Application of a Life Cycle Assessment Methodology to Agricultural Crops in Mainland Portugal

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Abstract

This article is part of a dissertation to obtain a Master's degree in Environmental Engineering, that consists on the application of a Life Cycle Assessment, at farm level based on the functional units, hectare of cultivated soil and ton of products obtained in one year, to assess the environmental performance of 10 major crops produced in Mainland Portugal, representing the rainfed and irrigated farming, as well as the intensive and extensive production systems.

Is also presented an assessment of the main environmental impacts associated with the studied crops, and what products and processes have most influence on the results, taking into account the specific characteristics of the main regions of production on national level.

The results show that natural pastures, vines for table wine and olive have the best environmental performance per hectare of cultivated soil, while tomato, potato and sugar beet showed the lowest environmental performance related to the hectare of cultivated soil. The crops with major environmental performance due to the ton of product are the vine for table wine, sugar beet and potato, in the other way, olive, barley and sunflower represent the lowest environmental performance crops regarding the ton of product.

The factors with main influence on the results obtained from the environmental impact assessment are the irrigation of the crops, mechanical fertilizing and harvesting operations, the quantities and characteristics of the applied fertilizers, as well as the seeds used on the crop production.

Keywords: Agriculture, Environmental Performance, Life Cycle Assessment, Environmental Impacts, Cradle-to-gate, Comparison of crops.
Introduction

The agriculture sector represents a very important role worldwide is responsible for the production of around 99% of the alimentary products consumed in the world (Aistrars, 1999). Besides food, the agricultural sector is also responsible for producing a wide range of products including textiles, fibers and fuels, as well as providing employment to millions of people worldwide (Deimling, et al., 2008).

However, this sector has constant needs for natural resources, being responsible, for about 70% of global water consumption with human origin, while the industrial sector consumes about 20% and the remaining 10% are allocated to domestic consumption (Achten et al., 2008).

Apart from the constant consumption of resources, the agricultural sector accounts for about 10 to 12% of total global anthropogenic emissions of greenhouse gases, which includes about 60% of emissions of nitrous oxides and 50% of global methane emissions (mainly due to livestock) (Deimling, et al., 2008).

The use of fertilizers and pesticides is responsible for the phenomena of aquatic environments eutrophication adjacent to the farms and of soil quality degradation, as well as the growing need for larger areas of cultivation leads to deforestation occurring around the world (Deimling, et al., 2008).

Conventional agriculture is characterized by intensive farming systems on large-scale, mostly devoted to one crop type, which uses various mechanical means, with systematic and intensive use of pesticides and fertilizers (Smith and McDonald, 1998).

Thus, it’s urgent the introduction of improved agricultural techniques and practices that allow an answer to the constant need for food production, but without jeopardizing the resources required for its production, as well as preserve ecosystems where they are located on farms.

Hansen (1996), indicates as more sustainable agricultural practices, the use of available resources within the farm, the reduced use of pesticides and fertilizers of synthetic origin, increasing the turnover and multiplicity of crops produced, instead of exclusive production of one crop type, the use of organic material such as soil improvement, as well as reducing the rate of storage products.

This paper, used to to obtain a Master’s degree in Environmental Engineering, is focused on an assessment of the environmental performance of some major crops produced in Portugal in rainfed (natural pastures, vine for table wine, wheat, barley and olive) and irrigated land (sunflower, tomato, sugar beet, potatoes and maize), produced on intensive and extensive systems, on the regions NUTS II North, Lisbon and Alentejo.

This assessment is carried out using the LCA methodology, based on resource requirements, fertilizers and mechanized operations of each crops, as well as their productivity and characteristics of soil and water resources in the regions where they are produced.
Case study

In 2007 were registered in Portugal, 2714.194 farms, representing a total UAA of about 3.454.844 hectares of soil. The crops with more agricultural area in Portugal are the meadows, pastures and forage, estimated at about 59% of national UAA, followed by cereal crops (11%), olive (9%), vine (5%) fruit (4%) and horticultural crops.

Regarding the agricultural production, cereal crops produced in 2008 about 1.309.684 tons, where corn has particularly highlight with an annual production of 699.666 tons. Crops for industry also showed a high production in Portugal, with the tomato for industry producing in 2008 about 1.147.600 tons (INE, 2009).

The overall quality of surface waters in Portugal varies from good to very bad. The regions with a better overall quality of surface waters are the North and the Algarve, with an average rating of good, followed by the Center region that shows a reasonable average quality. The Alentejo region has a poor average quality of surface water, and the Lisbon region, it shows the worst results of quality of surface water, which is on average very bad (www.inag.pt, visited on 27-08-2010).

