, representing an added value of 243 million EUR, with nearly 70% of the pulp produced being exported, mainly to European countries (CELPA 2008). This pulp is mostly based on eucalyptus (*Eucalyptus globulus*), with a small contribution from pine. Eucalyptus is used due to its higher productivity, lower rotation periods, and long fibers allowing a higher quality of pulp and paper (Soares et al. 2007).

The literature on pulp and paper production (e.g., IPCC 2001; das Tapas and Houtman 2004; Pokhrel and Viraraghavan 2004; Dias et al. 2007; CELPA 2008) identifies several environmental impacts such as soil erosion, biodiversity loss, climate change, eutrophication of water systems, acidification, and odors. In particular, the literature on fertilizer production and on the production of eucalyptus trees identifies impacts such as eutrophication from fertilizer use (Lopes et al. 2003; Dias et al. 2007), acidification from the use of machinery (Lopes et al. 2003; Dias et al. 2007), nitrous oxide (N_2O) emissions from fertilizer use (Mosier et al. 1998), and CO_2 associated with energy consumption for the production of fertilizers. Other impacts are biodiversity reduction from the use of eucalyptus monocultures, aquifer supply reduction, soil erosion from both loss of soil and nutrient depletion, and loss of landscape aesthetic value (Alves et al. 2007; Fabião et al. 2007; Carneiro et al. 2009).

During the last 12 years, the Portuguese pulp and paper industry invested in environmental improvements a total of 446 million EUR (CELPA 2008). Furthermore, research has been carried on identifying the benefits of leaving plant wastes of eucalyptus trees on the soil of plantations (Jones et al. 1999; Corbeels et al. 2005; Carneiro et al. 2009), the use of natural gas as an alternative energy source for the pulp production (Lopes et al. 2003), the type of pulping process (das Tapas and Houtman 2004), different bleaching processes (Dias et al. 2002; Fu et al. 2005), and different final disposal scenarios (Lopes et al. 2003).

Alternative fiber sources are not always considered as an option to eucalyptus as they generally produce lower quality pulp and paper. Interestingly, industrial hemp (*Cannabis sativa*) is a crop producing fiber of a quality similar to that from eucalyptus (Dutt et al. 2008). Industrial hemp is not currently used in paper production in Portugal and thus can constitute a diversification for the paper industry. Given the main differences between producing a tree (eucalyptus) and a crop (industrial hemp) and process differences in pulp production, evaluating the impacts of both types of fibers becomes an interesting exercise.

The aim of this paper is to compare the impacts of paper production from eucalyptus with those from industrial hemp making use of life cycle methodology. We have structured this paper as follows: Section 2 describes the methods used for data collection and analysis as well as the data; Section 3 presents the results from the life cycle assessment (LCA) and discusses these; and Section 4 concludes.

2 Methodology and data

2.1 Scope and goal definition

The main aim of this assessment is to compare the use of eucalyptus and industrial hemp (hemp hereafter) fibers in Portuguese paper production. Direct land use is taken into account to translate land use differences between the two fiber sources. The functional unit was defined as 1 t of white printing and writing paper produced from Kraft pulp. Given that eucalyptus trees take 14 years to grow and that a common practice is to use three eucalyptus rotations, the overall time period for both hemp and eucalyptus is 42 years for the production of 1 t of paper.

Once eucalyptus is cut, the tree can grow from the stumps left on the soil. The cut trees are cleared of branches, leafs, and barks before being transported to the pulp mill. Kraft pulp production is a chemical pulping process (das Tapas and Houtman 2004) making use of chemical additives, water, fuel oil, and fiber, and producing pulp and electricity as end products. In the pulp mill, trees are mechanically and chemically treated to extract the fiber and produce the paper pulp. The pulp is then dried to be ready to be transported to a paper mill. This process is energy intensive. Organic material from the tree other than fiber (the black liquor) is collected and used as biomass to reduce fossil fuel demand. The high amount of heat released in this process is recovered for the production of electricity as a co-product.

