Environmental and economic assessment of land allocation to bioenergy crops

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Abstract

In this paper we discuss the environmental, energetic and economic viability of the production and use of ethanol as a substitute for gasoline. Our main innovation is the fact that our study does not just compare the production and emissions of the two fuels by themselves, but also the consequences regarding land use. For the ethanol scenario we study the maize crops and for the gasoline one we consider sown irrigated pastures (SIP) in the same area. In order to make the two scenarios comparable and because the SIP are grazed by cattle, in the ethanol scenario we consider that these cattle are stabled.

We analyze these two scenarios considering carbon sequestration as well as without sequestration. The difference between them is the impact in greenhouse gas emissions. Although the difference between the two scenarios is bigger in the first case, the most favorable scenario is always the gasoline one.

Regarding the use of energy resources, in all cases, is possible to conclude that the ethanol scenario is favorable.

We also consider the production and use of ethanol without land opportunity cost, which is the usual scenario analyzed in literature. The results obtained are similar to Pimentel (2003) and indicate that more energy is necessary to produce ethanol than the energy that ethanol contains. However, this conclusion is also valid to the gasoline scenario. Regarding greenhouse gas emissions, and similarly to the results highlighted by the U.S. Department of Energy, our results indicate that the ethanol scenario is favorable. However it is not a complete life cycle assessment.

Therefore, the production and use of ethanol, is not, in the context of our study, a favorable choice in terms of greenhouse gases, but it is as an energy policy. The economic analysis shows that the gasoline scenario is the favorable one.

Key words

Agriculture, environment, sustainability, ethanol, land use

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Introduction

Nowadays, there is a very important discussion over the possibility of fossil fuels' extinction and pollution caused by its use. Hubbert (1956) predicted that U.S. oil production would peak in 1970 (Ulgiati, 2001). He also predicted that global oil production would peak in about 2000. He was correct in the first case and almost correct in the second one (Ulgiati, 2001). At about this time, energy extraction costs became higher than the actual energy yield, due to increased costs for research, deep drilling, as well as to the lower quality and accessibility of the remaining available oil storages (Ulgiati, 2001). However, new extracting techniques have decreased energy costs and allowed for better exploitation of fossil storages. As it was said before, another relevant problem associated with the use of fossil fuels is the pollution originated by its use. This problem justifies the commitment assumed by many countries of reducing the emission of greenhouse gases (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride). One of the main documents regarding this subject is the Kyoto's protocol. The National Program for the Climate Change is the Portuguese instrument that organizes a set of measures for the fulfillment of the Kyoto Protocol (PNAC, 2006). One of the measures present in this document is the operationalization of Directive 2003/30/CE which regulates the incorporation of biofuels as a substitute of fossil fuels, in the percentages shown in Table 1

Table 1 – Percentage of required biofuels incorporation, according to Directive 2003/30/CE.

Year	**Biofuels Incorporation (%)**
2005	2
2006	2,75
2007	3,5
2008	4,25
2009	5
2010	5,75

To the use of biofuels as a substitute of fossil fuels is associated a set of social, environmental benefits as well as an important change in energy policy.

Concerning the social benefits of biofuels incorporation, and according to the Decree- Law n.º 62/2006 (Portuguese Law), the promotion of bioenergy crops respecting sustainable agricultural and forest practices is predicted in the EU's Common Agricultural Policy and may create new opportunities regarding sustainable rural development as well as new markets for agricultural products. The creation of this new fuel market may create new jobs and contribute to the increase of rural populations as well as rural wealth.

Regarding the environmental benefits, and according to the same document, the use of biofuels leads to a significant reduction of dioxide carbon emissions. Effectively, in biofuels combustion, the carbon emitted was previously captured during photosynthesis. Regarding energy policy, the use of biofuels reduces the dependence on energy importation, increasing the medium and long run security of the supply.

However, the growing demand for bioenergy crops may also create further competition for land and water between existing agricultural activities, energy production and the use of agricultural land for nature conservation and urbanization needs (EEA, 2006). It is necessary to understand that the environmental impact of bioenergy production depends to a large extent on the selection of areas that are used for bioenergy production, the crops cultivated and the farming practice (EEA, 2006). Potential additional pressures of bioenergy production may occur as a result of intensification of farm management across the agricultural land area; incentives to transform extensively used land for fodder production into arable land for growing bioenergy crops; an inappropriate bioenergy crop mix, which does not take into account the specific environmental pressures of different crops. According to EEA (2006), these factors would have an additional negative impact with regard to the main environmental problems of agriculture in the different regions of Europe.

