Final Report on Task 4.1 Environmental impact assessment (EIA) of Energy Crops production in Europe

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Task 4.1 Environmental impact assessment (EIA) (UNINOVA)

In the scope of the project Future Crops for Food, Feed, Fiber and Fuel (4F Crops), supported by the European Union, an environmental impact assessment study was developed and applied to the production of potential energy crops in Europe. The following categories were selected: emissions to soil, air and water, impact on soil, impact on water and mineral resources, waste generation and utilization, biodiversity and landscape. In addition, a normalization and weighting procedure was applied, which attempts to aggregate environmental impacts. The influence of the crops traits and the choice of the farming location will also be investigated. Overall interactions and similarities or equalities will be pointed out. Environmental hot spots in the systems are detected and options for improvement are presented.

1. Introduction

Production of energy crops must be studied and evaluated in terms of environmental impacts, in order to integrate them into a sustainable agriculture development. As bioenergy carriers they offer ecological advantages over fossil fuels by contributing to reduction of greenhouse gases and acidifying emissions. However, there could be ecological shortcomings related to the intensity of agricultural production. There is a risk of polluting water and air, losing soil quality, enhancing erosion and reducing biodiversity.

In the framework of the project Future Crops for Food, Feed, Fiber and Fuel (4F Crops), supported by the European Union, this study aimed to assess the environmental impact of the cultivation of a set of energy crop species. These species have been allocated to the climatic regions of Europe most suited for their development.

Environmental Impact Assessment (EIA) is an evaluation method to explore the possible environmental effects of a proposed project. EIA examines the anticipated environmental effects and determines the importance of these effects, on both the short and the long term. It focuses on local environmental effects. Data are collected and evaluated on that level. The environmental impact analysis of crop production requires good knowledge of the cultivation operations, the requirements and the productivity of the various crops in different climates, soil types and methods of cultivation. There is not a general list of criteria to assess the environmental impact nor a general description of methods to be used. Fixing the environmental criteria is part of the EIA process. Usually criteria address emissions to soil, ground and surface waters and air, effects on living environment and health of people in the surroundings, effects on surrounding ecosystems, and effects on cultural assets.

2. Methodological approach

2.1. Goal and Scope

Goal is primarily to evaluate the environmental effects due to the production of different non-food crops in Europe.

2.1.1. Choice of the crops to be studied

- Fifteen energy crops were selected according to the decisions taken from WP2. Those chosen crops were also in agreement with what was studied in WP3 and on LCA (WP4).
    - Oil crops: Rapeseed, Sunflower, Ethiopian Mustard
    - Sugar crops: Sugar beet, Sweet sorghum
    - Fiber crops: Hemp, Flax
    - Lignocellulosic crops: Reed canary grass, Miscanthus, Switchgrass, Giant reed, Cardoon
    - Woody crops: Poplar, Willow, Eucalyptus
- Food crops: Wheat and potato were also included in the study along with the energy crops evaluated. These crops are for long well established in Europe, are widespread across the continent, represent an important share of the agricultural production and also are reported to present advantages and shortcomings from the environmental point of view. As wheat and potato are traditional crops, their performance will serve also for comparison with the energy crops to be established in Europe.
- Grass fallow was the reference system used.

2.1.2. Geographical scope

EU 27 was subdivided into representative regions**.** According to decisions taken from WP1, the geographical regions selected were:

- Nemoral, Continental, Atlantic North, Atlantic Central, Lusitanian, Mediterranean North and Mediterranean South.

These regions were defined according to Metzger *et al*. (2005) (Figure 2.1).

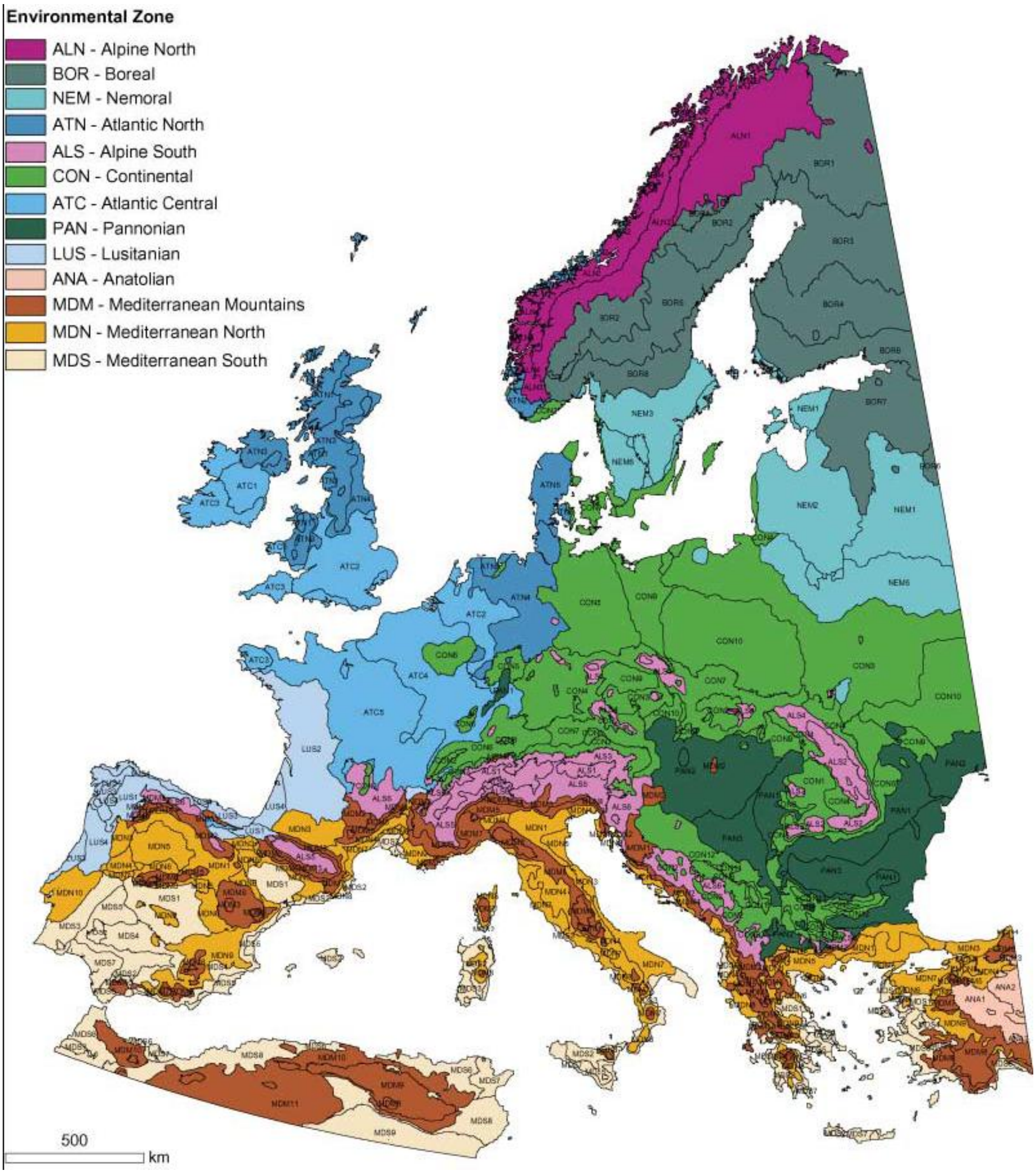

Figure 1 - Environmental Stratification of Europe (Metzger *et al.*, 2005).

2.1.3. Allocation of crops to environmental zones

The investigated crops have been allocated to the climatic regions of Europe most suited for their development (table 1 and figure 2). The allocation of the crops was previously carried out in the framework of the 4F Crops project, task WP2. Grass fallow, potato and wheat were allocated to all the environmental zones studied.

Table 1 - Allocation of the investigated crops to the environmental zones of Europe most suited for their development.

Type of crop	Crop	Environmental Zones
Oil crops	Rapeseed	Nemoral, Continental, Atlantic North, Atlantic Central, Lusitanian
	Sunflower	Mediterranean North
	Ethiopian Mustard	Mediterranean South
Sugar crops	Sugar beet	Continental, Atlantic Central
	Sweet sorghum	Lusitanian, Mediterranean North, Mediterranean South
Fiber crops	Hemp	Nemoral, Atlantic North, Lusitanian, Mediterranean North
	Flax	Continental, Atlantic Central, Mediterranean South
Lignocellulosic crops	Reed canary grass	Nemoral
	Miscanthus	Continental, Atlantic North, Atlantic Central, Lusitanian
	Switchgrass	Atlantic North, Atlantic Central
	Giant reed	Mediterranean North
	Cardoon	Mediterranean South
Woody crops	Poplar	Nemoral, Atlantic Central, Mediterranean North
	Willow	Continental, Atlantic North, Lusitanian
	Eucalyptus	Lusitanian, Mediterranean South

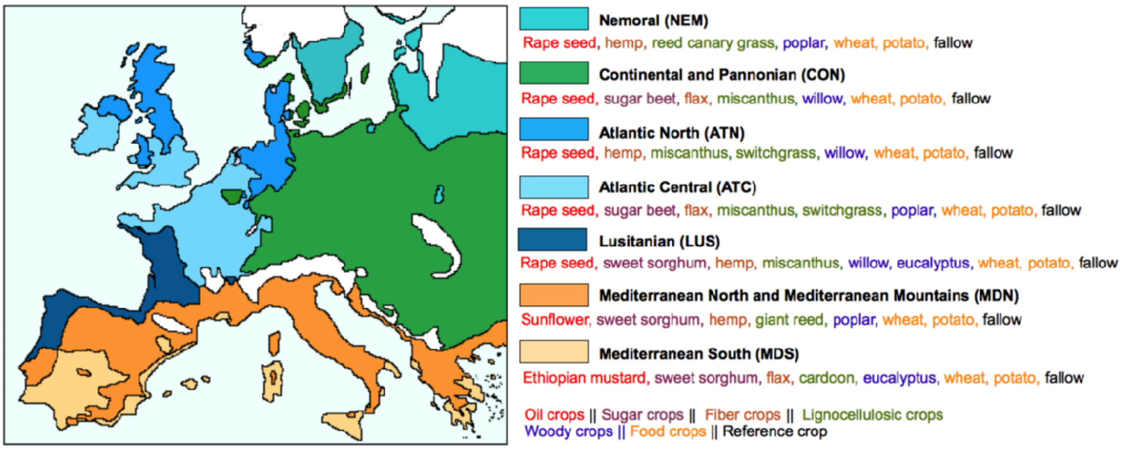

Figure 2 - Allocation of the investigated crops to the environmental zones of Europe most suited for their development.

2.2. Data collection

Most energy crops in Europe are cultivated in small-scale and often in experimental sites. Assessment of field data from literature was supplemented with and cross-checked by expert opinions. Some data were acquired as well from national and international organizations such as Food and Agriculture Organization (FAO) and Eurostat. The complete reference list of the surveyed results and references are available in Annex I.

Assessment of field data revealed the existence of variable inputs. Data analysis often encompasses ranges of inputs for each crop that can be intra-regional and inter-regional. In order to comply with the scope of this study, which aimed at setting an impact trend for each crop, results were displayed as averages (when ranges are available) or single figures (when literature did not provide further data). Thus, variability is not discarded from the analysis. It was decided not to include deviations and error bars in the graphs because it would not reflect actual uncertainty of the results. This study was based on a literature survey, thus the available information on the studied crops varies. More information may induce increased variability on the results. Relating this to uncertainty would give a strong bias towards crops with more available information. For example, fertilizer inputs of potato and wheat are widely documented and this large amount of data comprises wide ranges. On the opposite, crops such as switchgrass, willow or hemp are not so commonly referred thus showing small deviations. Error bars would not accurately show on field variability but reflect the amount of information that could be gathered on each crop.

2.3. Environmental impact assessment

An environmental impact assessment study must be based on data about the impact of a particular crop cultivated at a specific place. Categories such as the impact of a crop on soil need to be selected. In principle, it is possible to quantify the impact by means of chosen indicators.

In this study we followed the approach suggested by Biewinga and van der Bijl (1996), adjusting the methods whenever relevant. The focus is on the impact of cultivation on biotic and abiotic resources, through the analysis of the crop’s interaction with its environment and management practices. This EIA is divided into several categories, which comprise individual impact indicators:

- *Emission of minerals to soil, water and air* – an estimation of the amounts of minerals (N, P, K) applied to soil and their removal with the crop can show whether there is a mineral build-up in the soil or the reverse. Although high N, P and K content of the soil favors soil fertility, there is the risk that an excess of plant-available nutrients in the soil may be lost through future leaching or erosion, an important fact regarding the long-term fertility of the soil and the eutrophication of soil and water.

- *Emission of pesticides,* concerning the quality of soil, ground and surface water and air, one of the most serious problems is pollution by pesticides. The amount of emission is affected by the amount of pesticides used and characteristics of the pesticide.

- *Use of Water Resources* – The contribution of a crop to ground water depletion and desiccation correlates with its water use.

- *Hydrology* effects of cultivation occur when the land use alters the flow of water as ground water, stream water, runoff, transpiration, etc.

- *Use of Mineral Resources* – The use of mineral resources, i.e. withdrawal of materials from the environment, can lead to exhaustion. In this study, the use of phosphate and potash fertilizer, as a criterion for the exhaustion of fertilizer ores will be assessed.

- *Soil Erosion* is a serious kind of degradation since it is irreversible. The soil loss also means a loss of plant nutrients and organic matter which can impair the land's productivity.

- *Soil organic matter* plays an important role in several ways. It helps to keep plant nutrients available, contributes to good soil structure, prevents erosion and keeps soil moist.

- *Soil structure* is defined by the amount and distribution of pores. The pores are mainly filled with gas (air), water and plant roots. Soil compaction, i.e. loss of pore space, makes soils less suited for plant production.

- *Soil pH,* a very important factor, controls many chemical and biological activities in the soil, for example availability of plant nutrients and activity of soil microorganisms.

- *Waste production and utilization,* an inventory of waste products used and produced during biomass cropping will be performed. In this qualitative approach, each of them will be judge positively or negatively.

- *Biodiversity*, erasing diversified vegetation and replacing it with mono-cultural crops is always a violation against it, but the consequences appear as site-specific factors, such as the number of species affected by the cultivation.

- *Landscape*, the aesthetic value may be affected by the choice of the crops and cultivation systems. Two criteria are considered: effects on the variation of structure and effect on variation of colors.

Time reference of the study is 2010. Energy savings, greenhouse effects and acidification issues are being dealt in Task 2.2 (Life cycle assessment) of the 4F Crops Project.

2.3.1. Normalization

Although EIA can be more descriptive, it is necessary to aggregate information in order to condense numerous inventory data to more comprehensible information about potential environmental impact. To facilitate a direct comparison, parameters can be normalized: translated into the same measure. A simple form of normalization is used: all parameters are translated into a figure between 0 and 10, with 0 being the lower impact and 10 the highest impact for each category. Five is the score of the reference crop grass fallow. For each quantitative indicator "0" or "10" are determined by the most extreme result among the crops for each environmental zone (to overcome the inter-regional differences observed, e.g. rainfall, crop productivity). Regarding soil properties and the categories waste, biodiversity and landscape, qualitative evaluation was used to fulfill the lack of quantitative data. Qualitative scoring consisted on the individual evaluation of each crop for a set of pertinent parameters, through expert judgment and literature review.

2.3.2. Weighting

As a last step the scores on the different indicators can be weighted. Defining weighting factors is value-based pronouncement, which brings ambiguity and subjectivity to the study at hand. Some authors agree that, whenever applied, weighting should reflect the relative importance of the impact categories in the organizational context of the study (Schmidt and Sullivan, 2002). Since this study was performed at an European level, the weighting factors were built up according to the relative importance of each indicator studied considering the European Union Environmental Policies, which highlight greenhouse gases emissions, biodiversity and chemical pollution (EC, 2001). Moreover, it was considered that erosion and water availability are of greater concern in the Mediterranean regions (van der Knijff *et al.*, 2000; EEA, 2009) while fertilizer emissions have deeper impacts in northern regions (Biewinga and van der Bijl, 1996). In order to assess the influence of a weighting system (WS) on the final results, three different classifications were applied (table 2):

- WS1: all indicators have the same weight;
- WS2: greater emphasis on GHG emission drivers, namely N-fertilizer related emissions and soil degradation;
- WS3: greater emphasis on biodiversity.

Table 2 - Weighting systems applied. North: Nemoral, Continental, Atlantic North and Central, Lusitanian; South: Mediterranean North and South.