The paper production process for hemp is similar to that for eucalyptus, the main differences being in the crop production stage. Hemp is an annual plant, which needs to be sown and fertilized every year. Stalks are harvested, with leaves and roots being left on the field. Before transportation, hemp stalks need to be dried to reduce transport costs. The pulping process is similar.

2.2 Boundaries of the paper LCA

The simplified life cycle stages for printing and writing paper, shown in Fig. 1, were grouped into the following categories:

- Fiber production, which includes the production and use of fertilizer, machinery, eucalyptus trees, and industrial hemp;
- Fiber transport from the farming site to the pulp mill, which includes production and use of a van;
- Kraft pulp production, which includes eucalyptus pulp produced in Portugal, the best available techniques for industrial hemp pulp, electricity production from the Portuguese national grid, and energy consumed for the production of chemical additives.

We have included aspects typically excluded in recent studies, such as production of machinery for the forest/farming stage and N_2O emissions from the ground due to the use of fertilizers.

2.3 Handling of co-products' environmental impacts

Paper LCA comprises electricity as a co-product. Electricity's share of environmental impacts was handled by using

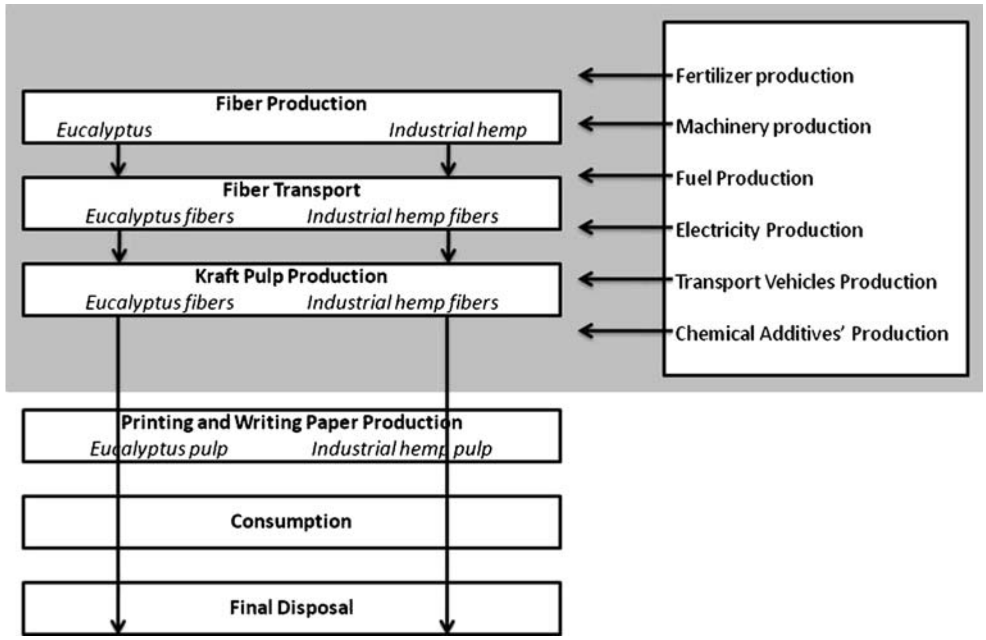

Fig. 1 System boundaries considered, showing the life cycle stages of printing and writing paper from two fiber sources: eucalyptus and hemp. Only processes in the *gray box* (fiber production, transport, and pulping) were included in the analysis

the concept of avoided environmental impacts allocated to the main product. The principle is that the production of the electricity will avoid the production of electricity from the national grid and, thus, eliminating the impacts of such production. Therefore, the environmental impacts of the same amount of electricity produced from the national grid are subtracted from the environmental impacts of the co-production of eucalyptus pulp and electricity. All the remaining impacts are allocated to the main product for that stage, eucalyptus pulp.