Concerning the soil Portugal has the worst potential quality of soils for agriculture, biomass production and growth of vegetation, compared with the Southern European Countries. 66% of the total length of national soil classified as low quality. Allied to the low potential quality of soils, is the high potential risk of erosion occurred, presenting the country, 30% of its area classified as high risk area of erosion (Giordano, et al., 1992).

Methodology

The environmental performance assessment of the crops analyzed, was based on the LCA methodology, and was done in two stages. First were analyzed the direct environmental impacts of the cultures on the water resources, and land use

On the second stage were assessed the indirect environmental impacts of the cultures, through the LCA software SimaPro 7.1, using the methods Eco-indicator 95, which bases its assessment on the effects associated with each of the environmental impacts considered, Eco-indicator 99, which aggregates the various environmental impacts, according to the environmental damage associated with them and Ecological Footprint, which calculates the carbon footprint of each culture associated with the consumption of fossil energy, nuclear and land occupation.

To perform the LCA, we defined a system at the farm level, i.e. a cradle-to-gate LCA, being the system boundaries established as the farm boundaries, thus all transformations and flows and performed beyond the farm limits were not accounted. The functional units considered were the hectare of cultivated soil and ton of product obtained annually, against which we assessed the impacts associated with the cultures.

About the functional unit ton of product obtained in one year, some considerations must be done. In case of natural pastures, productivity is presented in FU/ha (Forage Unit per hectare), while in the rest of the studied cultures is presented in t/ha. Productivity FU/ha is related to the energy that the cattle will be able to get through the consumption of crop products per
hectare of cultivated soil. Therefore FU is not a massic unit, but a energy unit, so when considering the functional unit ton of product only the other 9 crops were analyzed in order to preserve the quality of the results.

Throughout the development of this thesis has been taken into account the possibility of developing a methodology that allows farmers, autonomously obtain information about the environmental performance of their crops and thereby can be a valuable tool to support management of their farms.

Thus arises the possibility in future, to create a platform that allows, through a questionnaire constructed taking into account the skills of the farmers, to get information about their farms and crops. This information is then compiled on sheets of culture specific to the farm that are crossed with the base existing of environmental performance indicators. From these results on the creation of simplified environmental performance reports of the crops produced on their farms. In this way this platform can help the farmers on the adaptation of better environmental practices and agricultural techniques, as well of choosing according to the local characteristics for crops that present a better environmental performance.

**Results and discussion**

**Direct environmental impacts**

The direct environmental impacts of the cultures on the water resources regarded the nitrate (NO$_3^-$) leaching and phosphate (PO$_4^{3-}$) runoff associated to the cultures.

In order to analyze the impacts associated with the leaching of NO$_3^-$ was made a mass balance of nitrogen in soil. From this balance resulted that vine for table wine, wheat and barley, present smaller quantities of NO$_3^-$ leaching per hectare, and therefore have lower impacts associated. In the other way the crops maize, potato and sugar beet present the highest impacts on the NO$_3^-$ leaching per hectare. Regarding the functional unit ton of product, the crops with lower leaching of NO$_3^-$ are the tomato, sugar beet and potato, while barley, wheat and sunflower crops present the highest values, thus presenting higher environmental impacts associated per ton of product.

About the PO$_4^{3-}$ runoff associated to the cultures, sugar beet, tomato and maize are the crops with higher environmental impact associated per hectare, while natural pastures, olives and barley showed the lower environmental impacts on this impact category. When considering the ton of product the crops with better environmental performance are the olive, potato and tomato, while sunflower, wheat and barley showed the worst environmental performance per ton of product.

In concern to the land use, the environmental impacts were analyzed based on the operation hours of agricultural machinery, and use of equipment for mobilization of the upper layers of soil, such as harrowing, chiseling and plowing.

The crops that present less operation hours of agricultural machinery per hectare are vine for table vine, natural pastures and olive, having the lowest environmental impacts associated. In the other way, potatoes, tomato and sugar beet
present the higher associated impact per hectare. The results for the functional unit ton of product showed that vine for table wine, tomato and sugar beet, have lower environmental impacts associated, while olive, barley and wheat, present the biggest impacts per ton.

The crops that use more times equipment for soil mobilization per hectare are tomato, potato and sugar beet, showing greater impact, in the other way, vine for table wine, natural pasture and olive crops show better environmental performance, having the lowest utilization of this kind of equipment per hectare. In order to the ton of product, vine for table wine, tomato and sugar beet have the best environmental performance and olive, barley and wheat, have the worst environmental impact regarding this impact category.