Category	Indicator	Weighting factors				
		WS1	WS2		WS3	
			North	South	North	South
Emissions to soil, air and water	Fertilizer-related emissions	1	2.5	2.25	1	0.75
	Pesticide-related emissions	1	1	1	1	1
Impact on soil	Nutrient status	1	0.5	0.25	0.5	0.25
	Erosion	1	0.5	1	0.5	1
	Soil properties	1	2	2	1	1
Impact on mineral and water resources	Groundwater balance	1	0.5	1	0.5	1
	Effects on hydrology					
	Mineral ore depletion	1	0.5	0.25	0.5	0.25
Waste		1	0.5	0.25	0.5	0.25
Biodiversity		1	1.5	1.5	4	4
Landscape		1	0.5	0.5	0.5	0.5
Total		10	10	10	10	10

After the application of a weighting factor to each category, a weighted average final score for each crop was estimated according to equation 1.

$$Score_{crop} = \frac{\sum \left(score_{indicator} \times weight_{indicator} \right)}{\sum weight_{indicator}} \qquad \textbf{(Eq. 1)}$$

3. Results and Discussion

3.1. Emissions to soil, water and air

The industrialization of agriculture is a major contributor to the ongoing pollution of the environment. The application of chemicals such as pesticides and fertilizers, on soil and crops, release contaminants and nutrients to the natural ecosystems, which need to be controlled in order to avoid agricultural pollution.

3.1.1. Fertilizer-related emissions

Minerals like nitrogen, phosphorus and potassium are largely applied on soils as fertilizers in order to achieve and maximize profitable yields. Consequently, soil, water and air can became polluted by these elements. But, if minerals applied to the soil are lower than the amount removed by the crop, than soil reserves can became depleted.

Nitrogen applied to the soil can contribute to several environmental problems, according to Biewinga and van der Bijl (1996) and IPCC (2006):

- Volatilization of ammonia (NH_3) and oxides of N (NO_x) to the air; this contributes to the acidification.

- Leaching and runoff of ammonium (NH_4^+) and nitrate (NO_3^-) to ground and surface waters; this contributes to eutrophication and excess of nitrate in drinking water could be a threat to human health.

- Denitrification to nitrous oxide (N_2O); this contributes to the greenhouse effect and to ozone depletion. Some nitrous oxide can be produced during nitrification.

According to IPCC (2006), 10% of the N input can be lost by volatilization and 30% can be lost by leaching/runoff. The emissions of N_2O occur through both a direct pathway (i.e., directly from the N input, 1%), and through two indirect pathways: (i) following volatilization of NH_3 and NO_x from managed soils (1%) and (ii) after leaching and runoff of nitrogen, mainly as NO_3^-, from managed soils (0,75%) (IPCC, 2006).

So, for each crop, nitrogen losses can be estimated by using the IPCC emission factors. As N inputs we only considered fertilizers. A wide range of N fertilizer application, in each environmental zone studied, was observed, showing that N inputs are not regionally specific. So, N inputs and N emissions were considered at an European level. Figure 3 shows average values estimated for N emissions, for all the crops studied. Deposition from air was not considered once this input will be the same, for each region, for all the crops, including grass fallow. Symbiotic N-fixation was also not considered in the study.

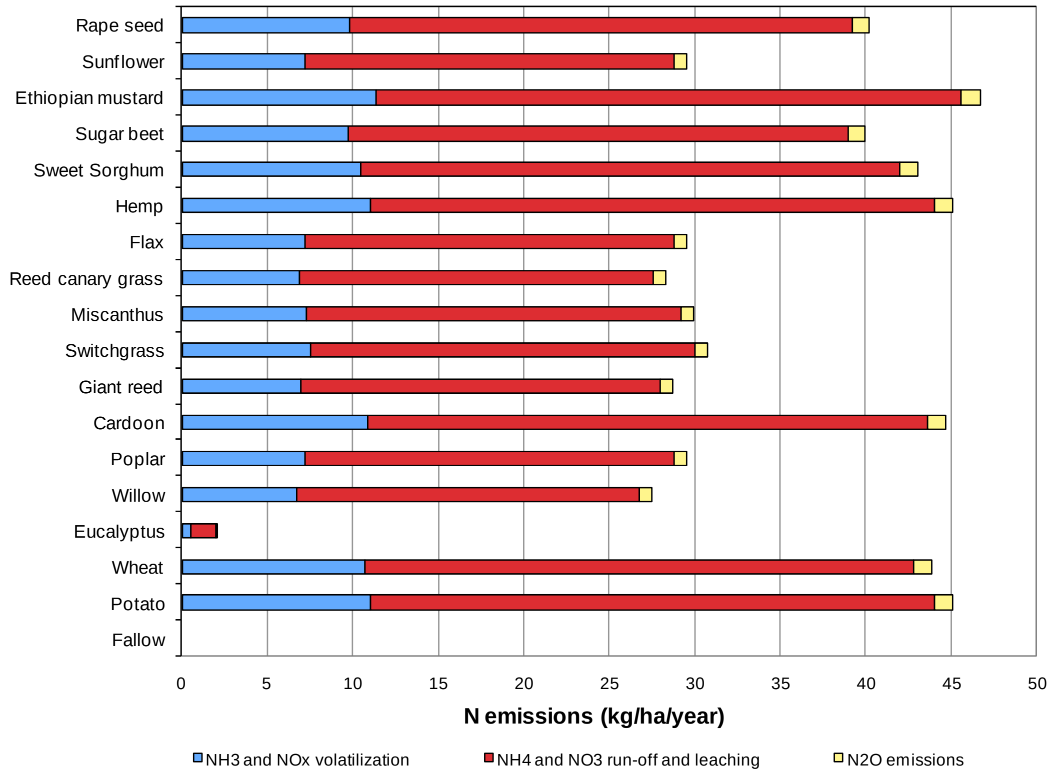

Figure 3 – Estimated nitrogen emissions (kg/ha/year) for all crops, in Europe (for each crop, mean from maximum and minimum results).

According to figure 3, run-off and leaching are important fractions and N_2O emissions are a negligible part of the N emissions. When comparing with grass fallow, Eucalyptus is the crop that shows the lowest N emissions. Annual crops showed the higher emissions. This includes the food crops (wheat and potato) and the energy crops (hemp, sweet sorghum, sugar beet, Ethiopian mustard and rape seed). Flax and sunflower were the annual energy crops that showed lower N emissions, similar to those estimated to perennials. Although a perennial crop, cardoon showed also high N emissions, comparable with those estimated for annual crops.

Nonetheless, IPCC emission factors don't take into account root and rhizome dynamics and N run-off and leaching can be lower due to the extensive root system of some of the crops studied. Several works on short rotation forestry systems and perennial grasses suggest that nitrate leaching is only of importance during the establishment of the crops, before roots have fully developed (Biewinga and van der Bijl, 1996). Perennial grasses have shown advantage in water and nutrient acquisition because underground standing biomass is massive and rhizome accumulation is significant (El Bassam, 1998, McLaughlin *et al.*, 1999, Bullard and Metcalfe, 2001, Panoutsou, 2007). According to Jørgensen and Schelde (2001), leaching is very limited cause of perennials efficiency at taking up nitrate due to their long growing season and the permanent and deep root system. Extensive root system may also slow the travel of surface water, decreasing run-off and allowing greater water infiltration, as it was observed with Switchgrass (Rinehart, 2006). Regarding willow and poplar, but not eucalyptus, they are eligible as vegetable filters for landfill leachates cause of their long growing season and permanent root system (Duggan, 2005).

While a negligible part of the N emissions, estimation of the N_2O emissions based on the IPCC 1% factor is still under debate. It is now understood that this factor should be superior (Crutzen *et al*., 2008), although full disclosing of soil N_2O release dynamics has not been achieved yet.

Concerning P and K emissions, while P from artificial fertilizer remains relatively inert in the soil, provoking no noteworthy effects, K may contribute to eutrophication of terrestrial ecosystems. This issue will be dealt with on the evaluation of the nutrient status of the soil (section 3.2.1.3).

3.1.2. Pesticide-related emissions

Pesticides contribute to ensure the supply of agricultural products. A profitable relation between pest control and agricultural productivity has been verified (Pimentel *et al*., 1992). However, the profit has a liability in terms of agricultural sustainability. The main shortcomings refer noxious human health effects, damage to flora and fauna, contamination of soil and groundwater and unbalacement of pests and diseases (Wilson and Tisdel, 2001).

Pesticides have an impact on the environment at several levels (Biewinga and van der Bijl, 1996):

- Use of energy resources for its production;
- Emissions to the environment during production, transport and storage of pesticides;
- Emissions to the environment during application of pesticides at the farm.

As most of the environmental burden is likely to come from application at the farm, this will be the only aspect to be focused.

Considerable amounts of pesticides end up in soil, water and air due to its application. The relative impact assessment of pesticide use should rely on quantity and harmfulness.

A pesticide score can be determined for each crop resulting from pesticide application. A risk score per crop can be attained through:

- the quantification of active substances applied in each crop;
- a survey on physical specifications, effects on the environment, fauna and human health of each active substance; this will score the toxicity of each pesticide;

- For each crop, a pesticide score can be calculated by multiplying the amount of each pesticide applied per hectare per year by the toxicity score of each pesticide and by adding up the scores (equation 2).

$$\text{Pesticide score}_{\text{crop}} = \sum (\text{amount}_{\text{active substance}\,(\text{kg ha}^{-1})} \times \text{toxicity score}_{\text{active substance}}) \qquad \textbf{(Eq. 2)}$$

Toxicity data on the substances was compiled from pesticides databases and the relative weight of each characteristic went according to Biewinga and van der Bijl (1996) and Portuguese Decree Portaria 732-A/96 (1996) (table 3). The toxicity score for each substance consisted on the sum of points attributed to each characteristic.

Table 3 - Toxicity score calculation framework (Biewinga and van der Bijl, 1996, Portaria 732-A/96, 1996).

Feature		**Ponderation**
Application		Yes = 1; No = 0
Water contamination: Solubility and Persistence in the water		Solubility > 1mg/l and > 28 days to degrade 70% = 1; Otherwise = 0
Soil contamination: Persistence in soil		DT_{50} > 267 days = 2; 90 days < DT_{50} ≤ 267 days = 1; DT_{50} ≤ 90 days = 0
Acute toxicity for water organisms		LC_{50} ≤ 1mg/l = 2; 1 mg/l < LC_{50} ≤ 10 mg/l = 1; LC_{50} > 10 mg/l = 0
Toxicity to terrestrial fauna		Yes = 1; No = 0
Toxicity to humans	Mammals	LD_{50} ≤ 25 mg/kg = 2; 25 mg/kg < LD_{50} ≤ 200 mg/kg = 1; LD_{50} > 200 mg/kg = 0
	Carcinogenic / Mutagenic	Yes = 1; Unknown = 0.5; No = 0
	Teratogenic	Yes = 1; Unknown = 0.5; No = 0

A survey on the substances applied, their amounts and traits was carried out thanks to an extensive bibliographic research in peer-reviewed journals, scientific reports and agricultural databases, to expert consulting and own field experience. Multiple references often document for the same crop the application of different pesticides with similar functions, or the application of the same pesticide in different quantities, or the needlessness of pesticide use. Hence, in these cases, a range of risks were calculated.

Figure 4 shows the pesticide scores for each crop in Europe (minimum and maximum risks).

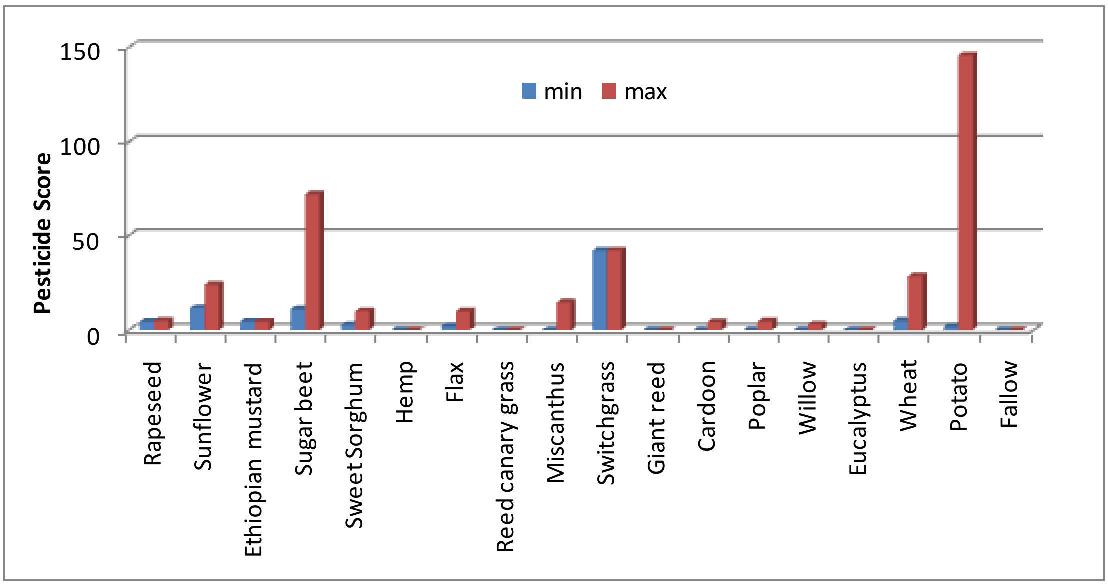

Figure 4 - Pesticide scores for each crop in Europe (minimum and maximum risks).

Figure 4 shows that most of the energy crops studied present lower pesticide impact, which reflects their apparently low susceptibility to pests and diseases. Crops that pose the least toxicity threat related to pesticide application are, obviously, the ones that do not need disease control and/or chemical weeding. According to literature, these are hemp, the trees (willow, poplar and eucalyptus) and the perennial grasses reed canary grass, Miscanthus, giant reed and cardoon. Nonetheless, there are reports of pesticide use in poplar, willow, Miscanthus and cardoon plantations, which increase their mean pesticide score. Besides the food crop potato, crops with higher pesticide risk are sugar beet and switchgrass. However, the estimated pesticide risk depends on the intensity level of pest control practices. Large differences between low and high intensity pesticide use exist in different places or according to different sources for the same crop species, such as in sugar beet and potato (figure 4). This implies that, although having high mean pesticide-related impact, these crops may have low to moderate impacts if managed in that manner.

3.2. Impact on soil

Common cropping management activities and crop characteristics affect soil quality through the change of nutrient, organic matter (SOM), structural and acidic statuses and erosion potentials (Biewinga and van der Bijl, 1996).

3.2.1. Nutrient status

3.2.1.1. Nitrogen

Nitrogen surplus results in soil accumulation. N surplus can be estimated by the difference between input (fertilisers) and output (emissions and crop uptake). But, if this surplus is negative, then soil N reserves become depleted. We assumed that uptake by fallow during its growth is returned to the soil during senescence and decomposition. As already referred in section 3.1.1, N inputs were considered at an European level. Estimation of N emissions was also done at European level, but crop uptake was determined at each environmental region due to differences in productivity and biomass composition among regions.

Figure 5 shows nitrogen surplus/deficit for all crops, in Europe (for each crop, average results of the several environmental zones). According to Figure 5, when comparing with grass fallow, sweet sorghum, hemp, flax, Miscanthus, switchgrass, poplar, willow and eucalyptus showed the lowest impact regarding N depletion of the soil. Sweet sorghum, flax, poplar and willow can even present a contribution to the soil N reserves. Sunflower and cardoon were the crops that showed a higher depletion of the soil N reserves. In the case of sunflower, this negative impact can be reduced if crop residues (straw) are incorporated in the field. The same is valid for cardoon when the seeds are the marketable product.