2.4 Cut-off processes

Paper production stage, distribution and consumption, and the production and maintenance of buildings were excluded from the study, as these stages were assumed similar for the two life cycles. The final treatment stage, besides the waste treatment operations already included in the fiber and pulp phases, was excluded from the study. This is because the waste treatment is assumed equal for the two life cycles.

If the final treatment for waste paper includes incineration, i.e., burning of waste paper and subsequent land filling of ashes, the carbon contained in paper will be emitted to the atmosphere in the form of carbon dioxide, amongst others. Given that eucalyptus and hemp absorb different amounts of carbon dioxide during their growth, mainly through photosynthesis and that these differences in the amount of carbon dioxide uptake will be reflected in the chemical composition of paper, in terms of carbon content, it can be expected that burning waste paper will emit different amounts of carbon dioxide depending on the fiber source. For this reason, non-fossil carbon dioxide (CO_2) emissions were not accounted for.

2.5 Inventory data: eucalyptus and hemp paper production

2.5.1 Fiber production

Fiber production involves fertilizer production, machinery production and use for the mechanical operations used by each culture, field emissions from fertilizer use, and the use of land area. The general inputs required for fiber production are described in Table 1.

Fertilizer needs for eucalyptus production were obtained from Cortez and Madeira (2000). Fertilization occurs in the first and third years of each cycle.

Eucalyptus production includes 43 mechanical operations per ton of paper, over the 42 years. We considered a 68-kW tractor. The distance (D) traveled by the tractor per ton of paper was estimated using Eq. 1

$$D = \mathrm{nop} \times (p \times a + 2 \times \mathrm{dfa} \times \mathrm{nd}), \quad (1)$$

where *nop* is the number of mechanical operations per ton of paper, using the tractor; p is the total distance (meters/hectare per each mechanical operation) covered by the tractor on the plot; a is the area of the plot (hectare); dfa (meter) is the distance between the plot and the garage (where the machinery is stored), 1,000 m/day; and *nd* (days/operation) is the number of days required for each operation. Parameter p is obtained by assuming 100 m long rectangular plots with 3 m distance between eucalyptus rows. Parameter a is based on plant productivity. Produc-

Table 1 Material inputs for the two paper life cycles (unit/ton paper)

	Eucalyptus	Hemp
Fertilizer inputs (kg)	4.3 (N)	40 (NH_3)
	14.1 (P_2O_5)	20 (P_2O_5)
	12.9 (K_2O)	60 (K_2O)
	8.4 (CaO)	160 (CaO)
Distance required for a tractor during mechanical operations (km)	5,573.5	120,129.4
Field emissions to water (kg)	0.002 (NH_3)	0.602 (NH_3)
	0.002 (PO_4^{3-})	0.041 (PO_4^{3-})
	4.83 (NO_3^-)	19.50 (NO_3^-)
Field emissions to air (kg)	0.004 (N_2O)	1.511 (N_2O)
Number of plants/mass of seeds	3.19 plants[a]	26.81 kg[b]
Area (ha/rotation)[c]	0.003	0.012
Fiber requirements (tons)[d]	1.08[e]	1.12
Pulp requirements (tons)[d]	0.6	0.6
Paper produced (ton)	1	1

[a] A tree density of 1,111 trees/ha was used (between 1,100 and 1,600 trees/ha under Portuguese law Portaria nr. 528/89)

[b] From van der Werf et al. (2005)

[c] 1 ha=10,000 m^2

[d] Dias et al. (2002), Lopes et al. (2003), Dias et al. (2007), Dutt et al. (2008), and Harris et al. (2008)

[e] Eucalyptus trees' cores: this value excluded the amount of barks used as biomass for energy in the process

tivity for eucalyptus was estimated using model Globulus 2.1 (Tomé et al. 2001) for a quality class of 21, i.e., 17 t/ha eucalyptus fiber for the first rotation and 13 t/ha for the remaining rotations. Parameter *nd* (in days per mechanical operation) was estimated using (Henriques and Carneiro 2001) Eq. 2

$$\mathrm{nd} = 2.5 \times (a) - 7 \quad (2)$$

with a, the area of the plot, in square meters. Mass and energy consumption and the air emissions associated with fuel consumption in the mechanical operations were estimated using average data for a tractor for the Dutch situation in 1989 (IDEMAT 1996).