There are several types of biofuels, but the most used are ethanol and biodiesel. In the Portuguese context, and according to the government, a big bet should be done in ethanol production. Ethanol can be produced from agricultural sugar containing crops (sugar beet, sweet sorghum) and starch containing crops (cereals, corn, potatoes). The easiest feedstock to use is sugar crops, while starch must be transformed to sugar prior to be in suitable form for fermentation (Khokhotva, 2004). In our case, the bioenergy crop considered is maize and regarding two different farming managements: conventional and with no-tillage. Although it is not the most suitable crop, in the Portuguese context it represents the most likely feedstock. According to INE (2006), wheat and maize are the most important temporary crops in all Portuguese production although their production has been decreasing, and Portugal imports almost 70% of all maize.

Regarding the environmental problems discussed above, the main issues related to maize crops are shown in Table 2.

Table 2 – Environmental impacts of maize crops.

Source: EEA, 2006

Environmental issue	Maize	
	Rank	Reason
Erosion	C	Soil is uncovered over long period, row crop
Soil compaction	B	Poorly developed root systems; average machinery use
Nutrient leaching to ground and surface water	C	High demand and often highly fertilized
Pesticide pollution of soils and water	C	High pesticide use due to poor competitive ability; subject to many diseases
Water abstraction	A/B	High water efficiency but often irrigated
Link to farmland biodiversity	C	High pesticide use, low weed diversity, some shelter in autumn
Diversity of crop types	B/C	Is dominant crop in some regions; self tolerance.

A-low risk; B-medium risk; C-high risk

In this paper we are going to discuss the importance and viability of using maize to produce bioethanol as a substitute for gasoline, considering the land opportunity cost. Therefore, we compare land use for maize production with another option, namely sown irrigated pastures (SIP). This comparison is particularly relevant, since, like biofuels, these pastures are also a contribution to the Portuguese Kyoto Protocol target. According to PNAC (2006), carbon sequestration in agricultural land should be promoted. According to an experimental study, SIP may sequester 19 ton CO2e.ha-1 (Carlos Carmona Belo, pers. com.). However, if land is used for pastures, there is an equivalent quantity of fossil fuel (namely, gasoline) that is not substituted by bioethanol. Furthermore, SIP are grazed by cattle, and so, to make the two situations comparable, we consider that, in the case of maize production, these cattle remain stabled. In both cases we consider the production of the fuel itself and the emissions caused by its use.

In sum, we analyze two different scenarios:

-The ethanol scenario (production and use of ethanol): Land is used for maize production, which is then used as a raw material for the production of ethanol. As a consequence, land can not be grazed by cattle, which remain in the stable.

-The gasoline scenario (production and use of gasoline): Land is used to the implantation of SIP, which are grazed by the cattle. However, since there is no maize production for bioethanol, there is no substitution of gasoline.

Therefore, our main innovation is the fact that our study doesn't just compare the production and emissions of the two fuels by themselves, but also all the consequences respecting land use.

In the available literature, much has been said about biofuels, especially about the necessity of its incorporation, examples of which are the EEA (2006) report as well as Portuguese laws, Kyoto Protocol, and the PNAC (2006) report. Other documents refer to the dangers associated with such change in the energy policy. Once again, the EEA (2006) report alerts to the dangers of bioenergy crops, while other documents discuss the possibility that the use of biofuels, especially ethanol, is an incorrect energy policy. Other articles, e.g., Niven, 2005, Gaffney and Marley, 1997, discuss the advantages and disadvantages of using ethanol as a substitute for gasoline during the combustion. Articles by Pimentel (2003 and 2005) and by Ulgiati (2001) argue that ethanol is not as "green" as it was supposed to be. However, in all the available literature, we couldn't find any articles that consider the opportunity costs of land use.

Method

To the environmental analysis we used a Life Cycle Assessment (LCA) approach. We chose the software SimaPro 6.0, which was developed by the National Reuse of Waste Research Programme and Pré Consultants of the Netherlands. An LCA starts with a systematic inventory of all emissions and all raw material consumption during a product's entire life cycle that are compiled in a list which is termed the impact list. The impacts are sorted by the effect (classification) and organized in impact categories (Goedkoop, 1998).