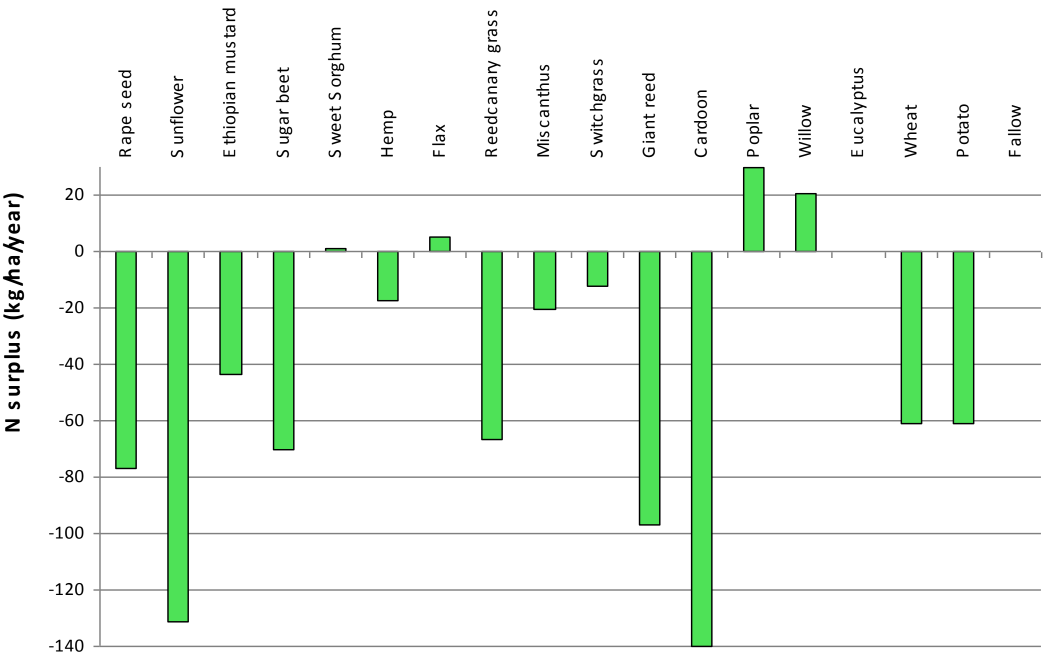

Figure 5 - Nitrogen surplus/deficit (kg/ha/year) for all crops, in Europe (for each crop, average results of the several environmental zones)

3.2.1.2. Phosphorus

In Europe, the present phosphate input in agricultural soils poses no threat to the quality of ground water, because soils have a high capacity to bind phosphate (Biewinga and van der Bijl, 1996). Nevertheless the risk is higher when manure is used and continued for a long period. Determination of the phosphorus surplus/deficit is a good indicator of the P soil accumulation or the P soil depletion.

As P inputs only fertilizers were considered and not manure. Deposition from air was not considered once this input will be the same, for each region, for all the crops, including grass fallow. As presented for nitrogen, a wide range of P fertilizer application, in each environmental zone studied, was observed, showing that P inputs are not regionally specific. So, P inputs were considered at an European level. P surplus/deficit was estimated by the difference between input (fertilizers) and output (crop uptake). As with N uptake, P uptake was determined at each environmental region due to differences in productivity and biomass composition among regions. It was also assumed that P uptake by fallow during its growth is returned to the soil during senescence and decomposition.

While figure 5 shows that most of the crops are soil N depleting, phosphorus balance presented in figure 6 shows a soil P surplus for most of the crops. According to these results, a balanced profile is presented: application of phosphorus was equal or superior to the crops uptake. Only Miscanthus and wheat showed a deficit, although negligible. Sweet sorghum and potato were the crops that contributed largely to the soil P reserves. However, considering that higher P inputs contribute to the exhaustion of mineral resources then, these results suggest that lower P inputs should be applied in those crops.

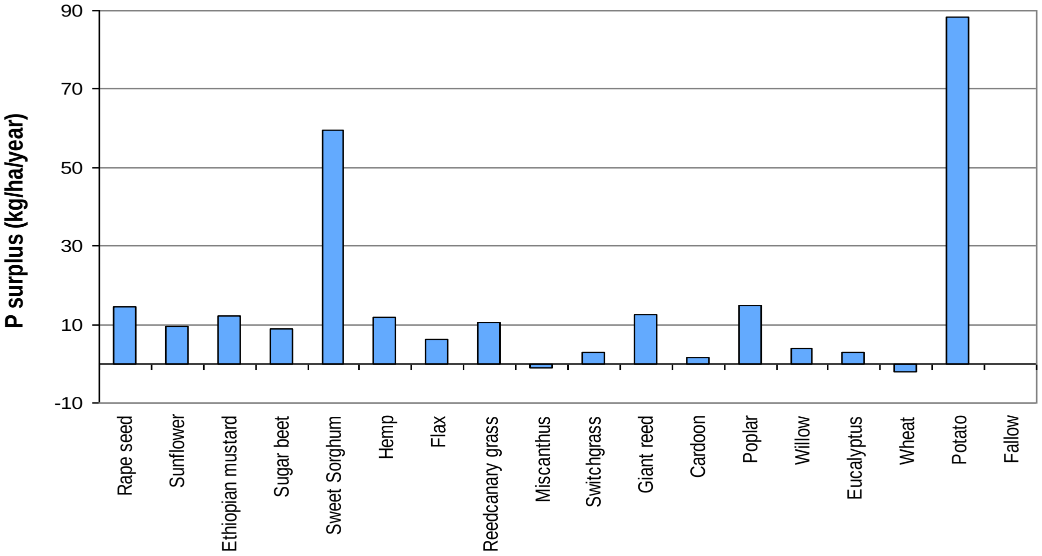

Figure 6 - Phosphorus surplus/deficit (kg/ha/year) for all crops, in Europe (for each crop, average results of the several environmental zones).

3.2.1.3. Potassium

Determination of the potassium surplus/deficit is a good indicator of the soil K accumulation and losses to the environment or the soil K depletion. Both aspects have a negative impact: the resulting K surplus may contribute to eutrophication of terrestrial ecosystems (Biewinga and van der Bijl, 1996) but if potassium inputs are lower than potassium crop uptake, K reserves of the soil might be depleted.

Fertilizers but not manure were considered as K inputs. Deposition from air was not considered once this input will be the same, for each region, for all the crops, including grass fallow. As it was observed for nitrogen and phosphorus, a wide range of K fertilizer application, in each environmental zone studied, was observed, showing that K inputs are not regionally specific. So, K inputs were considered at an European level. K surplus/deficit was estimated by the difference between input and output (crop uptake). K uptake was determined at each environmental region due to differences in productivity and biomass composition among regions. It also assumed that K uptake by fallow during its growth is returned to the soil during senescence and decomposition.

Figure 7 shows potassium surplus/deficit for all crops, in Europe. According to figure 7, most of the crops show a K deficit, especially both sugar crops (sugar beet and sweet sorghum), the perennial grasses reed canary grass, giant reed and cardoon and the food crop, wheat. Rapeseed, flax, Miscanthus and the woody crops, poplar, willow and eucalyptus showed a K surplus, but this accumulation of K in the soil may also present a negative impact, because it may contribute to eutrophication of terrestrial ecosystems (Biewinga and van der Bijl, 1996).

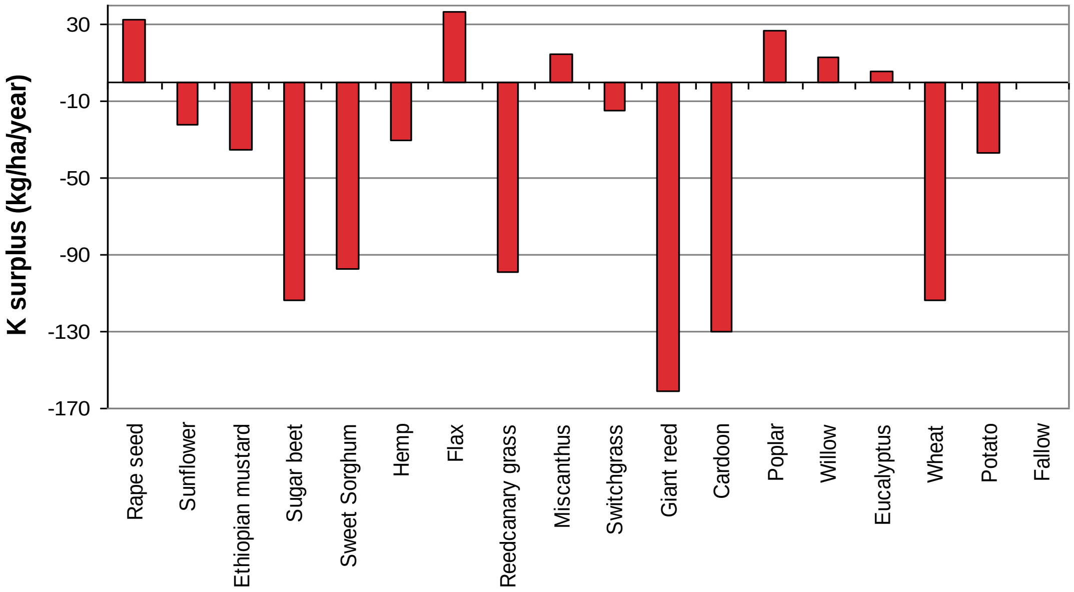

Figure 7 - Potassium surplus/deficit (kg/ha/year) for all crops, in Europe (for each crop, average results of the several environmental zones).

3.2.2. Soil properties

Soil as an agricultural or natural substrate plays a vital role in structural support and plant nourishment, watering and aeration. Moreover, its part in nutrient cycle, namely organic carbon storage, places soil quality in the basic requirements for enhanced agricultural productivity and environmental preservation (Reeves, 1997). Soil is an important carbon sink and its mismanagement can be a shortcoming for bioenergy systems' sustainability (Cannel, 2003; Brandão *et al*., 2010).

Common cropping management activities such as harvest and site preparation and the sheer prevalence of certain species can affect soil structure, pH and organic matter dynamics. These factors interact with influencing nutrient availability, thus soil fertility.

Assessing the impact of crops on soil organic matter content, structure and pH is highly dependent on local conditions. Nonetheless, there are generic trends documented in literature that allow a comparison between trees, perennial grasses and annual crops.

Residue cover left on soil enhances organic matter content, water storage and nutrient recycling and promotes structural integrity (Angers and Caron, 1998; Cannel, 1999; Lal, 1997; Sessiz *et al*., 2008). Litter removal, ploughing and tillage and use of synthetic fertilizers in detriment of organic fertilizers are seemingly impactful practices for depleting organic matter (Lal, 2005; van der Werf, 2004; Sessiz *et al*., 2008; Singh *et al.,* 2009).

Brandão *et al*. (2010) compared soil organic carbon stocks under rapeseed, Miscanthus and willow SRC land use. They concluded that rapeseed cultivation reduces soil organic carbon while Miscanthus increases it. Willow also has a negative effect, although milder than rapeseed.

Miscanthus had been previously suggested to accumulate organic matter in the soil owing to its permanence, high inputs of residues and rhizome storage (Kahle *et al*., 2001). Zan *et a*l. (2001) and Bransby *et al*. (1998) reported that switchgrass has the same enriching effect, namely through deposition of senescent leafs. Switchgrass contributes more to the soil's organic matter content than willow (Zan *et al*., 2001).

Long-established unmanaged forests benefit from long time accumulation of soil carbon, both in standing biomass and soil cover (Lal, 2005; Alexandrov, 2007). The same cannot be stated of managed forest species plantations. Much less organic matter is contained in a plantation owing to their smaller average biomass (namely at floor level) and precocious felling (Cannel, 1999; Alexandrov, 2007). Studies on the particular case of *Eucalyptus* have confirmed the negative effect on soil cover resulting from harvesting options practiced on this crop (Carneiro *et al*., 2008), further enhanced by its allelopathy, which limits the presence of understory vegetation (Sasikumar *et a*l., 2001; Zhang and Fu, 2009).

Soil revolving by tillage and ploughing and litter removal are more intensive in annual systems (Fragoso *et al*., 1997). Thus, annual crops are more likely to induce soil quality depletion through loss of organic matter and structure than perennial grasses and trees (Börjesson, 1999, Zan *et al.*, 2001).

Penetrating roots is one of the key points of the influence of plants in soil structure. Root growth promotes the formation of macropores, which are believed to enhance yields (Angers and Caron, 1998). Perennial grasses and trees have deeper roots than annual crops. Accordingly, perennial grasses accumulate more organic matter in the soil, followed by trees and annual crops. Litter deposition should not be higher in annual crops than in fallow. However, slower turnover in fallow than in arable fields (Friedel *et al.*, 2001) favors the annuals. Among them, it was assumed that sugar beet harvest depleted the soil from organic matter plus compromising soil physical integrity. On the other hand, rapeseed, Ethiopian mustard and flax benefit from roots and part of the stem left on the ground. Hemp and sweet sorghum have deep roots that improve structure and, being left in the ground after harvest, enhance organic matter content. The same happens with sunflower, although with less extent because of bigger spacing and smaller roots.

Regarding soil pH, forests and forestry crops can significantly increase soil acidity compared to short vegetation (Cannel, 1999), which limits nutrient availability thus crop growth (Bona *et al.*, 2008). Soil acidification results from the deposition of atmospheric pollutants absorbed by leafs and branches, such as HNO_3, HCl and NH_3, and of sulfate and nitrate aerosols accumulated in cloud water. These phenomena depend on regional pollution levels and meteorology but have been proven impactful in European regions such as the United Kingdom (Cannel, 1999).

Annual crops have a higher need for soil amendment, which quite often alters soil pH. Use of ammonia fertilizer significantly acidifies the soil (Bohn *et al.*, 2001). Although this modification might favor soil fertility for the desired crop, it can inflict a sharp deviation from soil pH native conditions. Perennial herbaceous fields have less fertilizers input and the higher organic matter content also curbs pH variation. Nonetheless, Kenaf – an annual crop – and Miscanthus cultivation data indicated negligible fluctuations in pH along the time (Fernando, 2005; Fernando *et al.*, 2007).

After an extensive literature review, crops and crop-types were benchmarked towards fallow and towards each other in a qualitative fashion (figure 8).

Lignocellulosic crops provide organic matter accumulation and structural enhancement related to permanence, high inputs of residues and vigorous root development. Consequently, these crops present a positive impact regarding SOM and soil structure (figure 8). Woody crops are reported to accumulate less SOM than herbaceous perennials, whereas eucalyptus induces further stress through the depletion of ground level vegetation by allelopathy. Annual cropping systems are the most damaging in terms of SOM content and structure due to high soil revolving, short permanence and litter removal. The impact is minor when crops have deep roots (e.g., hemp) and if litter is left on field and enhanced when the harvesting process removes a portion of the soil (e.g., sugar beet). Regarding soil pH, woody crops significantly increase soil acidity compared to short vegetation. Intensive soil amendment in annual systems may lead to sharp pH variations from the native status of the soil. The same processes can affect herbaceous perennials systems, but such has not been verified.

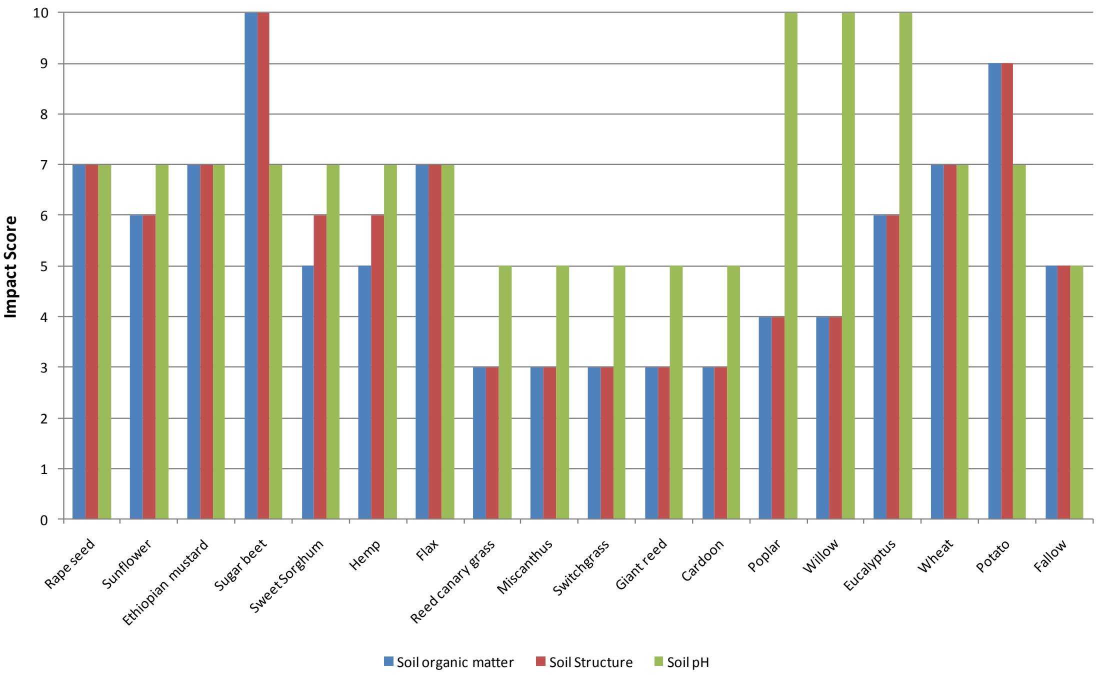

Figure 8 - Soil structure, organic matter content and pH impact scores of crops.

3.2.3. Erosion

Soil conservation through soil erosion prevention is crucial for maintaining productivity. Erosion leads to the loss of fertile soil and structurally damage crops. Moreover, displacement of materials, such as nutrients and contaminants, through wind and water can affect nearby terrestrial and aquatic ecosystems.