To determine the field emissions from fertilizer use, we considered that the applied fertilizer is absorbed by plants, leached or denitrified. Fertilizer leaching and denitrifying data was obtained from van der Werf et al. (2005) and Crutzen et al. (2008). The remaining fertilizer left on the soil is available for plants to absorb during their growth.

Plant wastes left on the soil are feed for soil bacteria, and only 1.5% of total waste/year is made available to the plants (Stevenson and Cole 1999); as waste on the soil; eucalyptus leaves leafs, branches, roots, and 60% of the mass of barks. The remaining bark mass is transported to the pulp mill together with the main part of the eucalyptus.

According to Dias et al. (2007), the impacts of producing eucalyptus plants can be neglected. We have therefore not considered these.

For hemp, fertilization inputs were obtained from van der Werf et al. (2005) for a productivity of 6.72 t/ha. Energy consumption, CO_2, SO_2, and NO_2 emissions from fertilizer production were obtained from van der Werf et al. (2005). Five operations per year are conducted using machinery. The same procedure used for eucalyptus was used for hemp, where the distance traveled by a tractor to perform the mechanical operations is given by Eq. 1. Parameter p is obtained by assuming 100 m long rectangular plots with 0.2 m between rows (di Bari et al. 2004).

The residue from hemp not used for fiber production is left on the soil. The impacts of hemp seed production were considered negligible (van der Werf et al. 2005).

2.5.2 Fiber transport

Fiber is transported from the farm or forest to the pulp mills. Transportation involves the use of 3.5 t capacity vans. A distance of 50 km was used, as an average distance between woodlands and pulp mills, according to the Portuguese Paper Industry Association (CELPA). For eucalyptus, having three tree rotations implies transportation occurs three times, transporting 0.38 t each time (the total mass of eucalyptus cores required for pulping divided by the number of rotations). Given that hemp is an annual crop, transport occurs 42 times, transporting 0.03 t of fiber each time (estimated similarly to eucalyptus). Mass and energy flows of van production and use were estimated from ESU-ETHZ (1994) in Pré Consultants (1996).

2.5.3 Kraft pulp production

Both pulps are bleached using chlorine dioxide (elemental chlorine free process). Information on the production of pulp was obtained from the literature for both eucalyptus (IPCC 2001; Dias et al. 2002; Lopes et al. 2003; Dias et al. 2007) and hemp (Dutt et al. 2008; Harris et al. 2008).

Eucalyptus pulp uses renewable energy sources, such as barks and black liquor (0.9 t/t paper), and fuel oil (21.3 kg/t paper; Dias et al. 2002). For the co-generation of electricity in the eucalyptus pulp process (110.14 kWh/t paper, IPPC 2001), avoided impacts from the national electric grid were estimated from Antunes et al. (2003), using marginal values for electricity use.

Due to the low yield of hemp stems in terms of fibers, where only 34.3% is usable for the pulp industry (Cherrett et al. 2005), hemp pulping process produces high amounts of black liquor, which are used as a source of renewable energy in the process (Harris et al. 2008). This black liquor together with natural gas (4.8 dm^3/t paper) make up the energy requirements of hemp's pulping process.

CO_2 emission values per unit of energy source were obtained from StoraEnso (2002). The amount of chemicals used by each type of pulp was obtained from the literature (IPCC 2001; Dutt et al. 2008). The energy needs for the production of the different chemicals used was obtained from Fu et al. (2005).

2.6 Environmental impact assessment

For the environmental impact assessment, data was introduced in and analyzed with Microsoft Excel®. Five environmental impact indicators were taken into account: global warming, photochemical oxidant formation (POF), acidification, eutrophication, and direct land use. The characterization factors for the first four impact categories were obtained from IPCC (2001), Heijungs et al. (1992), Hauschild (1998), and Lindfors et al. (1995), respectively.