As referred above, it is necessary to introduce the input inventory. The functional unit we chose is 1 ton of ethanol which is equivalent to 0.27 ha in the case of conventional maize crops, 0.25 ha with no-tillage management and 0.72 ton of gasoline. Although the conventional and no-tillage management only applies to maize crops of the ethanol scenario, to make the two scenarios comparable, the corresponding areas must be considered also in the gasoline scenario as SIP.

Regarding the ethanol scenario, it is necessary to consider all the aspects stated below.

Concerning maize production, we used data from a MADRP (2004) document. From this document we collected all the operations that take place as well as all the added substances. We also considered the emissions proceeding from the use of fertilizers and NO3- leaching with the values considered in the document of Van der Werf (2005). In the case of no-tillage, we considered a carbon sequestration of 3 tonCO2e.year-1.ha-1 (ECCP, 2003).

The cattle, in the stable, are fed from 7.2 to 12 months, increasing their weight in 216 kg. We considered the cattle emissions resulting from enteric fermentation and manure, according to the values recommended by IPCC (1997) and PNAC (2003).

For the ethanol production are considered the inputs and productivity given by Pimentel (2003). There is a subproduct from the process, which is dry distiller grain (DDG). DDG may be used for feeding ruminants, and is generally used as substitute for soybean feed. According to Pimentel (2003), 2.1 kg of soybean is required to provide the equivalent of 3.3 kg of DDG.

In order to evaluate the emissions from the combustion of 1 ton ethanol, we used the values recommended by Portugal et al. (2007). They consider the emissions of CO2, CO, NOx, CH4 as the most important ones.

In the gasoline scenario, we considered the following aspects.

Concerning the inputs of SIP, we used data from a personal communication by Carlos Carmona Belo. We considered two different moments: installation and maintenance. Installation is only required once each ten years, but these pastures require yearly maintenance. Regarding emissions, we considered those of N2O from legumes, according to Rochette e Janzen (2005), as well as carbon sequestration, according to a personal communication by Carlos Carmona Belo, and phosphate run off in Van der Werf (2005).

Apart from grazing, in these pastures the cattle require feed only as a complement, in the equivalent to their needs for 2 months in the stable. We also considered the emissions resulting from enteric fermentation and manure, according to IPCC (1997) and PNAC (2003).

Using the data base from SimaPro, we simulated the production of 0.72 ton of gasoline. For the emissions analysis it is used the document considered in the ethanol scenario.

Since our question is which of the two scenarios is better, we present all results as the sum of impact of all issues of the ethanol scenario minus the sum of the impact of all issues of the gasoline scenario (see Table 3)

Table 3 – Main issues considered in the required analysis.

The ethanol scenario	The gasoline scenario
Land used for maize production	SIP
Cattle in stables	Cattle in pastures
Production of ethanol and DDG	Production of gasoline
Combustion of ethanol	Combustion of gasoline

To the economical analysis we used the direct cost of the different issues.

Results and discussion

The main results are shown in Table 4 . The choice of the best scenario depends on the impact category. As it was discussed before, the most relevant categories are greenhouse gases and energy resources.

Regarding the impact on the greenhouse gases theme, with conventional farming systems, and considering the carbon sequestration, the ethanol scenario originates the double of the impact of the gasoline scenario. No-tillage practices do not improve significantly the impact of the ethanol scenario. A reasonable explanation lies in the fact that the pastures of the gasoline scenario are able to sequester 19 ton CO2.ha-1.yr-1 and for the ethanol scenario the carbon sequestration only happens with no-tillage farming and in a smaller amount. In order to understand the influence of carbon sequestration in results, and because carbon sequestration represents a temporary effect, we also consider the analyses without it. In this case the gasoline scenario continues to be favorable.

In the context of Kyoto's Protocol fulfillment, it does not matter if the carbon emission is avoided or if it is sequestered. In that case the results of are completely applied and in terms of greenhouse gas emissions the ethanol scenario is not favorable.

Considering only the production and use of ethanol versus gasoline and without the carbon sequestration, we conclude that the ethanol scenario is favorable. In this case it is not considered the land opportunity cost and therefore we are not considering all the implications of the use of ethanol versus gasoline.