In this study water erosion is assessed by the adaptation of the protocol by Biewinga and van der Bijl (1996) crossing the potential damage caused by rainfall with the soil cover characteristics of the crops during their cultivation cycles.

Each crop growth was divided in four phases comprised between:

- A – start of growth
- B – closure of crop
- C – start of senescence
- D – harvest

Crop management factors (C-values) were defined for each phase of each crop. C-values reflect the soil cover rate of the crop (which depend on canopy development), remaining and buried crop residues and tillage. C-values are between 0 (soil totally covered) and 1 (soil completely uncovered). Definition of growth stages and C-values for each crop at each environmental zone was gathered through own field experience and literature review.

For each crop stage in each region, an accumulated precipitation (R-value) was determined by adding up the monthly average rainfall (mm). Precipitation data was supplied by Joint Research Centre (JRC, 2010). For each crop and region, C and R are multiplied and summed up; this sum is then multiplied by P, the erosion control factor, to obtain the total harmful rainfall (equation 3).

$$\text{Total harmful rainfall}_{\text{crop and region}} = \sum (\mathrm{C} \times \mathrm{R})_{\text{stage and region}} \times \mathrm{P}_{\text{region}} \qquad \textbf{(Eq. 3)}$$

The erosion control factor (P-value) reflects the control of erosion and soil conservation carried out in each region. Values of P are between 0 (well established erosion control) and 1 (no erosion control). European Commission data indicate that areas in Southern and Central Europe as well as in the Baltic region have higher erosion risks than the Atlantic climates (van der Knijff *et al.*, 2000). Biewinga and van der Bijl (1996) consider that there are established erosion control systems in Portugal and less established ones in the Netherlands and the United Kingdom, while none in Continental Germany. However, Fullen (2003) reviews soil erosion control and prevention studies and programs carried out in most northern European countries, comprising Nemoral, Atlantic, Lusitanian and Continental regions. Such initiatives can be also identified in Lithuania and Poland (Wilson and Maliszewska-Kordybach, 2000) and in the Mediterranean basin (Poesen and Hooke, 1997). Consequently, it was assumed that erosion control takes place in all climatic zones. Hence, for all regions it was decided to use a P value of 0.8.

Results corroborate the suggestions by Kort *et al.* (1998) that lignocellulosic and woody crops exhibit average lower erodibility potential owing to greater interception of rainfall and more surface cover for a longer time period (figure 9). The continuous presence of an underground biomass in the soil also contributes to these findings. Among perennials, reed canary grass and cardoon presented the lower erosion potential, in line with fallow, because these crops were studied in Mediterranean South and Nemoral, two environmental zones where annual precipitation is very low.

In contrast, annual crops pose higher erosion risks, particularly potato, rape seed, sunflower, sweet sorghum, hemp and wheat. Concerning sweet sorghum and sunflower, in a Mediterranean setting this may be an important factor, since that region has the highest erosion potential in Europe (van der Knijff *et al.*, 2000). Ethiopian mustard, however, shows an impact similar to that of perennials owing to the fact that this is a winter crop, and its permanence in the soil is very long. Along with this fact, Ethiopian mustard was studied in South Mediterranean, where annual precipitation is very low.

Nevertheless, in this erosion impact analysis it was only considered the exposure of the soil to rainfall. Other important factors that might contribute to the erosion potential of each crop, such as wind, SOM and soil structure, which also influence the soils integrity, were not considered in this study.

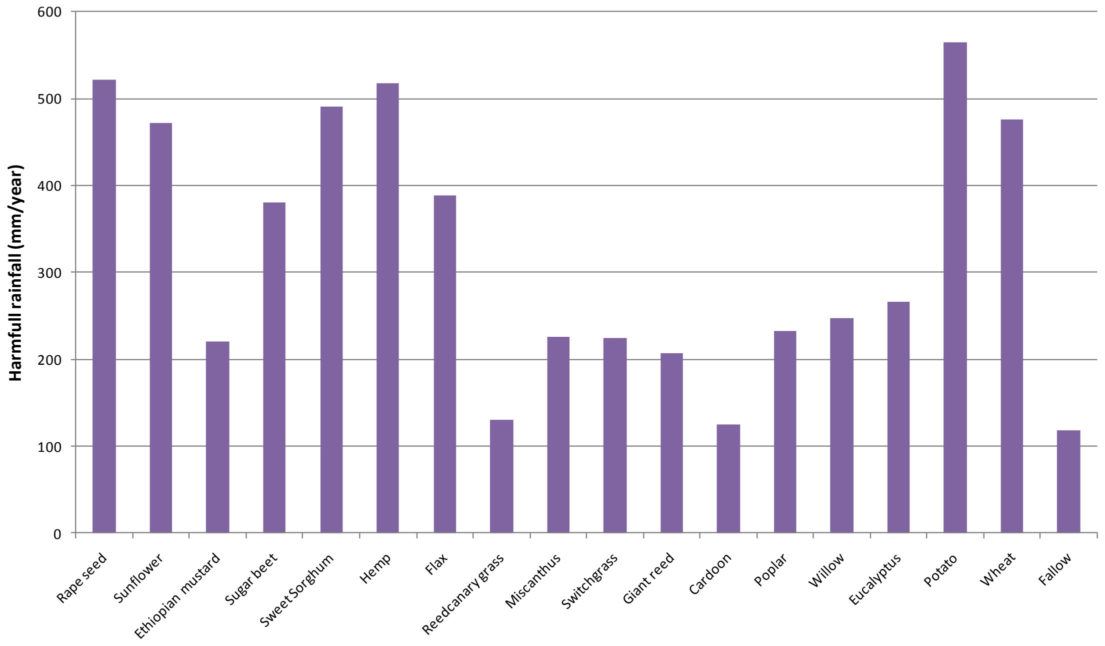

Figure 9 – Harmful rainfall for all crops in Europe (for each crop, average results of the several environmental zones).

Assessement of the erosion risk is highly site specific, naturally owing to the weight of pluviosity. Nemoral and Mediterranean regions are drier. Hence, the average erosion risk verified there is lower than in climates with higher precipitation, such as atlantic north and lusitanian. Figure 10 shows the sensitivity to region of this indicator, since each crop type present the same curve as the regional distribution of annual precipitation.

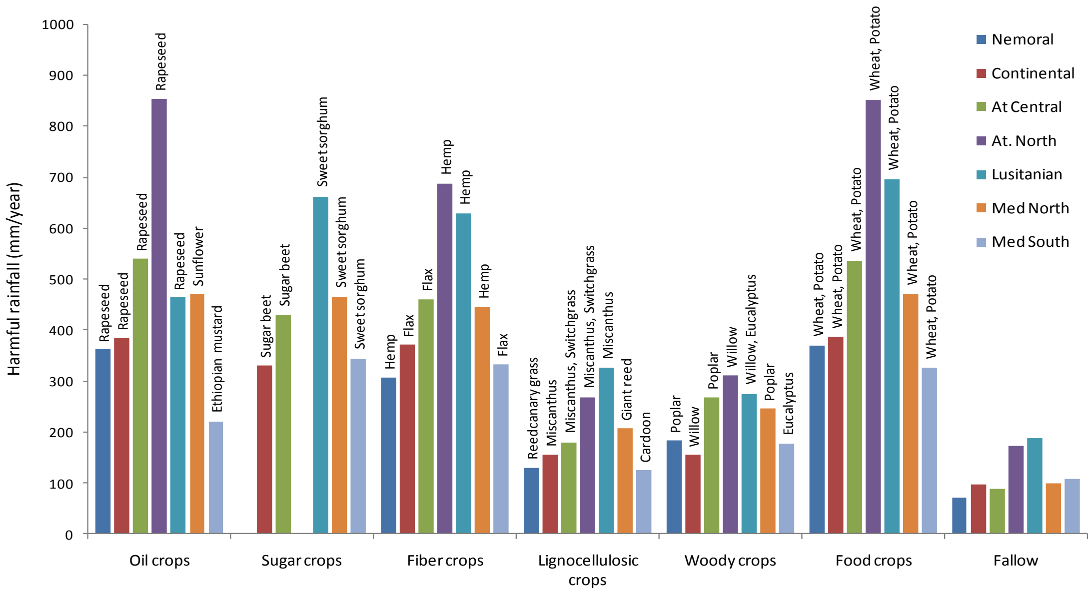

Figure 10 – Harmful rainfall for each type of crop in each environmental region of Europe.

3.3. Impact on Water and Mineral Resources

3.3.1. Groundwater balance and effects on hydrology

Agricultural products account for the largest share of worldwide freshwater demand in the world (FAO, 2010). Meeting the claims of the food and bioenergy markets and other industries for high agricultural productivity is stressing water resources (Gerbens-Leenes *et al.*, 2009).

Plant water use is expressed by evapotranspiration. Besides inherent factors, this process is bound to climatic aspects such as solar radiation and relative humidity. Moreover, the water that is in fact obtainable by the rooting system is dependent on local hydrological processes such as drainage and infiltration (Gerbens-Leenes and Nonhebel, 2004).

Lacking site-specific data, a more broad approach was carried out. Crops can either be irrigated or suppress their water needs by accessing aquifers and precipitation water. Whichever way, unless rainfall tops requirements, freshwater must be extracted from surface or groundwater, which depletes natural stocks. Hence, depletion of groundwater resources was determined by comparing the available water provided by rainfall and the water requirements of the crop.

A generic amount of water (mm yr^{-1}) required by each energy crop was determined through literature review. The availability of precipitation water of each climatic region was considered to correspond to the accumulated monthly average rainfall of several European locations within each climatic region. For annual crops, the rainfall was only accounted for when lying within the limits of crop growth: from start of growth to harvest. For perennials, it was accounted the annual precipitation, because of its permanent and deep root system efficiency at taking up water (El Bassam, 1998, McLaughlin *et al.*, 1999, Bullard and Metcalfe, 2001, Panoutsou, 2007).

Subtracting water needs to available rainfall would reveal a deficit in supply or the accommodation of the requirement by the availability. It was assumed that the resulting calculus would correspond to groundwater balance, expressed in mm (equation 4).

$$\mathrm{Groundwater\ depletion} = \mathrm{available\ rainfall} - \mathrm{water\ requirement} \qquad \textbf{(Eq. 4)}$$

Figure 11 shows groundwater balance results for all the studied crops, in Europe.

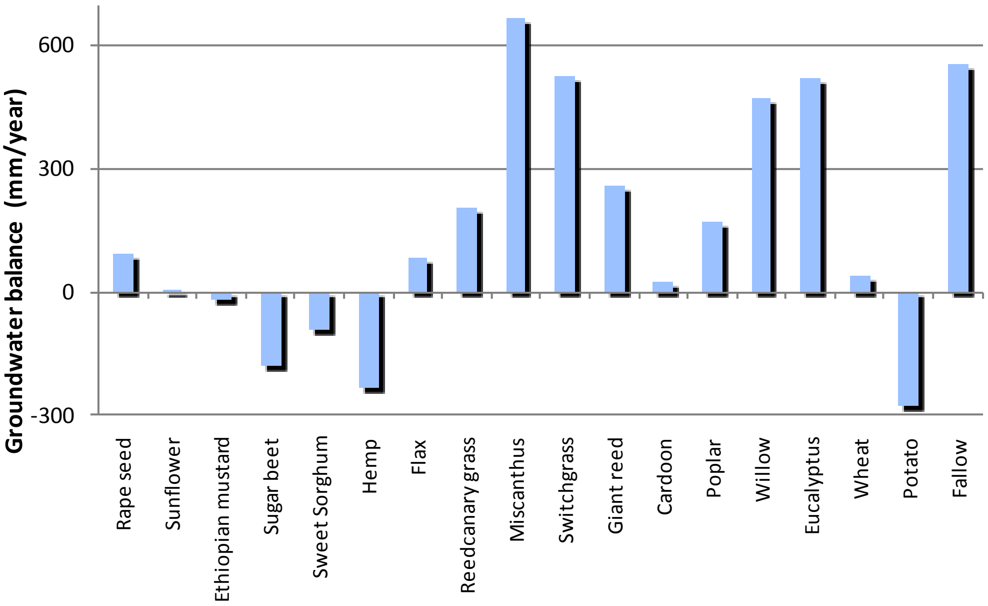

Figure 11 - Groundwater balance for each crop in Europe (average results from the several environmental zones studied)

According to these results, the sugar crops, sugar beet and sweet sorghum, hemp and potato may lead to depletion of groundwater resources (Figure 11). The crop with most severe average exhaustion potential is potato, followed by hemp and sugar beet. All other crops do not inflict a depletion of groundwater resources. Perennial grasses and woody crops show the highest positive water balances. Among perennials, Miscanthus, switchgrass, willow and eucalyptus performed better, in line with fallow.

The impact on groundwater is highly site specific (figure 12). Regions with lower rainfall (Nemoral, Mediterranean North and Mediterranean South) record higher deficits. But, interaction between region and crop is also highly significant. Annual crops are more prone to negative water balances than perennial grasses and trees. Nonetheless, high water demanding crops can present a balanced amount in regions with higher precipitation, like hemp in Atlantic north. Rapeseed, for example, presents a high positive water balance in Lusitanian due to the fact that the limits of crop growth in this region are coincident with this region highest rainfall period. On the other hand, hemp in Mediterranean North shows higher groundwater depletion than flax in Mediterranean South, because hemp is more water demanding than flax.

Perennial grasses and woody species show positive water balances. Even so, in regions with less precipitation, balances results can be lower, such as with cardoon in the Mediterranean South.

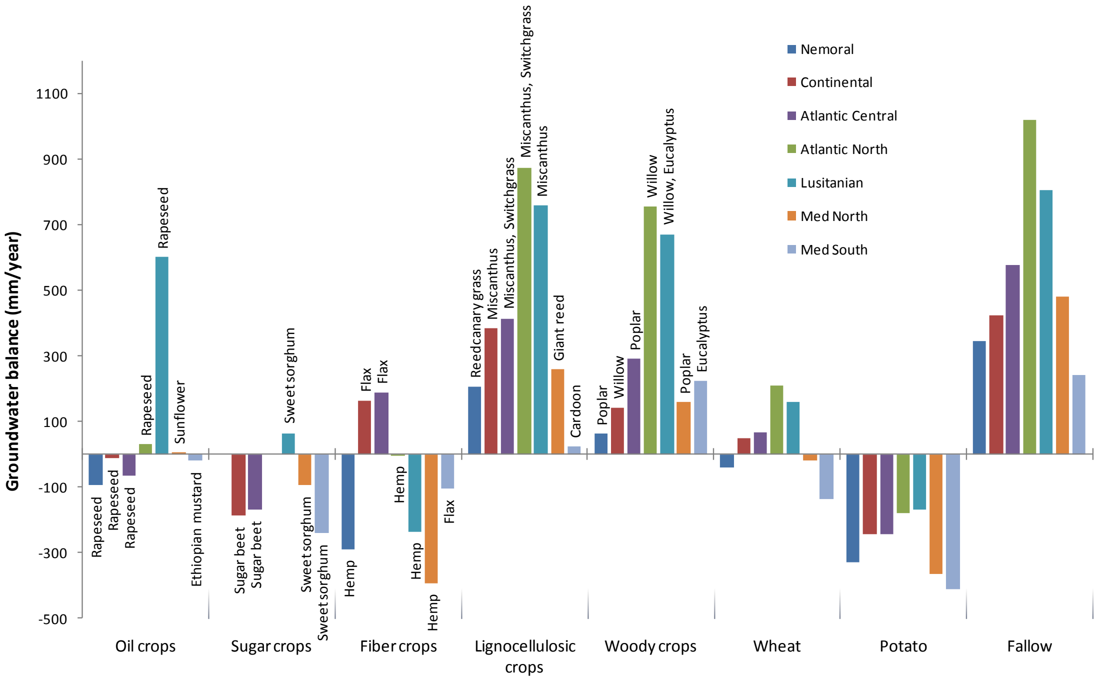

Figure 12 - Groundwater balance per type of crop in each environmental region of Europe.

Land use for agricultural practices does not always safeguard the levels and quality of water resources (Gerbens-Leenes *et al.*, 2009; Biewinga and van der Bijl, 1996). Hydrology effects of energy crops cultivation can go beyond their water demand, focusing also on the crops cultivation effects on the flow of ground water, stream water, run-off, etc. These aspects are highly site specific as well as related to crop traits (Hall, 2003).