Direct land use corresponded to accounting for cropland and forestland and built-up land in terms of fiber and pulp production only. The cropland and forestland are the areas used for crop (for industrial hemp) or forest (for eucalyptus) production. An extra 20% was added to account for storage facilities in the fields (as in resemblance with the study from van der Werf et al. (2005) for hemp production). The built land is the area of the pulp and paper mills. In this case, typical mill areas per unit of production (in square meters year per ton of pulp) are multiplied by the production units required for the functional unit. For both area types, values are summed with no differentiation between the qualities of the areas.

We have compared our results with earlier studies on the environmental impacts of the Portuguese paper industry based on eucalyptus and softwood (pine) fibers (Dias et al. 2002; Lopes et al. 2003; Dias et al. 2007) and of hemp fiber production (van der Werf et al. 2005). The three studies on the eucalyptus Portuguese paper industry include the environmental impact categories of global warming, POF, acidification, and eutrophication. For hemp production, van der Werf's study includes the environmental impact categories of global warming, acidification, eutrophication, and land use.

3 Results and discussion

The main results from the environmental impact analysis are presented in Fig. 2. The eucalyptus paper life cycle has the lowest impacts in all the categories analyzed. Figure 2 also shows that for all the stages taken into account, transport impacts are negligible. Overall, transport impacts presented here are much lower than the ones from the literature (Dias et al. 2002, 2007; Lopes et al. 2003). This is because we have only taken into account fiber transport from the woodland or cropland to the pulp mill. Furthermore, all transport was assumed for a distance of 50 km (100 km return). As hemp makes use of higher amounts of chemical additives and fertilizer, the inclusion of the impacts of transport of chemical additives would contribute even more to the differences between eucalyptus' and hemp's impacts.

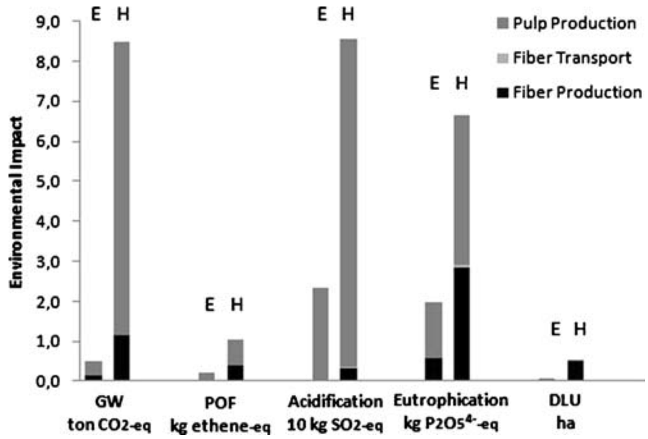

Fig. 2 Environmental impacts of eucalyptus (E) and industrial hemp (H) paper production. Values are per ton of paper. *GW* global warming, *POF* photochemical oxidant formation, *DLU* direct land use

The main differences between life cycles lie in the higher fertilizer, mechanical operations, and chemical additive needs for hemp. Fertilizer use contributes highly to eutrophication (nitrates and phosphates) resulting in high field emissions for hemp production. Fertilizers' contribution to global warming, either through the energy requirements for their production or through N_2O emissions from the soil contribute little compared to the pulp stage.

Mechanical operations used during the farming/forestry stage contribute to POF due to the emission of hydrocarbons. We have made a few assumptions regarding mechanical operations that, given the similarity with the results in the literature, we conclude do not influence much the results. These assumptions were all fiber production mechanical operations used a tractor with a power of 68 kW, whether they were sowing, plowing, path opening, or debarking. Furthermore, data used for the emissions from the production and use of machinery was quite old (IDEMAT 1996). This would influence the emissions from the mechanical operations; in addition, we assumed a 1,000-m (2,000 m return) distance from the garage where the tractor is kept to the crop/woodland. If emissions from mechanical operations, for both fiber sources, are cut by half (due to technological improvements from 1996 to today) or the number of mechanical operations for hemp