On the subject of the indirect environmental impacts, the results obtained with the Eco-Indicator method, showed tomato is the crop with greater associated impact in all categories considered. Potato has the second highest impact in all categories followed by sugar beet. These two crops only change position in the emission of carcinogenic substances.

The crops with lower associated environmental impact in virtually all categories considered are the natural pastures, vine for table wine and olive. The vine for table wine is only superseded in the categories of winter smog and depletion of the ozone layer, where olive have less impact.

Figure 1 shows the ranking of the crops based on the associated impacts of this crops per hectare, resulted from the Eco-Indicator 95 analysis.
Considering the functional unit ton of product, the olive is the crop with highest associated environmental impact in all categories, except in the case of summer smog, followed by sunflower and barley. The sunflower has the second highest associated environmental impact in all categories except the categories of eutrophication and emission of carcinogenic substances. The barley is associated with a greater environmental impact on eutrophication, emission of substances responsible for the depletion of the ozone layer, acidification, heavy metals and carcinogenic emissions. The crops with better environmental performance per ton of product are the vine for table wine, sugar beet and potato. The ranking of the crops based on the associated impact level is shown on the Figure 2.

![Figure 2: Crop ranking due to the environmental impact per ton - Eco-indicator 95.](image)

Focusing on the results obtained from the LCA performed using Eco-indicator 99, considering the functional unit hectare of soil cultivated, its concluded that the tomato, potato and sugar beet are the crops with greater associated environmental impact on almost all of the considered impact categories. The impact associated to the tomato crops only in the impact categories of damages caused by emissions of carcinogenic substances and land use, is not the greatest of all crops. The crops with lower environmental impact associated per hectare of cultivated soil are the natural pastures, vine for table wine and olive, and so this crops show a better environmental performance. On Figure 3 is presented the crop ranking based on the impacts per hectare.
Concerning on the functional unit ton of product, the crops that present a higher associated impact are the olive sunflower and barley, while the vine for table wine, sugar beet and potato are the crops with better results, and so present a better environmental performance in all the impact categories, as shown on Figure 4.

Regarding the results obtained with the method Ecological Footprint, for the functional unit hectare of cultivated soil, the crops that shown smaller total ecological footprint associated are the natural pastures, the vine for table wine and olive. In the other way tomato, potato and sugar
beet present the largest ecological footprint. These results can be observed in Figure 5 that presents the impact ranking of the analyzed crops in function of the hectare of cultivated soil.

In order to the ton of product, the crops that present a smaller total ecological footprint are the vine for table wine, sugar beet and potato, while the crops of olive, sunflower and barley are the ones with biggest total ecological footprint. The ecological footprints ranking associated to the analyzed cultures is presented on figure 6.

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**Figure 5:** Crop ranking due to the ecological footprint per hectare - Ecological Footprint.

**Figure 6:** Crop ranking due to the ecological footprint per ton - Ecological Footprint.
**Conclusions**

As main conclusions of the study, we can assume that the choice of the functional unit is fundamental in order preserve the quality of the results. As can be seen on the results obtained from the analysis, when the functional unit considered is the hectare of cultivated soil, usually rainfed crops presents a better environmental performance, compared to the irrigated crops. This result relies on the fact that the irrigation is the principal contributor to the increase of the level of impact of these crops in almost all the impact associated categories.

Next to the irrigation, the fertilizers added to the crops and the requirement of machinery also show a big influence in the increase of the crops environmental impacts, and irrigated crops are characterized by a bigger requirement of fertilizers and machinery than the rainfed crops. Although, the irrigation and the use of fertilizers allows the crops to obtain higher productivities per hectare, and this fact is shown on the results of the analysis concerning to the ton of product obtained annually.

Tomato, potato and sugar beet presents the higher associated environmental impacts in almost all the impact categories when the analysis is done in order of the hectare of cultivated soil.

Natural pastures, vine for table wine and olive, are the crops that presents a better environmental performance per hectare of cultivated soil.

When the functional unit considered is the ton of product, the vine for table wine, is the crop with best environmental performance, presenting the smallest environmental impacts, due to its small requirement of machinery and fertilization, associated with no needed of irrigation. After the vine for table wine, sugar beet and potato, because of their high productivity present the second and third best environmental performance. The crops that present the worst environmental performance in order to the ton of product are the olive, barley and sunflower. This result again is connected with the reduced productivity obtained from these crops.

**References**