There are overall conclusions pointing towards neutral to beneficial effects. Tolbert *et al*. (1998) state that soil covering minimize surface run-off and sediment and nutrient losses. Decreased run-off allied to soil drying and increased penetration effects render energy crops useful in flood management when cultivated in wet fields (Rowe *et al.*, 2009; Biewinga and van der Bijl, 1996). Hall (2003) claim that on optimal locations the impact of energy crops on water quality is likely to be positive owing to less agrochemical inputs when compared to traditional farming.

On the other hand, shortcomings should be expected from species combining higher growth rates and transpiration rates, longer seasonal growth and deeper and more complex root system (such as SRC and herbaceous C4 plants, but also hemp and sweet sorghum). Deep rooting slows down rainfall refill of aquifers, especially when associated with high evapotranspiration losses (Stephens *et al.*, 2001). However, grasses exhibit less transpiration owing to shorter harvest cycles and improved water use efficiency (Hall, 2003).

Figure 13 shows the impact on hydrology by the different energy crops studied, in Europe.

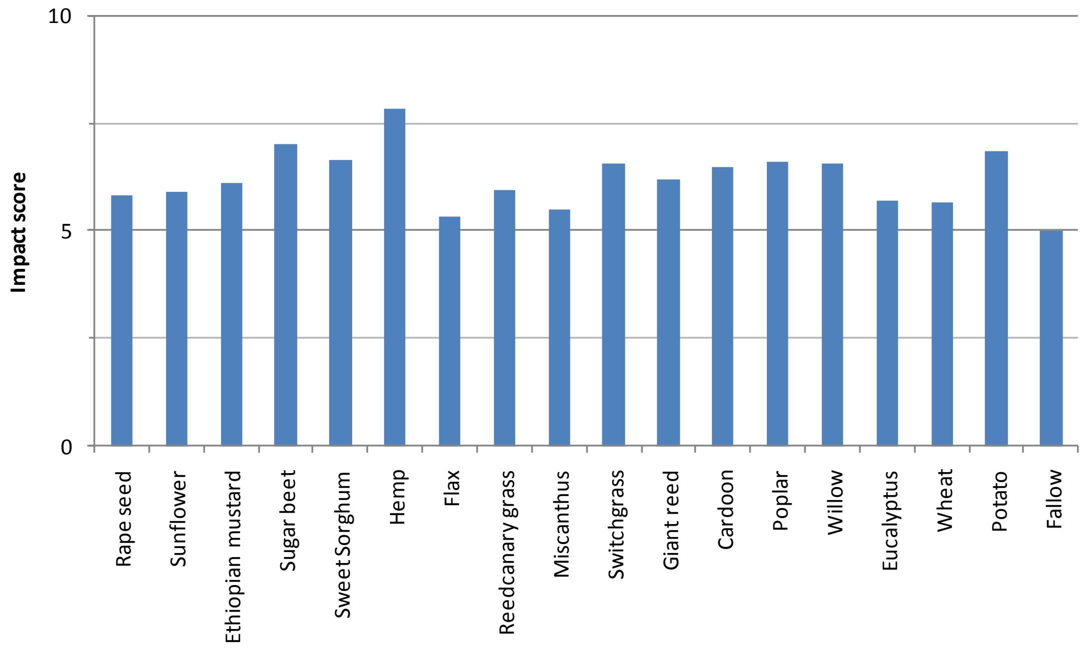

Figure 13 – Impact on hydrology of each crop, in Europe (average results from the several environmental zones studied).

Effects on water flow and run-off and on refill of aquifers were scored according to the crop permanence on soil, the crop water needs and the crop root system. The longer the crops permanence in the soil (e.g. perennials and fallow) the better the beneficial effect due to minimization of surface run-off. On the opposite, crops with shorter permanence in the soil have a higher impact on hydrology (e.g. potato). Shortcomings concerning aquifer refilling were credited to crops with higher water needs (e.g., sugar beet, hemp, switchgrass, poplar and willow) and deeper root systems (e.g., perennials, hemp and sweet sorghum).

3.3.2. Mineral ore depletion

Natural stocks limit the exploitation of abiotic resources. The current intensive extraction of mineral resources today will force future generations to extract lower quantities from lower grade ores. This leads to an increased impact on environment and economy, since the cost and environmental burden of the extraction varies oppositely to the concentration in the mined deposits (Steen, 2006). Accordingly, as environmental and economic costs increase, use and production volumes will decrease.

Agricultural systems rely on a supply of artificial fertilizers that in turn depend on the input of mineral resources (Biewinga and van der Bijl, 1996). Hence, fertilizers use influence the depletion of mineral ores.

This category was assessed according to Biewinga and van der Bijl (1996) who suggest that phosphate and potassium fertilizers should be taken into account, once they are mined as mineral ores, with limited resources. Minimum and maximum P and K fertilizer inputs for the cultivation of each crop in Europe were quantified. The exhaustion of mineral ores is expressed as kg K_{eq} ha^{-1} determined according to eq. 5 (as phosphate fertilizer is scarcer, it will weight five times more than the weight of potassium fertilizer).

$$PK\,fertilizer\,use\,(kg\,K_{eq}/ha) = 5 \times P\,input\,(kg/ha) + K\,input\,(kg/ha) \qquad \text{(Eq. 5)}$$

Figure 14 show the impact of the energy crops cultivation on the exhaustion of mineral ores. Most crops have a high range of PK fertilizer use. Hence, the different PK use intensities indicate that some crops whose average mineral ore depletion level is high may be cultivated in a lower-impact regime. Rapeseed, sunflower, sugar beet, flax and the food crops fit that case, since their minimum PK input is much lower than the maximum. However, some of these crops showed K depletion of the soil (section 3.2.1.3), so care should be taken to avoid additional impact on soil. Crops like rape seed or flax that showed both P and K positive balances give margin to this lower impact regime.

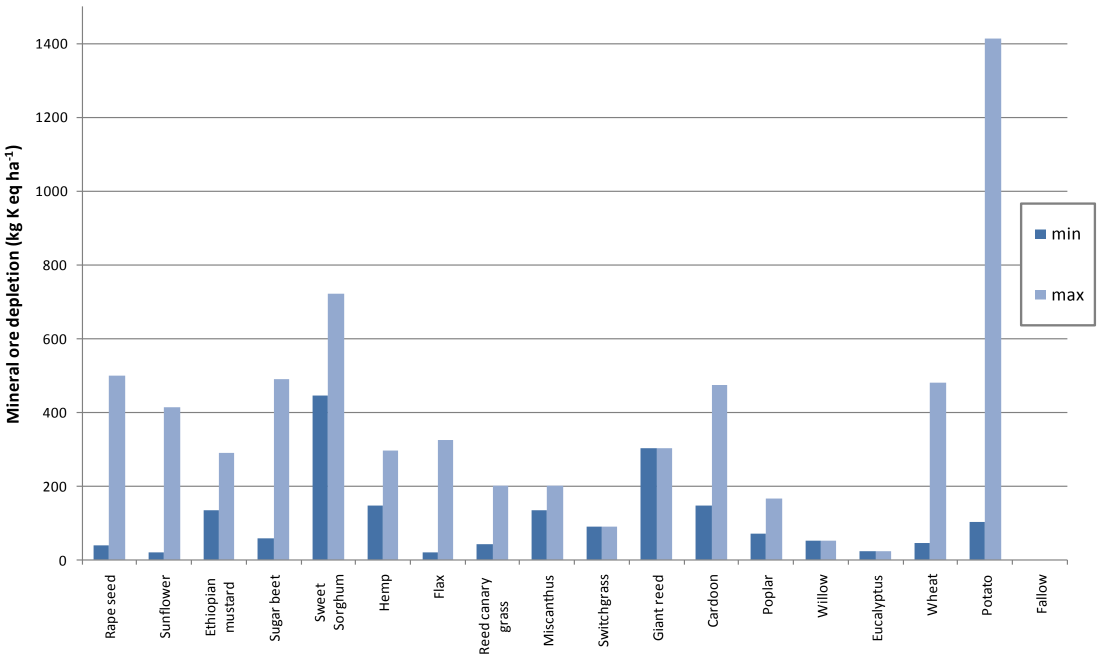

Figure 14 – Ranges of mineral ore depletion impact of each crop in Europe.

Perennials are less P and K demanding, although differences to most of the annual crops studied are not significant (figure 14). Lower impact is observed for eucalyptus and willow whereas sweet sorghum and potato present the highest risk concerning mineral resources.

3.4. Waste

Plants have the ability to serve as filters, lowering the contaminant level of heavy metal polluted soils, wastewaters and landfill leachates. Thus, this environmental impact analysis included the possibility of using the selected crops for soil correction, restoration of contaminated sites and/or including in their life cycle inputs such as municipal solid waste compost (MSWC), sewage sludge and wastewater for fertilization and irrigation.

This assessment section consisted on scoring the crops relatively to their ability to take up contaminants and nutrients from sludge, slurry, landfills, wastewaters and soils and to their propensity to produce undesired waste during cultivation. The crops were, then, scaled towards fallow, that scored 5 (figure 15).

Energy crops have been thoroughly documented as apt remediators of heavy metal contaminated soils and landfill leachates. Irrigation with wastewaters and soil amendment with sewage sludge is reported as well. Thus all crops studied scored the same as fallow fields, where it was assumed that phytorremediation and application of wastewaters and manure is also possible.

Willow and poplar have been documented as efficient landfill caps treating its leachates (Börjesson, 1999; Duggan, 2005). Willow plantations have been irrigated with wastewater and sewage sludge (Heller *et al.*, 2003; Rosenqvist and Dawson, 2005; Hansson *et al.*, 1999). Poplar was tested with success for remediation of soil amended with non-hazardous levels of industrial waste (Giachetti and Sebastiani, 2006). Guo *et al.* (2002) reported the irrigation of Eucalyptus plantations with meatworks effluent.

Reed canary grass, Miscanthus and switchgrass are considered suitable for disposal of sewage sludge in soils (Bullard and Metcalfe, 2001; Fernando, 2005). Börjesson (1999) reports reed canary grass appropriate for treatment of landfill leachate as well. Irrigation with wastewater from municipal and/or industrial sources are reported cultivation practices alternatives for reed canary grass (USDA, 2006) and giant reed (Mavrogianopoulos *et al.*, 2002). The latter is further documented to have high tolerance to metals in the soils treated with sewage sludge (Papazoglou, 2007). Liquid manure application from pig farms as nitrogen substitute is an added value strategy for cardoon and sugar beet cultivation (Luger, 2003; Draycott, 2006).

Concerning annual crops, rape seed is documented for phytoextration of heavy metals (Sheng *et al.*, 2008; Rossi *et al.*, 2002), although Marchiol *et al.* (2004) reported low phytoextraction potential. Batchelor *et al. (*1995) indicate that sewage sludge and animal excreta can be used as fertilizers on the plantations. Niu *et al.*, 2007 successfully used oilseed crops sunflower and Ethiopian mustard for phytoextraction of metals from sewage sludge. Bioremediation capabilities have also been suggested for hemp (Linger *et al.*, 2002), flax (Bjelková *et al.*, 2001; Grabowska and Baraniecki, 1997) and sweet sorghum (Epelde *et al.*, 2009).

Irrigation of wheat and potato plantations with waste water and sewage sludge is possible (Antonious *et al*., 2003; Dvořák *et al*., 2003) but may cause accumulation of metals (Abd-El-Fattah *et al.*, 2002; Dvořák *et al*., 2003) and contamination with pathogens (Amahmid, *et al.* 1999) in edible parts, hence compromising food quality. Despite the augmentation of heavy metals and faecal coliforms concentration in soil, treatments with MSWC can be effective, with positive gains in wheat yields (Cherif *et al*., 2009). But, edible crops may face the problem of accumulation of chemicals and of biological contamination beyond accepted toxicity limits. In this case, the application of waste can only be taken into account if for non-food purposes, when relevant.

Regarding the generation of waste during cultivation, it was assumed that all crops produce it in the form of pesticide and fertilizer disposed packages and old machinery (Biewinga and van der Bijl, 1996), thus scoring higher impact than fallow fields. Being less management intensive, perennial grasses and trees generate less waste than annual crops (figure 15). Soil sticking to the sugar beet during the harvest further increases the impact of this crop because this waste cannot return to the field due to phytosanitary reasons (Biewinga and van der Bijl, 1996).

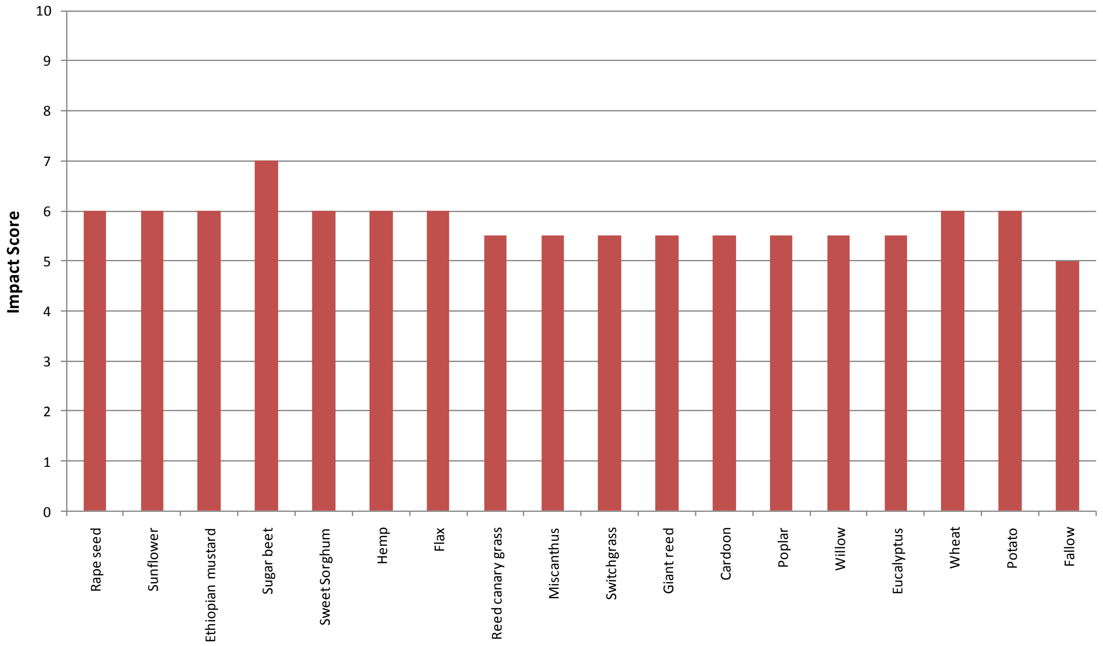

Figure 15 – Impact of waste generation and use of each crop in Europe.

3.5. Biodiversity

Biodiversity impact assessment is highly site-specific since it analyzes the effect of the introduction of a crop and its cultivation system on the structure of ecological units and the sustainable development and use of an existing population (Stlootweg and Kolhoff, 2003; Rodrigues *et al*., 2003; Biewinga and van der Bijl, 1996).

Landscape configuration and habitat richness have an impact on its community's diversity (Dauber *et al*., 2003). It is agreed that more complex structure and heterogeneity of a vegetation system have a positive influence on its cover value for wildlife (Smeets *et al*., 2009). Establishment of a monoculture as a replacement of natural diversified vegetation is a violation against biodiversity (Mattson *et al*., 2000; Bringezu *et al*., 2009). By definition, any natural vegetation type has the best performance concerning the ecosystem services and, consequently, biodiversity (Smeets *et al*., 2009). Hence, compared to a natural system even if fallow land, any energy crop will have negative effects and they will be more severe the farther the system shifts from the native conditions (Paine *et al*., 1996). These effects vary, nonetheless, with the traits inherent to the crop, plantation siting and its management system (McLaughlin and Walsh, 1998; Fragoso *et al*., 1997).

Facing the lack of local onset data and extensive and systematic reference studies for each crop species, a generic approach was implemented. Data on biodiversity impact assessment of each crop was compiled through an extensive literature review. Crops and crop-types were benchmarked towards fallow and towards each other in a qualitative fashion. Subsequently, biodiversity impact scores were calculated through the deliberation of the collected data. Scoring and scaling of the crops was related to fallow field reference (figure 16). In general terms, establishment of a monoculture (all crops studied) and aggressiveness of species (*Eucalyptus* spp., reed canary grass and giant reed) result in a higher impact. On the other hand, native species (cardoon, reed canary grass and rapeseed) and colorful blossomed crops contribute to the biodiversity value. Globally, trees were considered richer in terms of biodiversity value and annual crops poorer. Perennial grasses were scored in between. The remaining variations in scoring are due to characteristics of the plants or of their cultivation practices and also to documented negative or positive impacts. The judgment of these results is dependent on the fitness of the background data, which comes from studies that are not systematic, do not encompass the full lifetime of the plantations and are not available for every species. The analysis was, therefore, subjective and often involved extrapolating knowledge of one species to its similes (figure 16).