Table 2 Photochemical oxidant formation contributions in three different scenarios: A, approach followed throughout the study; B, reducing mechanical operations to one half; and C, reducing mechanical operations to 1/40. Values in kilogram ethane-eq/ton paper

	Scenario A		Scenario B		Scenario C	
	Mechanical operations stage	Overall life cycle	Mechanical operations stage	Overall life cycle	Mechanical operations stage	Overall life cycle
Eucalyptus	0.02	0.22	0.01	0.21	0.00	0.20
Hemp	0.39	1.05	0.2	0.85	0.01	0.66

are reduced by half (to 105 mechanical operations per ton of paper), the impacts of hemp's mechanical operations in terms of POF become lower, but hemp still has higher impacts than eucalyptus (Table 2). The impacts of mechanical operations in hemp only become negligible compared to eucalyptus' mechanical operations when emissions from mechanical operations are reduced by a factor of 40.

In terms of chemical additives used for pulp production, their production and use contributes to global warming (due to the energy requirements for their production), POF, acidification (from SO_2 and NO_x emissions), and eutrophication.

The main difference between life cycles in terms of direct land use is the fiber production stage, where hemp requires larger areas than eucalyptus. The high difference between hemp and eucalyptus land requirements is influenced by an initial assumption of a quality class for eucalyptus of 21. Lower quality classes are translated into lower eucalyptus productivity, which in turn will increase the area required for producing eucalyptus. Furthermore, tree density and rotation length was assumed best practice; in reality, the case can be different, using higher tree density or shorter rotation lengths. In addition, climate, soil fertility, and water availability (especially important for hemp) also influence eucalyptus productivity (Soares et al. 2007). None of these has been taken into account. All of these have implications for the whole productivity of eucalyptus trees and therefore influence the woodland area required for eucalyptus. In spite of these assumptions, our results seem to be qualitatively coherent with the literature, where trees are generally presented with higher land efficiency than crops (for example, Alden et al. 1998).

In terms of eucalyptus trees' production, the main differences with the literature are in terms of global warming contributions. The values estimated here (140 $kgCO_{2\text{-eq}}$/t paper) are higher than the ones from the literature (≅50 $kgCO_{2\text{-eq}}$/t paper) in a factor of 2.8. This is because we have additionally included N_2O emissions from the fertilizer applied to the soil, which greatly contribute to global warming.

In terms of hemp production, the differences between our results and the ones presented in the literature are in terms of field emissions. These differences are mostly due to van der Werf's values having been estimated according to Mosier et al. (1998). Our values were estimated through a more recent study conducted by Crutzen et al. (2008). As a result, field emissions contribute 1.6 and 4.2 times less to acidification and eutrophication, respectively. Hemp yields were assumed to be 6.72 t/ha based on the results from France in van der Werf et al. (2005). Some farmers in Portugal reported higher yields. If this is so, impacts of producing industrial hemp would be lower than the ones estimated here. Varying hemp yields introduces little differences in the main results, as we can see from Table 3.

In terms of eucalyptus pulp production, our results are very similar to the ones presented in the literature in all impact categories.

We emphasize also that impact categories not considered in this paper are likely to be important when comparing the two life cycles. These are biodiversity, water consumption, depletion of soil nutrients, breakdown of soil structure, the decreasing on water holding capacity of the soil, and aesthetics. With some of these impacts, there is high uncertainty on available data, for example, although nutrient availability from the decomposition of biomass in soil has been the target of research (for example, Jones et

Table 3 Sensitivity analysis to the environmental impacts for hemp paper production by varying hemp productivity: from 6.72 t hemp stalks/t of paper (current productivity values used) to 10 t hemp stalks/t paper