Respecting the use of energy resources, in all cases it is necessary more energy to the gasoline scenario than to the ethanol scenario. This means that as an energy policy it is favorable to use ethanol as a substitute to gasoline. Looking to the other impact categories, it must be shown that the impact in carcinogens and eutrophication is bigger in the ethanol scenario, which is related to the bigger use of fertilizers in maize crops. The ethanol scenario is favorable for the ozone layer depletion and acidification categories.

Concerning the economical analysis, the gasoline scenario is favorable with and without subsidies (Table 5 and Table 6).

Independently of what was said before, two other issues must be discussed: the need of subsidies to ethanol observed in many countries and the food versus fuel competition.

In order to be economically competitive, the ethanol needs to have a government subsidy, which does not represent an economical sustainable situation. Besides this, exempting biofuels fully from the fuel excise tax to make them cost-competitive needs brings economic disadvantages. Fuel taxation typically seeks to satisfy multiple objectives. In the case of transport fuels, for which ethanol substitute, these objectives include raising government revenue for general purposes; efficiently allocating resources to and within the transport sectors; financing road provision and maintenance; reducing congestion; reducing the environmental externalities of road transport; and redistributing incomes (UN, 2007).

Because ethanol is used largely as a substitute for gasoline, providing a large tax reduction for ethanol blended into gasoline reduces government revenue, targeting mainly the non-poor. A detailed study for ethanol in the United States calculated that these subsidies totaled US$5 billion in 2006, about half of this in the form of fuel tax credits and reductions. The subsidy amounted to more than 40 percent of the market price. These subsides are considerable larger than the benefits of potentially lower greenhouse gas emissions that arise from switching to liquid biofuels (UN, 2007).

Besides the environmental and economic discuss we also analyzed the fuels versus food competition. The expansion of liquid biofuel production could affect food security at the household, national and global levels through each of four major dimensions: availability, access, stability, and utilization. These effects may be positive or negative, depending on the situation. If a country or a household is a net buyer or seller of energy and food services will fundamentally influence whether biofuels will be beneficial or detrimental to their welfare (UN, 2007).

Availability is applied, at one hand, in the extent that land, water, and other productive areas are diverted away from food production. Similarly if biofuel production drives up commodity prices, as appears to be the case for maize in 2006 and early 2007, food access could be compromised for low-income net food purchasers. At the other hand, modern bioenergy could make energy services more widely and cheaply available in remote rural areas, supporting growth in agriculture or other sectors with positive implications for food availability and access. Stability refers to the time dimension of food security, which could be affected by the growth of biofuels because prices volatility from the petroleum sector would be more directly and strongly transmitted to the agricultural sector. Utilization refers to peoples' ability to absorb the nutrients contained in their food and is closely linked to health and nutrition factors such as access to clean water and medical services. If biofuel feedstock production competes for water supplies, it could make water less readily available for household use, threatening the health status and thus the food security status of affected individuals. Although, if modern bioenergy replaces more polluting sources or expand the availability of energy services, it could make cooking both cheaper and cleaner, with positive implications for food utilization (UN, 2007).

To the extent that increased demand for biofuel feedstock diverts supplies of food crops and diverts land from food crop production, global food prices will increase. Rising commodity prices, while beneficial to producers, will mean higher food prices with the degree of price rise, with negative consequences for poor consumers (UN, 2007).

Table 4 – Final results of the environmental analysis to the ethanol scenario.