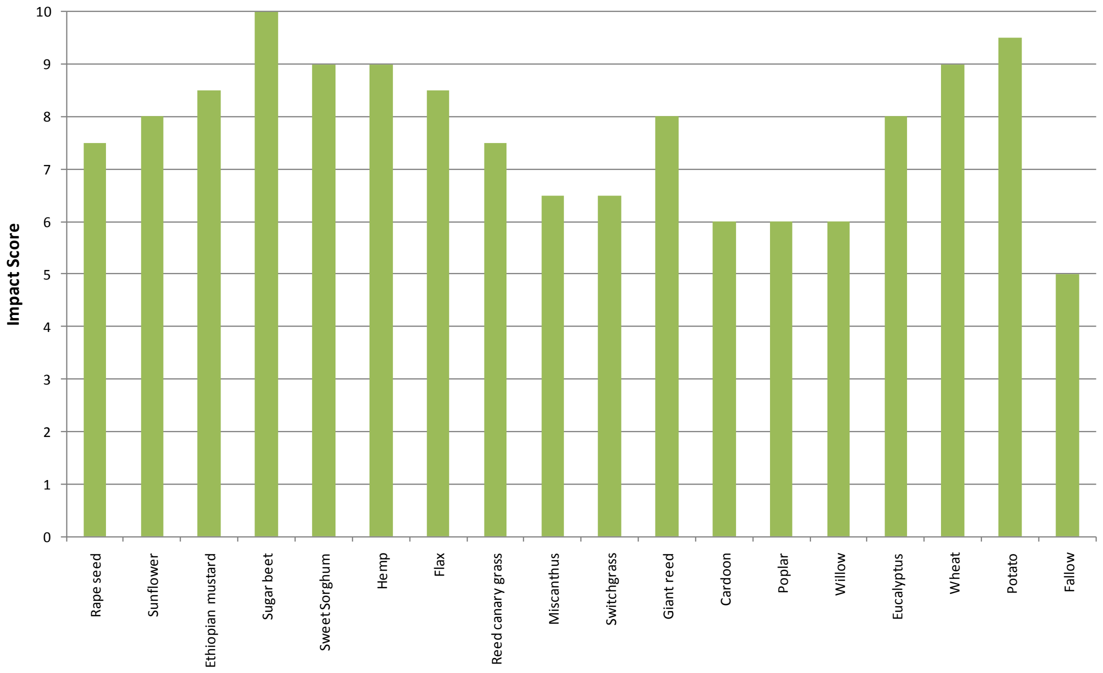

Figure 16 - Impact on biodiversity of each crop in Europe.

Detailed explanation on discrimination of scores shown in figure 16 ensues:

Perennial rhizomatous grasses like switchgrass, Miscanthus, reed canary grass, giant reed and cardoon require a reduced soil tillage and use of agrochemicals (as fertilizers, pesticides and herbicides). Owing to this little land disturbance compared to annual crops, perennial grasses crops have a high cover value for wildlife (Prochnow *et al*., 2009; Börjesson, 1999; Boehmel *et al*., 2008). These plants have a high above and belowground biomass, leading to high soil organic matter content due to rhizome biomass accumulation and litter deposition. These conditions favor diversity and occurrence of soil microorganisms and soil fauna, especially decomposers such as earthworms, wood lice, harvestmen and carbides (Börjesson, 1999). Moreover, since the crops are usually harvested in the spring, the fields are used as an over-wintering sites for invertebrates and shelter for birds and small mammals (Bellamy *et al*., 2009; Smeets *et al*., 2009; Semere and Slater, 2007a and 2007b).

Semere and Slater (2007 b) reported that the weed cover in Miscanthus fields increased the general invertebrate diversity of many orders. Semere and Slater (2007a and 2007b) pointed out that Miscanthus cultivation supports more diversity and abundance than reed canary plantations or arable fields within the following biological groups: weed flora, ground beetles, butterflies, and arboreal invertebrates. Since the known references indicated the same biodiversity value both in Miscanthus and switchgrass plantations (Smeets *et al*., 2009) and there are documented references of those values, these species got the same score. Nonetheless, there are claims that Miscanthus support less biodiversity than SCR plantations, which is the reason why perennials were scored with a lower value than trees (Rowe *et al*., 2009).

Reed canary grass and giant reed share the advantage of the previously mentioned crops. Still, their aggressive behavior leads to the replacement of other desired indigenous or cultured vegetation (USDA, 2006; DAISIE, 2009), especially when grown in monoculture and when subject to mismanagement. Hence, these crops were scored with higher impact than Miscanthus and switchgrass.

Native crops serve as a biodiversity-friendly feedstock, like the cardoon (native to the Mediterranean region) or reed canary grass and rape seed, as they should have more benefits as habitat for native species than foreign options (Groom *et al.*, 2008). Cardoon and rape seed further benefits from a period of inflorescence in its scoring.

Annual crops have been reported as source of seemingly biodiversity loss. Literature asserts that perennial grass and tree plantations support more, microfauna, soil fauna and bird species (Fragoso *et al.*, 1997; Berg, 2002; Börjesson, 1999). This is due to short permanence on soil and thorough management, including high agrochemical inputs, ploughing and tillage and removal of litter soil cover (Mineau and McLaughlin, 1996; Fragoso *et al.*, 1997; Berg, 2002). Hence, these crops were scored with the highest impact when compared to trees and perennial grasses. Nonetheless, annual crops that undergo a flowering period should attract insects and birds, increasing their diversity and numbers. Such has been reported in sunflower fields (Jones and Sieving, 2006) and is likely to happen in other colorful blossomed annual crops such as flax, rapeseed and Ethiopian mustard.

Sugar beet has the worst performance, since it does not gain relevant structure and its harvesting should be very aggressive to soil fauna owing to the total removal of the plant. Wheat and potato share shortcomings of annual crops. Although potato bears inflorescence in its life cycle and is a well structured crop, it has a very short permanence on ground and its harvest is similar to sugar beet.

Literature accounts that poplar and willow increase bird species number and diversity and provide transitional habitats in farmland settings (Börjesson, 1999; Skärbäck and Becht, 2005; Rowe *et al.*, 2009; Christian *et al.*, 1997; Berthelot *et al.*, 2005; Berg, 2002). The presence of SRC cultivation might have negative impact for changing the dynamics of local flora and fauna, increasing pests and creating shelter for predators (Paine *et al.*, 1996; Börjesson, 1999). However, the overall effect is stated as negligible at a regional level to being a positive trade-off between productivity and species richness at a local level (Cannel, 1999; Ulrich *et al.*, 2004). Their structure and longer life cycle awards these systems with higher biodiversity values than perennial herbaceous plantations (Rowe *et al.*, 2009), for which they received a score closer to fallow's.

Eucalyptus bears drawbacks in relation to the other trees. Its aggressiveness has been thoroughly discussed and results from the DAISIE Project (2009) report many of the species of this genre to be invasive in European countries. Moreover, it is a management-intensive system in which soil disturbance during preparation and harvest distress understory flora (Carneiro *et al.*, 2009). Allelopathy further limits the development of native vegetation (Sasikumar *et al.*, 2001). Nonetheless, some reports point to the prevalence of certain species and deny the reduction of specific diversity (Fabião *et al.*, 2007). These arguments support the negative biodiversity value outcome of this genre plantation.

3.6. Landscape

Anthropogenic alterations on the landscape character may induce visual impact. Whether this impact is an enhancement or degradation determines gain or loss of value of this economical and environmental resource.

Landscape impact assessment was performed by comparing the crops with fallow land. Lacking onset data, the analysis was performed based on a subjective analysis of know crop traits. By suggestion of Biewinga and van der Bijl (1996) the structure and colour were chosen as criteria to evaluate landscape quality and greater variation earned positive evaluation. Fallow land was considered a standard and variation was assumed to be a deviation in landscape characteristics of the crop towards fallow.

The evaluation of structure included height, density, heterogeneity and openness of the crop. Assessment of variation of colour considered significant variation of colour of the crop along its life cycle and/or presence of structures, such as inflorescences, with distinct coloration.

The assessment commenced by answering two questions:

- Does the crop vary in colour and/or structure comparing with fallow?
- If so, does the variation in colour and/or structure consist of an aesthetical enhancement?

The crops were scaled against fallow from 0 to 10 in each parameter, being fallow = 5. 10 would represent the landscape with most value and 0 the landscape with less. Variation was considered to be a benefit when it embraced gains in structure and/or colour and variation implying loss of structure and/or colour debited the landscape values. Hence, positive scoring yielded from increases in height, heterogeneity, density, openness and colour. Negative scoring resulted from the opposite. Non-variation was considered to be neutral.

The final landscape value score was calculated through a weighed mean, in which colour valued two times more (figure 17).

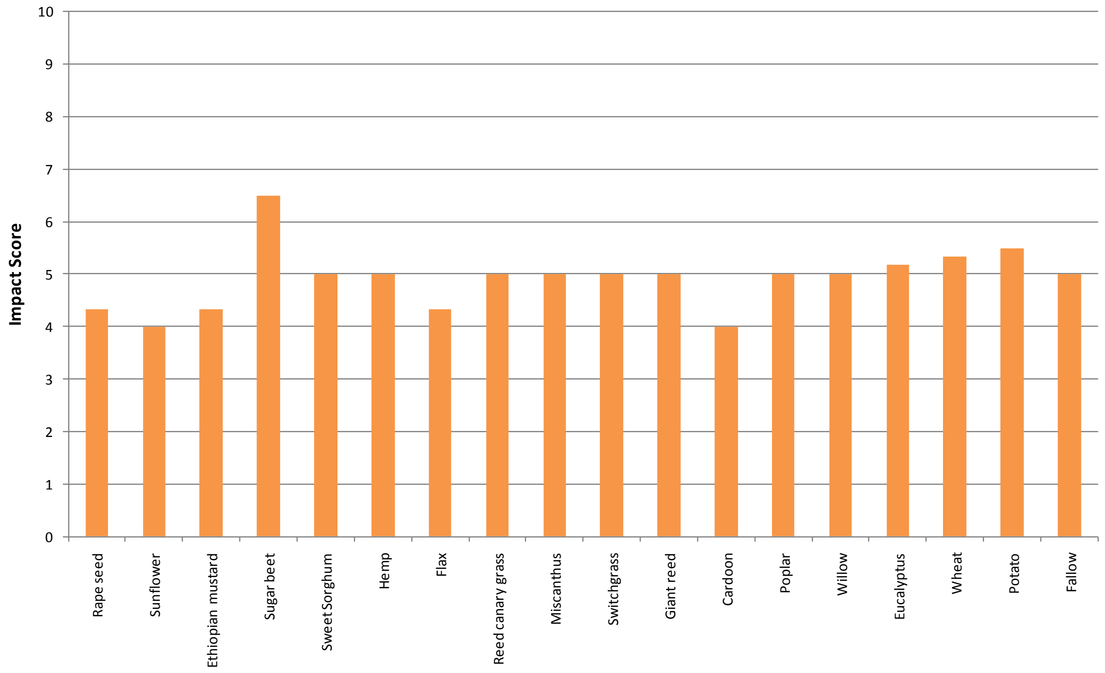

Figure 17 – Impact on landscape values of each crop, in Europe.

The impact on landscape values in even among crops (figure 17). The exception is sugar beet, which have a higher impact. Sugar beet is the only crop at hand which represents a downgrade to landscape when comparing with fallow. While potato looses in homogeneity, it gains in structure, hence being evaluated in line with fallow. Blossoming crops have the lower impact.

3.7. Overall results

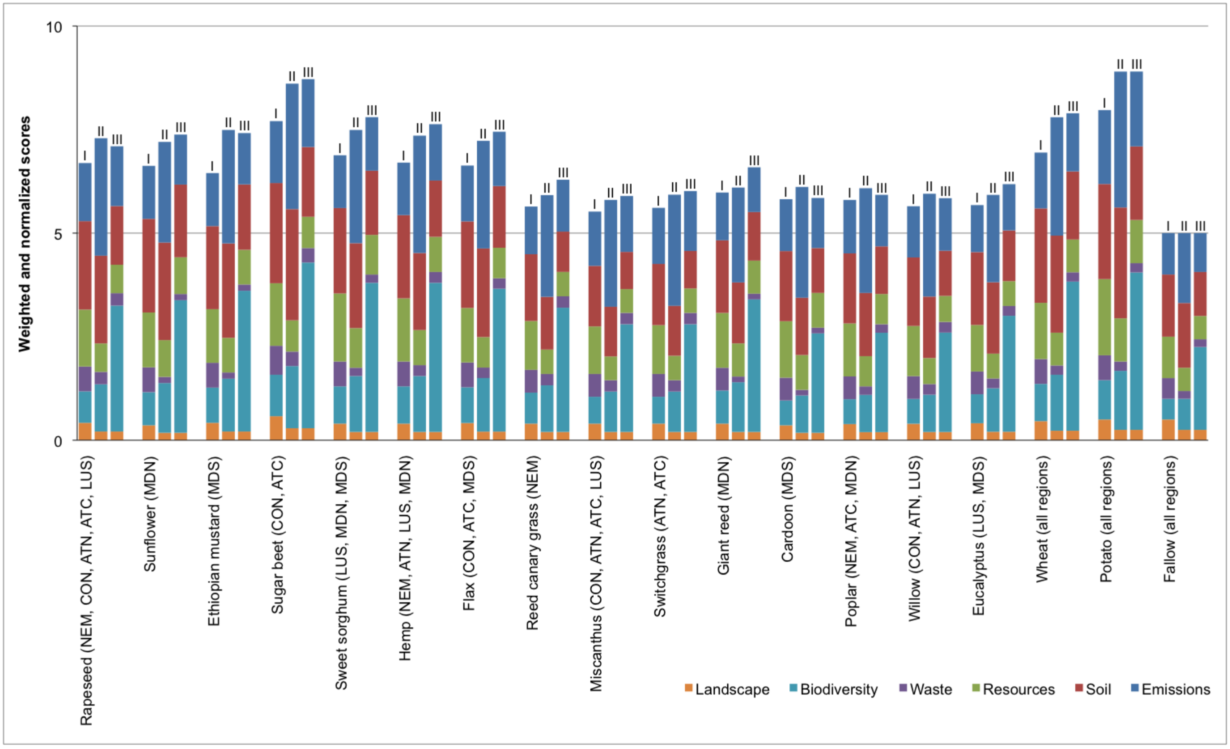

Figure 18 - Final environmental impact assessment of energy crops cultivation in Europe (I – WS1; II – WS2: III – WS3).

Results show that the application of the weighting step aggravates the impact of all crops. Emphasis on biodiversity (WS3) in detriment to GHG emission drivers (WS2) inflicts a higher impact except for rapeseed, Ethiopian mustard, cardoon, poplar, willow and potato. However, if crops were to be sorted according to their performance, weighting would not significantly influence their relative position.

The most striking observation to emerge from the data is the lower overall impact of lignocelullosic and woody crops when comparing to annual species. Among perennials no significant differences were observed either. Among the annual species, potato and sugar beet present the highest impact. All the other annual systems were more or less even.

All the investigated crops present higher overall environmental impact than fallow, but, less impact than potato and, except sugar beet, than wheat as well. Therefore, the results suggest that growing energy crops would benefit the environment (regarding the studied categories) comparing to potato and wheat farming. On the other hand, cultivating them in fallow land shows an increased impact. On this matter, concerns related to the impact of land use change should also be considered. These and other issues such as socioeconomic analysis fall out of the scope of this study.

Caution must be applied, nonetheless, when the results rely on quantified ranges dependent upon the intensity level of inputs. This fact is even more pertinent considering that some of the studied crops have not yet been upscaled to a commercial level in Europe.

3.8. Results by Environmental Zone

Figures 19-21 show the final environmental impact assessment for each environmental zone studied.

