Dynamic Life Cycle Assessment of the *Ribeiro* wine appellation (NW Spain) in the period 1989-2009

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ABSTRACT

Land use changes (LUCs) are an important source of environmental changes in production systems, especially in the agricultural sector, where LUCs have been found to be a relevant factor to take into consideration when analyzing greenhouse gas (GHG) emissions. The viticulture subsector, as part of a broader agricultural sector, is not alien to the problematic of GHG emissions and climate change. Spain, as one of the main producers of wine worldwide, but also due to the important legislative and productive changes that have occurred ever since it joined the European Union, plays an important role in the analysis of how LUCs linked to the viticulture sector have effects on the environment. Therefore, in the current study we examined the LUCs that have occurred in the Ribeiro appellation in NW Spain between 1989 and 2009. For this, GIS was used to map the gradual dynamic changes on an annual basis of the areas used for wine production. Thereafter, the different land uses that substituted or were substituted by vineyards were identified in order to calculate the carbon storage and carbon emission dynamics based on the IPCC guidelines. Finally, operational activities linked to viticulture, including changes in technology over time, were added to the model in order to obtain a broad picture of entire impact of viticulture in terms of GHG emissions. The results present an interesting pattern, with GHG emissions linked to LUCs steadily decreasing in the timeframe analyzed. Similarly, the improvement of machinery, the reduction on fossil dependency in the Spanish electricity mix and the stricter use of specific standards for the use of plant protection agents also contributed to a gradual decrease in GHG emissions per functional unit (i.e. 1 ha of cultivated vineyards). These results are aimed at providing the appellation and other appellations throughout with environmentally relevant information regarding how different factors influencing their change through time can be analyzed to give support in policy making and decision making at a business level.

Keywords: appellation, dynamic LCA, land use changes, Life Cycle Assessment, viticulture.

1. Introduction

Wine production in Spain and other Mediterranean countries constitutes an important source of income in many rural areas. In fact, Spain is the country in the world with the highest surface area destined to wine production, even though the final gross productivity is still higher in Italy and France. In addition, the increasing interest in wine tasting worldwide, together with the limitations in wine-growing enforced by the Common Agricultural Policy of the European Union, have produced important changes in the sector since the early 1990s. In the first place, an increasing number of wine producing regions have clustered in appellations, in order to increase the visibility of the wine produced abroad, as well as to create a series of standards of production. This has led to higher level of technological improvements in the appellations, as compared to subsistence practices used until the mid-1980s. Secondly, most rural areas in Spain have suffered important demographic losses in the past 30 years, due to a wide range of factors, which include urbanization and the impact of the new European agricultural policies. Finally, changes in the wine consumption market, which is now targeted to a more educated wine taster, in which the wine product is no longer a companion of a meal, but a quality product in itself, have also led wine-growers to change the markets they serve and the way in which wine products are presented.

All these factors that have been briefly described have derived in important changes in the landscape of numerous appellations across Spain, with a gradual decrease in surface area destined to wine making, but with more intensive practices and with a higher level of appellation control in terms of operational practices (e.g. use of plant protection agents or application of fertilizers) on the individual wine-growers. In addition, these changes in landscape have also created changes in two important spheres. On the one hand, on the land use changes (LUCs), an issue that has been identified by the IPCC as an important generator or inhibitor of greenhouse gas (GHG) emissions, depending on the direction of the LUC. Hence, the substitution of agricultural land by forestry is most likely to create conditions for carbon storage, not only from an aerial perspective in the vegetation, but also due to the enhancement of the storage capacity of the soil (Williams et al. 2011). On the other hand, technological improvements and changes in the use of materials in the viticulture sector have also occurred in the past two decades. For instance, the trellis, which was traditionally constructed with wood, has been gradually substituted by other materials through time, such as granite slabs, and more recently, slate slabs or galvanized iron.

Based on these on-going trends in the sector, the main aim of this study is to understand from a timeline approach how these changes are affecting the environmental profile of wine produced in a selected appellation in NW Spain: *Ribiero*, located in the autonomous community of Galicia. The selected method for this analysis was Life Cycle Assessment (LCA), an internationally standardized assessment method that provides, based on detailed inventories with a life-cycle approach, an integrated analysis of different environmental dimensions, such as climate change, toxicity or use of resources among others (ISO 2006a). Therefore, LCA is used to monitor the changes in the environmental profile of *Ribeiro* wine from a timeline perspective from 1989 to 2009, with the aid of GIS mapping and the IPCC guidelines, in order to understand the evolution of its environmental burdens and to analyze the implications it may have in future policy making and decision making at a business level.

2. Methods

2.1. Goal and scope of the study

The main goal of this study was to understand the environmental profile of wine production in the *Ribeiro* appellation in the period 1989-2009. The selected functional unit (FU) for this case study was fixed as 5380 ha of land. This choice of FU is based on the fact that this was the entire land surface that was destined to wine production in the period 1989-2010. In other words, all land used for viticulture in this period was included within the system boundaries, regardless of the fact that either this land may have changed land use during this period, or that at the beginning of the period (1989) the land had a different use other than viticulture. This choice of a land FU is based on the lack of data regarding the yield on a temporal basis. Moreover, even if it were available, it would be subject to interannual changes due to natural fluctuations in yield. Therefore, the FU that was finally used serves as an adequate proxy to determine the changes in environmental impact in the appellation in the past two decades.

The system boundaries of the study included, as aforementioned, the entire surface destined to viticulture in the appellation, regardless of any LUC that may have occurred in the timeline under analysis. Based on this geographical boundary, that includes a total of 5380 ha, the biogenic carbon interactions on-going on an annual basis were monitored based on the IPCC guidelines for monitoring carbon release and/or storage due to LUCs. In addition, the entire life-cycle of viticulture activities, such as the production and use of fertilizers and plant protection agents, the use of trellis, machinery and operational activities in the vineyards, as well as the final harvesting activities up to the gate of the vinification plant, were included within the boundaries.