Method	Impact category	Unit	Ethanol (CT)	Gasoline (CT)	F (CT)	Ethanol (NT)	Gasoline (NT)	F (NT)
Ecoindicator 95	Greenhouse gases. without carbon sequestration	kg CO_2	1.5E+04	**1.3E+04**	1.2	1.4E+04	**1.2E+04**	1.2
	Greenhouse gases. with carbon sequestration	kg CO_2	1.5E+04	**7.5E+03**	2.0	1.3E+04	**7.5E+03**	1.8
	Ozone layer	kg CFC11	**3.8E-04**	4.8E-04	0.8	**3.7E-04**	4.8E-04	0.8
	Acidification	kg SO_2	**9.2E+00**	9.4E+00	1.0	**8.2E+00**	9.2E+00	0.9
	Eutrophication	kg PO_4	2.8E+00	**1.8E+00**	1.6	2.5E+00	**1.7E+00**	1.5
	Heavy metals	kg Pb	5.5E-02	**1.2E-02**	4.7	5.3E-02	**1.1E-02**	4.7
	Carcinogens	kg B(a)P	2.6E-04	**5.3E-05**	4.9	2.3E-04	**5.0E-05**	4.6
	Winter smog	kg SPM	5.9E+00	**5.4E+00**	1.1	5.6E+00	**5.3E+00**	1.1
	Summer smog	kg C_2H_4	1.4E+00	**1.1E+00**	1.3	1.4E+00	**1.1E+00**	1.3
	Energy resources	MJ LHV	**3.5E+04**	4.4E+04	0.8	**3.4E+04**	4.3E+04	0.8
	Solid waste	kg	1.4E+01	**5.9E+00**	2.4	1.3E+01	**5.5E+00**	2.4
Ecoindicator 99 (H)	Carcinogens	DALY	5.8E-04	**1.5E-04**	3.9	5.5E-04	**1.4E-04**	3.9
	Resp. organics	DALY	3.7E-06	**2.6E-06**	1.4	3.5E-06	**2.6E-06**	1.4
	Resp. inorganics	DALY	1.5E-03	**9.1E-04**	1.7	1.4E-03	**8.9E-04**	1.6
	Climate change without carbon sequestration		5.0E-03	**3.2E-03**	1.6	3.7E-03	**3.1E-03**	1.2
	Climate change with carbon sequestration	DALY	4.0E-03	**2.2E-03**	1.8	3.6E-03	**2.1E-03**	1.7
	Radiation	DALY	6.6E-06	**2.5E-06**	2.6	6.5E-06	**2.4E-06**	2.7
	Ozone layer	DALY	**3.1E-07**	3.8E-07	0.8	**3.0E-07**	3.8E-07	0.8
	Ecotoxicity	PDA*m^{2}yr	1.3E+03	**2.8E+02**	4.7	1.2E+03	**2.7E+02**	4.6
	Acidification/ Eutrophication	PDF*m^{2}yr	**3.9E+01**	4.1E+01	1.0	**3.2E+01**	3.9E+01	0.8
	Land use	PDF*m^{2}yr	6.6E+01	**5.3E+01**	1.3	6.7E+01	5.0E+01	1.3
	Minerals	MJ surplus	1.2E+02	**1.2E+01**	9.7	1.1E+02	1.2E+01	9.7
	Fossil fuels	MJ surplus	**2.5E+03**	5.7E+03	0.4	**2.3E+03**	5.7E+03	0.4

CT – Conventional tillage; NT – No-tillage

Numbers in bold represent the smaller impact

F represents the ratio between the impact of the bioethanol scenario and the gasoline scenario

Table 5 – Final results of the economical analysis to the ethanol scenario.

Ethanol Scenario		
Activity	**Cost CT (€. ton bioethanol^{-1})**	**Cost NT (€. ton bioethanol^{-1})**
Maize production	490.07	451.20
Animal feed	420.06	391.28
Bioethanol production without ISP	907.56	907.56
Bioethanol production with ISP	1069.65 - 1107.65	1069.65 - 1107.65
DDG	-151.96	-151.96
Total (without ISP)	**1665.72**	**1598.07**
Total (with ISP)	**1827.81 - 1865.81**	**1760.16 - 1798.16**

CT – Conventional tillage; NT – No-tillage

Table 6 – Final results of the economical analysis to the gasoline scenario.

Gasoline scenario		
Activity	**Cost CT (€. ton bioethanol^{-1})**	**Cost NT (€. ton bioethanol^{-1})**
SIP	143,04	133,35
Animal feed	175,02	163,03
Gasoline production without ISP	765,64	765,64
Gasoline production with ISP	1309,34	1309,34
Total (without ISP)	**1083,71**	**1062,03**
Total (with ISP)	**1627,40**	**1605,72**

CT – Conventional tillage; NT – No-tillage

Conclusions

We can conclude that:

-As an energy policy the use of ethanol as a substitute for gasoline is favorable;

-Regarding the greenhouse gas emissions the use of ethanol is not a favorable option;

-The use of ethanol is favorable in terms of ozone layer depletion and acidification categories;

-Economically speaking, the use of ethanol is not favorable.

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