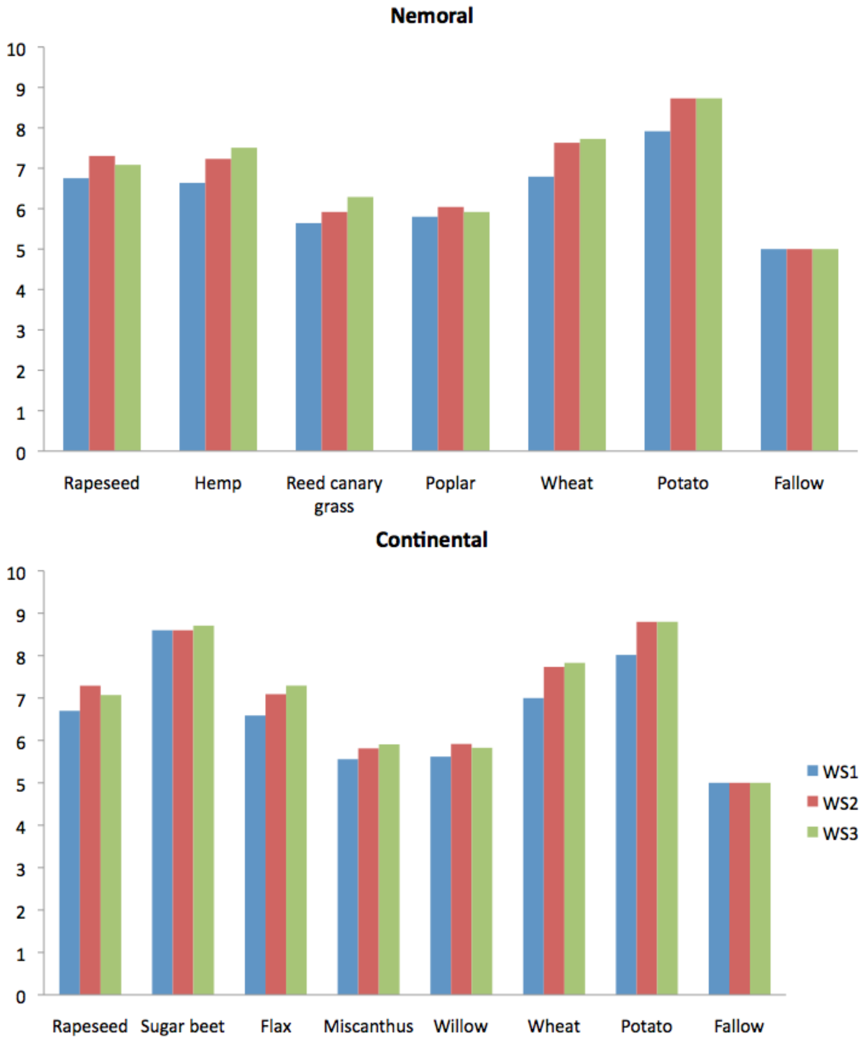

Figure 19 - Final environmental impact assessment of energy crops cultivation in the Nemoral and Continental regions per weighting system (WS).

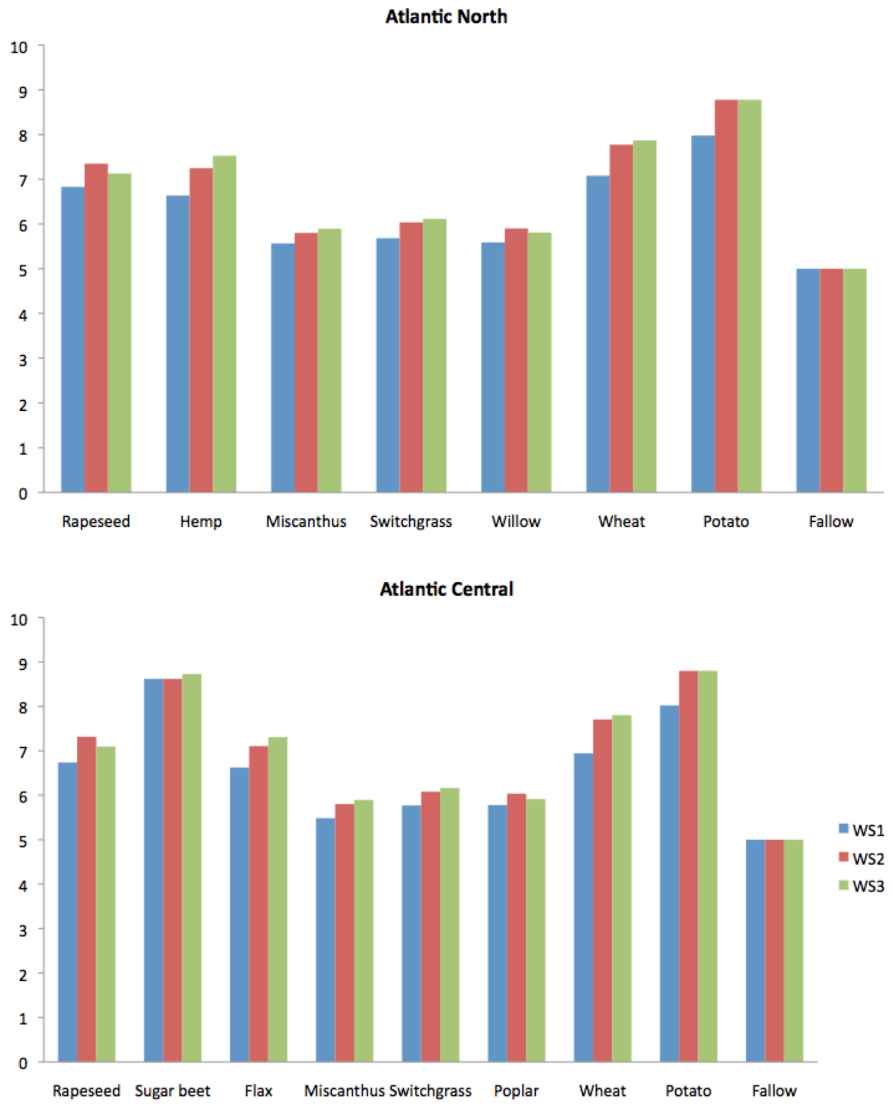

Figure 20 - Final environmental impact assessment of energy crops cultivation in the Atlantic North and Central regions per weighting system (WS).

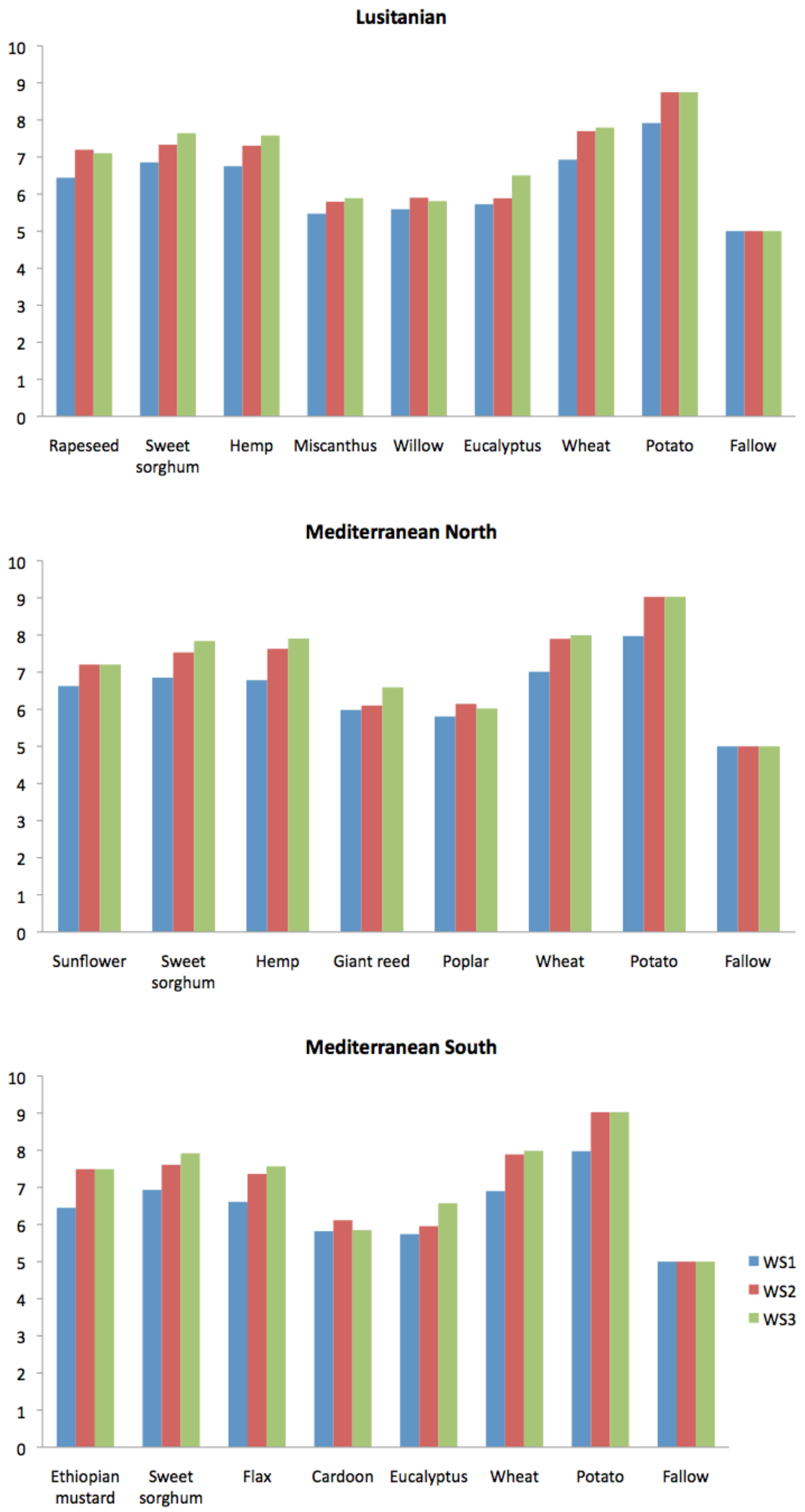

Figure 21 - Final environmental impact assessment of energy crops cultivation in the Lusitanian and Mediterranean North and South regions per weighting system (WS).

As the figures 19 to 21 show, lignocellulosic and woody crops share the lowest impacts in every region. Aside from the impactful crops potato and sugar beet, the gap from annual to perennial crops is similar among regions. Furthermore, the same crop has about the same impact independently of the region of the assessment. Averaged regional results are similar as well, consequently. I.e. no significant distinction can be reckoned between the impacts verified in each region.

This suggests that, although the impact of a crop is site specific, as long as cultivation takes place in appropriate locations, accurately assessed, the overall environmental performance can differ depending upon crop management options.

4. Conclusions

This study provides a generic framework on the expected environmental consequences of cultivating a set of energy crops previously allocated to different European regions. Results suggest that growing energy crops do not inflict higher impact to the environment comparing to potato and wheat farming (regarding the studied categories). The assessed impact pathways rely primarily on management intensity and crop traits. Annual cropping systems (oil, sugar, fiber and food) are more management intensive than the remaining types, since they require more inputs and land disturbance, build up less biomass and have shorter permanence periods. Thus they have a more negative impact on the environment than lignocellulosic and woody species. Annual crops do stand out as being more burdening than the remaining types regarding erodibility and biodiversity. Annual systems and woody crops are also more damaging to soil quality than herbaceous perennials. However, differences among crop types are not as evident in the remaining indicators. Further, each crop type often contains uneven outcomes among species, consequence of the environmental zone allocation but also on crop management options.

Impact reduction strategies are limited to crop management options which can influence emissions, nutrient status and mineral ore depletion. All other impacts are site specific dependent, intertwined with crops traits. Therefore, the implementation of impact-lean bioenergetic agrosystems should root also on the adequacy between crop and location. For that, adding to the generic trends we hereby set, decision makers and stakeholders should assess site-specific factors (e.g. on-field emission fluxes, quality assessment of soil and groundwater, effect on local biodiversity and landscape).

5. References

Abd-El-Fattah, A., S.M. Shehata and A.S. Talab (2002) Evaluation of irrigation with either raw municipal sewage river water on element uptake and yield of lettuce and potato plants. *Egyptian Journal of Soil Science*, 42 (4), pp 705-714.

Alexandrov, GA (2007) Carbon stock growth in a forest stand: the power of age. *Carbon Balance and Management,* **2** (4)

Amahmid, O, Asmama, S and Bouhoum, K (1999) The effect of wastewater reuse in irrigation on the contamination level of food crops by *Giardia* cysts and *Ascaris* eggs. *International Journal of Food Microbiology,* **49** (1-2), pp 19-26.

Angers, DA and Caron, J (1998) Plant-induced changes in soil structure: processes and feedbacks. *Biogeochemistry*, **42**, pp. 55-72

Antonious, GF, Patterson, MA and Snyder, JC (2003) Pesticide residues in soil and quality of potato grown with sewage sludge. *Bulletin of environmental contamination and toxicology*, **71** (2), pp. 315-322.

Batchelor, SE, Booth, EJ and Walker, KC (1995) Energy analysis of rape methyl ester (RME) production from winter oilseed rape. *Industrial Crops & Products*, 4 (3) pp. 193-202.

Bellamy, P, Croxton, P and Heard, M, Hinsley, S, Hulmes, L, Hulmes, S, Nuttall, P, Pywell, R and Rothery, P (2009) The impact of growing miscanthus for biomass on farmland bird populations. *Biomass and Bioenergy*, 33, pp. 191 –199

Berg, Å (2002) Breeding birds in short-rotation coppices on farmland in central Sweden—the importance of *Salix* height and adjacent habitats. *Agriculture, Ecosystems and Environment,* 90 (3), pp. 265-276

Berthelot, A, Augustin, S, Godin, J and Decocq, G (2005) Biodiversity in poplar plantations in the Picardie region of France. *Unasylva-FAO*, 221 (56), 18-19.

Biewinga, E.E., van der Bijl, G. (1996) *Sustainability of energy crops in Europe. A methodology developed and applied*. Centre for Agriculture and Environment, Utrecht, February , CLM 234 -1996.

Bjelková, M, Tejklová, E, Griga, M, Zajíková, I and Genurová, V, Flax, linseed and hemp in phytoremediation, *Natural Fibres (Poznan) – Special Edition: Proc. 2nd Global Workshop Bast Plants in the New Millennium*, Borovets, Bulgaria, p. 285 (2001)

Boehmel, C., Lewandowski, I., Claupein, W. (2008) Comparing annual and perennial energy cropping systems with different management intensities. *Agricultural Systems*, **96**, 224-236.

Bohn, H, McNeal, B and O'Connor, G (2001) Soil Chemistry – second edition. John Wiley & Son, 260 pp.

Bona, KA, Burgess, MS, Fyles, JW and Camiré, C (2008) Weed cover in hybrid poplar (*Populus*) plantations on Quebec forest soils under different lime treatments *Forest Ecology and Management*, 255, pp. 2761–2770

Börjesson, P (1999) Environmental effects of energy crop cultivation in Sweden—I: identification and quantification. *Biomass and Bioenergy*, 16 (2), pp. 137-154

Brandão, M, Millá-i-Canals, L and Clift, R (2010) Soil organic carbon changes in the cultivation of energy crops: Implications for GHG balances and soil quality for use in LCA. *Biomass and Bioenergy,* doi:10.1016/j.biombioe.2009.10.019 (2010)

Bransby, DI, McLaughlin, SB and Parrish, DJ (1998) A review of carbon and nitrogen balances in switchgrass grown for energy. *Biomass and Bioenergy* , 14 (4), pp. 379-384

Bringezu, S, Schutz, H, Brien, MO, Kauppi, L, Howarth, RW, McNeely, J and Otto, M (2009) Assessing Biofuels. UNEP, 120 pp.

Bullard, M., Metcalfe, P. (2001) Estimating the energy requirements and CO_2 emissions from production of the perennial grasses *Micanthus*, Switchgrass and Reed canary grass. ETSU/ADAS Consulting.

Cannell, MGR (1999) Environmental impacts of forest monocultures: water use, acidification, wildlife conservation, and carbon storage. *New Forests*, 17, pp. 239-262

Cannell, MGR (2003) Carbon sequestration and biomass energy offset: theoretical, potential and achievable capacities globally, in Europe and the UK. *Biomass and Bioenergy*, 24 (2), pp. 97-116

Carneiro, M, Serrão, V, Fabião, A, Madeira, M, Balsemão, I, Hilário, L (2009) Does harvest residue management influence biomass and nutrient accumulation in understory vegetation of *Eucalyptus globulus* Labill. plantations in a Mediterranean environment?. Forest Ecology and Management, **257** (2), 527-535.

Carneiro, M., Fabião, A., Martins, M.C., Fabião, A., Abrantes da Silva, M., Hilário, L., Lousã, M., Madeira, M. (2008) Effects of harrowing and fertilisation on understory vegetation and timber production of a *Eucalyptus globulus* Labill. plantation in Central Portugal. *Forest Ecology and Management*, **255**, 591–597.

Cherif, H.; Ayari, F.; Ouzari, H.; Marzorati, M.; Brusetti, L.; Jedidi, N.; Hassen, A.and Daffonchio, D. (2009) Effects of municipal solid waste compost, farmyard manure and chemical fertilizers on wheat growth, soil composition and soil bacterial characteristics under Tunisian arid climate. *European Journal of Soil Biology*, **45**, 138-145.