Impact category	Hemp yield (ton/ha)	Impacts (unit/t paper)
Global warming	6.72	8.5 t $CO_{2\text{-eq}}$
	10	8.2 t $CO_{2\text{-eq}}$
POF	6.72	1.05 kg $\text{ethane}_{\text{-eq}}$
	10	1.05 t $\text{ethane}_{\text{-eq}}$
Acidification	6.72	85.4 kg $SO_{2\text{-eq}}$
	10	84.9 kg $SO_{2\text{-eq}}$
Eutrophication	6.72	6.6 kg $PO_4{}^{2-}{}_{\text{eq}}$
	10	6.5 kg $PO_4{}^{2-}{}_{\text{eq}}$
Land use	6.72	0.5 ha
	10	0.3 ha

Table 4 Measures intended to reduce the environmental impacts of hemp's paper production

Fiber production	Pulp and fertilizer production
The use of *thermo-mechanical or bio-pulping* processes rather than Kraft pulp reduces the amount of fiber needed (Alden et al. 1998; das Tapas and Houtman 2004). Reducing fiber needs reduces the amount of fertilizer produced and used and the length of mechanical operations	*Bio-pulping*, *enzyme bleaching*, and *total chlorine free (TCF) bleaching* can introduce advantages in terms of energy, the amount of chemical additives required, and the environmental impacts of their use and disposal (Dias et al. 2002; das Tapas and Houtman 2004; (Fu et al. 2005)
Develop *genetically modified hemp* with less needs for nutrients, reducing the amount of fertilizer, or more adapted to winter seasons, reducing water demand (Stevenson and Cole 1999; van der Werf et al. 2005; di Bari et al. 2004)	Reduce the *size of pulp mills* and locate them near industrial hemp producing sites. This would reduce transport costs and impacts or the need for storage facilities (Alden et al. 1998)
Produce *organic hemp*, reducing fertilizer inputs (Cherrett et al. 2005; van der Werf et al. 2005)	Use *cleaner energy sources* such as agriculture wastes as biomass (Harris et al. 2008), natural gas, photovoltaic, wind, or hydroelectricity
Reduce tillage (e.g., through direct drilling), reducing the amount of mechanical operations required and soil erosion (van der Werf et al. 2005)	Use higher efficiency *gas and water treatment* facilities
Combine hemp with a winter crop, reducing the amount of fertilizer needs (Stevenson and Cole 1999) and maximizing area use efficiency	Use of *high efficiency energy technologies* and combined cycles
Use *organic matter* to substitute some of the fertilizer requirements	

al. 1999; Corbeels et al. 2005; Carneiro et al. 2009), the implications of this to fertilizer needs and plant productivity is still not well understood.

4 Conclusions

The main differences between the life cycles were in the fiber and pulp production stages. In fiber production, the main differences were in terms of POF, eutrophication, and direct land use. For pulp production, the main differences were for global warming, POF, acidification, and eutrophication. In all of these indicators, hemp paper produces higher impacts than eucalyptus paper. This is because the processes that most affect the environment are the mechanical operations required for crop production, emissions from fertilizer use (leaching), and the production of chemical additives used for pulp production, for which hemp presents higher values in all of these.

5 Recommendations and perspectives

The literature is quite rich in measures than can be used for the reduction of environmental impacts associated with the fiber production stage. Some of the measures to reduce hemp's environmental impacts are described in Table 4. Some of these measures might have little impact on the reduction of environmental impacts, and perhaps a combination of measures might be more efficient. For example, measures focused on reducing hemp's mechanical operations in farming or increasing hemp yields might not introduce a significant difference in the results (see Tables 2 and 3). However, combined with other improvements, they might actually make a more significant reduction in the overall environmental impacts of hemp's paper production. Some of the measures proposed can have other indirect impacts on the environment, not accounted for with the indicators used here. For example, introducing a genetically modified crop has been the target of discussion for the past few decades, as its impacts on biodiversity and human health are not very well understood today (for example, Stirling and Mayer 2000). Research is relevant for all these cases. Following these, the pulp and paper industry can continue its progress towards a more environmentally friendly paper production, and we, as environmental researchers, can be proud of the greening of our printed publications, i.e., if we choose not to use electronic resources.

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