Christian, DP, Collins, PT, Hanowski, JM and Niemi, GJ (1997) Bird and Small Mammal Use of Short-Rotation Hybrid Poplar Plantations. *The Journal of Wildlife Management*, 61 (1), pp. 171-182

Crutzen, P J, Mosier, A R, SMITH, K A, Winiwarter, W. (2008) N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmospheric Chemistry and Physics,* **8**, 389–395

DAISIE (2009) Delivering Alien Invasive Species In Europe Project: www.europe-aliens.org (accessed: February 2009)

Dauber, J, Hirsch, M, Simmering, D, Waldhardt, R, Otte, A and Wolters, V (2003) Landscape structure as an indicator of biodiversity: matrix effects on species richness. *Agriculture, Ecosystems and Environment*, 98 (1-3), pp. 321-329

Draycott, AP, *Sugar Beet*. Blackwell Publishing, UK (2006)

Duggan, J. (2005) The potential for landfill leachate treatment using willows in the UK—A critical review. *Resources, Conservation and Recycling*, **45**, 97–113.

Dvořák, P, Tlustoš, P, Száková, J, Černý, J and Balík, J (2003) Distribution of soil fractions of zinc and its uptake by potatoes, maize, wheat and barley after soil amendment by sludge and inorganic Zn salt. *Plant Soil Environment*, 49, pp. 203-212.

EC (2001) Environment 2010: Our Future, our choice. 6th EU Environment Action programme, 2001-2010. European Commission, Luxembourg, 14 pp.

EEA (2009) Water resources across Europe — confronting water scarcity and drought. EEA Report 2/2009. European Environment Agency, Denmark. 55 pp.

El Bassam, N. (1998) *Energy crop species: their use and impact on the environment and development*. James & James (Science Publishers) Ltd, London, United Kingdom.

Epelde, L, Mijangos, I, Becerril, JM and Garbisu, C (2009) Soil microbial community as bioindicator of the recovery of soil functioning derived from metal phytoextraction with sorghum. *Soil Biology and Biochemistry*, 41 (9) pp. 1788-1794.

Fabião, A, Carneiro, M, Lousã, M e Madeira, M (2007) Os impactes do eucaliptal na biodiversidade da vegetação sob coberto. *In:* Alves, AM, Pereira, JS e Silva, JMN eds. - O eucaliptal em Portugal: impactes ambientais e investigação científica. pp. 177 – 206.

FAO (2010) FAOWater, Development Management Unit: http://www.fao.org/nr/water/# (accessed: February, 2010).

Fernando, A, Duarte, MP, Morais, J, Catroga, A, Serras, G, Lobato, N, Mendes, B, Oliveira, JFS (2007) Final report of FCT/UNL to the Biokenaf project*,* FCT/UNL, Lisbon, Portugal, 44 p.

Fernando, ALAC (2005) *Fitorremediação por Miscanthus x giganteus de solos contaminados com metais pesados*, PHD Thesis, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Lisbon, 502 p.

Fragoso, C, Brown, GG, Patron, JC, Blanchart, E, Lavelle, P, Pashanasi, B, Senapati, B and Kumar, T (1997) Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of earthworms. *Applied Soil Ecology*, 6 (1), pp. 17-35

Friedel, JK, Gabel, D and Stahr, K (2001) Nitrogen pools and turnover in arable soils under different durations of organic farming: II: Source-and-sink function of the soil microbial biomass or competition with growing plants?. *Journal of Plant Nutrition and Soil Science*,164 (4), pp. 421-429

Fullen, MA (2003) Soil erosion and conservation in northern Europe. *Progress in physical geography*, 27 (3), pp. 331-358

Gerbens-Leenes, P. W., Hoekstra, A. Y., van der Meer, T. (2009) The water footprint of energy from biomass: A quantitative assessment and consequences of an increasing share of bio-energy in energy supply. *Ecological Economics*, **68**, 1052-1060.

Gerbens-Leenes, P. W., Nonhebel, S. (2004) Critical water requirements for food, methodology and policy consequences for food security. *Food Policy*, **29**, 547-564.

Giachetti, G and Sebastiani, L (2006) Metal accumulation in poplar plant grown with industrial wastes. *Chemosphere*, 64 (3) pp. 446-454.

Grabowska, L and Baraniecki, P, Three year results on utilization soil polluted by copper-producing industry. *Proc. of the Flax and other Bast Plants Symp. Natural Fibres, Spec. Ed. INF Pozna*, pp. 123-131 (1997)

Groom, M, Gray, E and Townsend, P (2008) Biofuels and Biodiversity: Principles for Creating Better Policies for Biofuel Production. *Conservation Biology*, 22 (3), pp. 602-609

Guo, LB, Sims, REH and Horne, DJ (2002) Biomass production and nutrient cycling in Eucalyptus short rotation energy forests in New Zealand. I: biomass and nutrient accumulation. *Bioresource Technology*, **85** (3) pp. 273-283

Hall, R.L. (2003) *Grasses for energy production: hydrological guidelines*. UK Department of Trade and Industry, 15 pp.: www.berr.gov.uk/files/file14946.pdf (accessed: January 2010)

Hansson, PA, Svensson, SE, Hallefält, F and Diedrichs, H (1999) Nutrient and cost optimization of fertilizing strategies for Salix including use of organic waste products. *Biomass and Bioenergy*, 17 (5) pp. 377-387.

Heller, MC, Keoleian, GA and Volk, TA (2003) Life cycle assessment of a willow bioenergy cropping system. *Biomass and Bioenergy,* 25 (2) pp. 147-165.

IPCC (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

Jones, GA and Sieving, KE (2006) Intercropping sunflower in organic vegetables to augment bird predators of arthropods. *Agriculture, Ecosystems and Environment*, 117 (2-3), pp. 171-177

Jørgensen, U., Schelde, K. (2001) *Energy crop water and nutrient use efficiency*. The International Energy Agency. IEA Bioenergy Task 17, Short Rotation Crops. Danish Institute of Agricultural Sciences (DIAS), Department of Crop Physiology and Soil Science, Research Centre Foulum, Tjele, Denmark 38 pp: www.p2pays.org/ref/17/16275.pdf (accessed: December 2009)

JRC (2010). Interpolated meteorological data Source JRC/MARS - Meteorological Data Base, European Commission – Joint Research Centre.

Kahle, P., Beuch, S., Boelcke, B., Leinweber, P. Schulten, H.R. (2001) Cropping of *Miscanthus* in Central Europe: biomass production and influence on nutrients and soil organic matter. *European Journal of Agronomy*, **15**, 171-184.

Kort, J, Collins, M and Ditsch, D (1998) Review of soil erosion potential associated with biomass crops, *Biomass Bioenergy*, **14**, 351-359

Lal, R (1997) Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2-enrichment. *Soil & Tillage Research*, **43**, 81-107

Lal, R (2005) Forest soils and carbon sequestration. *Forest Ecology and Management*,

Linger, P, Müssig, J, Fischer, H and Kobert, J (2002) Industrial hemp (*Cannabis sativa* L.) growing on heavy metal contaminated soil: fibre quality and phytoremediation potential. *Industrial Crops & Products*, 16 (1) pp. 33-42

Luger, E. (2003) Cardoon: introduction as an energy crop. BLT. http://blt.josephinum.at/ (accessed: November 2009)

Marchiol, L, Assolari, S, Sacco, P and Zerbi, G (2004) Phytoextraction of heavy metals by canola (*Brassica napus*) and radish (*Raphanus sativus*) grown on multicontaminated soil. *Environmental Pollution,* 132 (1) pp. 21-27.

Mattsson, B., Cederberg, C., Blix, L. (2000) Agricultural land use in life cycle assessment (LCA): case studies of three vegetable oil crops. *Journal of cleaner production*, **8**, 283-292.

Mavrogianopoulos, G, Vogli, V and Kyritsis, S (2002) Use of wastewater as a nutrient solution in a closed gravel hydroponic culture of giant reed (*Arundo donax*). *Bioresource technology*, 82 (2) pp. 103-107.

McLaughlin, S. and Walsh, M (1998) Evaluating environmental consequences of producing herbaceous crops for bioenergy. *Biomass and Bioenergy*, 14 (4), pp. 317-324.

McLaughlin, S., Bouton, J., Bransby, D., Conger, B., Ocumpaugh, W., Parrish, D., Taliaferro, C., Vogel, K., Wullschleger, S. (1999) Developing Switchgrass as a Bioenergy Crop. *In: Perspectives on New Crops and New* Uses - *Proceedings of the Fourth National Symposium New Crops and New Uses: Biodiversity and Agricultural Sustainability*, 282 – 299.

Metzger, M. J., Bunce, R. G. H., Jongman, R. H. G., Mücher, C. A., Watkins J. W. (2005) A climatic stratification of the environment of Europe. *Global Ecology and Biogeography*, **14**, 549–563.

Mineau, P and McLaughlin, A (1996) Conservation of biodiversity within Canadian agricultural landscapes: integrating habitat for wildlife. *Journal of Agricultural and Environmental Ethics*, 9 (2), 93-113

Niu, Z, Sun, L, Sun, T, Li, Y and Wang, H (2007) Evaluation of phytoextracting cadmium and lead by sunflower, ricinus, alfalfa and mustard in hydroponic culture. *Journal of Environmental Sciences*, 19 (8) pp. 961-967.

Paine, LK, Peterson, TL, Undersander, DJ, Rineer, K, Bartelt, G, Temple, S., Klemme and DWS (1996) Some ecological and socio-economic considerations for biomass energy crop production. *Biomass and Bioenergy,* 10 (4), pp. 231-242

Panoutsou, C. (2007) Socio-economic impacts of energy crops for heat generation in Northern Greece. *Energy Policy*, 35 (12), pp. 6046-6059.

Papazoglou, EG (2007) *Arundo donax* L. stress tolerance under irrigation with heavy metal aqueous solutions. *Desalination*, 211 (1-3) pp. 304-313.

Pimentel, D., Acguay, H., Biltonen, M., Rice, P., Silva, M., Nelson, J., Lipner, V., Giordano, S., Harowitz, A., D'Amore, M. (1992) Environmental and Economic Costs of Pesticide Use. *BioScience*, **42**, 750-760.

Poesen, JWA and Hooke, JM (1997) Erosion, flooding and channel management in Mediterranean environments of southern Europe. *Progress in Physical Geography*, 21 (2), pp. 157-199

Portaria 732-A/96 (1996) Regulamento para a notificação de substâncias químicas e para a classificação, embalagem e rotulagem de substâncias perigosas. Diário da República, I Série – B, **286**, 4434 – (2-693).

Prochnow, A, Heiermann, M, Plöchl, M, Linke ,B, Idler, C, Amon, T, and Hobbs, PJ (2009) Bioenergy from permanent grassland – A review 2: Combustion; *Bioresource Technology*, 100, pp. 4945–4954.

Reeves, DW (1997) The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil & Tillage Research*, 43 (1-2), pp. 131-167

Rinehart, L. (2006) *Switchgrass as a Bioenergy Crop*. National Sustainable Agriculture Information Service: http://attra.ncat.org/attra-pub/switchgrass.html (accessed: January, 2010)

Rodrigues, GS, Campanhola, C and Kitamura, PC (2003) An environmental impact assessment system for agricultural R&D. *Environmental Impact Assessment Review*, 23 (2), pp. 219-244

Rosenqvist, H and Dawson, M. (2005) Economics of using wastewater irrigation of willow in Northern Ireland. *Biomass and Bioenergy* , 29 (2) pp. 83-92.

Rossi, G, Figliolia, A, Socciarelli, S and Pennelli, B (2002) Capability of Brassica napus to Accumulate Cadmium, Zinc and Copper from Soil. *Acta Biotechnologica*, 22 (1-2), pp. 133-140.

Rowe, RL, Street, NR and Taylor, G (2009) Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renewable and Sustainable Energy Reviews*, 13 (1), pp. 271-290

Sasikumar, K, Vijayalakshmi, C and Parthiban, KT (2001) Allelopathic effects of four *Eucalyptus* species on redgram (*Cajanus cajan* L.). *Journal of Tropical Agriculture*, 39, pp. 134-138

Schimdt, W-P, Sullivan, J. (2002) Weighting in Life Cycle Assessments in a Global Context. *International Journal of Life Cycle Assessment*, **7** (1), 5-10

Semere, T and Slater, F (2007a) Ground flora, small mammal and bird species diversity in Miscanthus (*Miscanthus_giganteus*) and reed canary-grass (*Phalaris arundinacea*) fields. *Biomass and Bioenergy*, **31**, 20–29

Semere, T and Slater, F (2007b) Invertebrate populations in Miscanthus (Miscanthus_giganteus) and reed canary grass (*Phalaris arundinacea*) fields. *Biomass and Bioenergy*, **31**, 30–39

Sessiz, A, Sogut, T, Alp, A and Esgici, R. (2008) Tillage effects on sunflower (*Helianthus annuus* L.) emergence, yield, quality and fuel consumption in double cropping system. *Journal of Central European Agriculture*, 9 (4), pp. 697-710

Sheng, XF, Xia, JJ, Jiang, CY, He, LY and Qian, M. (2008) Characterization of heavy metal-resistant endophytic bacteria from rape (*Brassica napus*) roots and their potential in promoting the growth and lead accumulation of rape. *Environmental Pollution,* 156 (3), pp. 1164-1170.

Singh, S, Mishra, R, Singh, A, Ghoshal, N and Singh, KP (2009) Soil Physicochemical Properties in a Grassland and Agroecosystem Receiving Varying Organic Inputs. *Soil Science Society of America Journal*, 73, pp. 1530-1538

Skärbäck, E and Becht, P (2005) Landscape perspective on energy forests. *Biomass and Bioenergy*, 28 (2) pp. 151-159

Slootweg, R and Kolhoff, A (2003) A generic approach to integrate biodiversity considerations in screening and scoping for EIA. *Environmental Impact Assessment Review*, 23 (6), pp. 657-68

Smeets, E., Lewandowski, I., Faaij, A. (2009) The economical and environmental performance of miscanthus and switchgrass production and supply chains in European setting. *Renewable and Sustainable Energy Reviews*, **13**, 1230-1245.

Steen, BA (2006) Abiotic Resource Depletion Different perceptions of the problem with mineral deposits. *The International Journal of Life Cycle Assessment*, **11** (Special Issue 1), 49-54

Stephens, W, Hess, T and Knox, J (2001) Review of the effects of energy crops on hydrology. Cranfield University, 71 pp.

Tolbert, V, Thornton, FC, Joslin, J, Bock, B, Bandaranayake, W, Tyler, D, Pettry, D, Green, T, Makik, R, Bingham, L, Houston, A, Shires, M, Dewey, J and Schoenholtz, S (1998) Soil and Water Quality Aspects of Herbaceous and Woody Energy Crop Productions: Lessons from Research-Scale Comparisons with Agricultural Crops. In:BioEnergy '98: Expanding Bioenergy Partnerships, Madison, USA, 4-8 Oct 1998. http://bioenergy.ornl.gov/papers/bioen98/tolbert.html (accessed: January 2010)

Ulrich, W, Buszko, J and Czarnecki, A (2004) The contribution of poplar plantations to regional diversity of ground beetles (*Coleoptera: Carabidae*) in agricultural landscapes. *Annales Zoologici Fennici*, 41 (3), pp. 501-512

USDA (2006) Plant Guide: Reed Canary Grass: http://plants.usda.gov (accessed: November 2009).

Van der Knijff, JM, Jones, RJA and Montanarella, L (2000) Soil Erosion Risk: Assessment in Europe. European Soil Bureau - European Commission, 38 pp.

van der Werf, HMG (2004) Life Cycle Analysis of field production of fibre hemp, the effect of production practices on environmental impacts. *Euphytica*,140, pp. 13-23

Wilson, C., Tisdell, C. (2001) Why farmers continue to use pesticides despite environmental, health and sustainability costs. *Ecological Economics*, **39**, 449-462.

Wilson, MJ and Maliszewska-Kordybach, B (2000) Soil Quality, Sustainable Agriculture and Environmental Security in Central and Eastern Europe. NATO Science Series, 2 – Environmental Security, 69. Kluwer Academic Publishers, the Netherlands, 375 pp.

Zan, CS, Fyles, JW, Girouard, P and Samson, RA (2001) Carbon sequestration in perennial bioenergy, annual corn and uncultivated systems in southern Quebec. *Agriculture, Ecosystems and Environment*, 86 (2), pp. 135-144

Zhang, C and Fu, S (2009) Allelopathic effects of eucalyptus and the establishment of mixed stands of mixed stands of eucalyptus and native species. *Forest Ecology and Management*, 258, pp. 1391–1396