2.2. Data acquisition and IPCC guidelines

Data were obtained from a wide range of sources. In the first place, data on LUCs changes in the appellation were obtained from land use maps purchased from the Spanish Ministry for the Environment. These maps were only available for the period spanning from 1989 to 2009 and, therefore, guided the final time delimitation (see Table 1). Secondly, based on these LUCs, the IPCC guidelines for LUCs were taken into consideration to monitor which land use dynamics had a positive impact on carbon storage, or whether these changes were actually contributing to carbon emissions, as depicted in Table 2 (IPCC 2006). In addition, data for operational activities of vineyards in the appellation were retrieved from previous LCA studies analyzing the appellation (Vázquez-Rowe et al. 2012; 2013; Villanueva-Rey et al. 2013). Finally, data on trellis appeared to suffer major changes in the past two decades. Therefore, the appellation authorities provided guidance regarding changes in trellis materials in vineyards over time (DO Ribeiro, 2014, personal communication).

Table 1. Land use changes for selected years in the *Ribeiro* appellation. All values presented in hectares.

	1989	1993	1997	2001	2005	2009
Forest land	535	428	321	214	107	0
Forest land (transition)	0	323	645	968	1290	1613
Vineyards – Forest	0	323	645	968	1290	1613
Vineyards	4448	3981	3513	3046	2578	2111
Vineyards (transition)	0	186	373	559	746	932
Forest – Vineyards	0	107	214	321	428	535
Meadows – Vineyards	0	16	32	49	65	81
Other crops - Vineyards	0	31	62	94	125	156
Other land – Vineyards	0	32	64	96	128	160
Meadows	81	65	49	32	16	0
Meadows (transition)	0	20	40	60	80	100
Vineyards – Meadows	0	20	40	60	80	100
Other crops	156	125	94	62	31	0
Other crops (transition)	0	35	70	105	140	175
Vineyards-Other crops	0	35	70	105	140	175
Fallow land	160	128	96	64	32	0
Fallow land (transition)	0	77	154	230	307	384
Vineyards - Fallow land	0	77	154	230	307	384
Wetlands	0	0	0	0	0	0
Wetlands (transition)	0	13	26	39	52	65
Vineyards – Wetlands	0	13	26	39	52	65
TOTAL	**5380**	**5380**	**5380**	**5380**	**5380**	**5380**

Table 2. Land use changes for selected years in the *Ribeiro* appellation. All values presented in hectares.

Land use		Emissions/capture of CO_2	Emissions/capture other GHG	Total t CO_2eq
Initial land use	Transition to…	Metric tons of CO_2	t CO_2 eq	
Forest land	Forest land	-24.35	0.13	-24.22
Vineyards	Forest land	-35.53	0.13	-35.40
Vineyards	Vineyards	18.40	0.57	18.97
Forest land	Vineyards	241.61	0.99	242.60
Meadows	Meadows	0.00	0.00	0.00
Vineyards	Meadows	18.27	0.00	18.27
Meadows	Vineyards	0.47	0.75	1.22
Fallow land	Fallow land	0	0.00	0
Vineyards	Fallow land	19.28	0.00	19.28
Fallow land	Vineyards	-5.74	0.62	-5.12
Vineyards	Wetlands	21.83	5.69	27.52
Other crops	Other crops	0	0.50	0.50
Vineyards	Other crops	-2.41	0. 50	-1.91
Other crops	Vineyards	-4.76	0.72	-4.04

2.3. Life Cycle Inventory

The Life Cycle Inventory (LCI), as explained briefly in the previous section included LCI data for the appellation used in prior studies (Vázquez-Rowe et al. 2012; 2013; Villanueva-Rey et al. 2013). However, it was important to adapt the operational activities to the entire extent of the period analyzed in two different steps. On the one hand, contacts were made with stakeholders in the appellation in order to understand the operational changes, including machinery, use of fertilizers and plant protection agents. Moreover, specific data were disclosed by the appellation authorities linked to historical data on trellis and use of pesticides. On the other hand, once these data were structured correctly, and inserted in the software selected (i.e., SimaPro v8.0), background processes supporting these data were adapted to the different years of assessment. For this, the electricity mix for Spain was modelled for all years of analysis and inserted into the software, in order to link each production process (i.e., production of fertilizers, pesticides, etc.) to the most appropriate electric profile (see Table 3). In addition, similar processes were done regarding machinery and the use of fossil fuels.

Table 3. Electricity mix profile for Spain in selected year of assessment. Data reported per 1 kWh.

	1989	**1993**	**1997**	**2001**	**2005**	**2009**
Electricity, hard coal, at power plant	0.3102	0.3649	0.2806	0.2307	0.2403	0.1255
Electricity, lignite, at power plant	0.0772	0.0847	0.1532	0.096	0.0344	0.0063
Electricity, oil, at power plant	0.0743	0.012	0.0503	0.1119	0.0833	0.06339
Electricity, natural gas, at power plant	0.0118	0.0058	0.0384	0.1059	0.2695	0.3853
Electricity, industrial gas, at power plant	0	0	0	0	0	0
Electricity, hydropower, at power plant	0.0803	0.0958	0.1113	0.0998	0.0736	0.0904
Electricity, hydropower, at pumped storage power plant	0.0053	0.0048	0.0045	0.0022	0.0049	0.0103
Electricity, nuclear, at power plant	0.4562	0.4219	0.3712	0.2898	0.1963	0.1827
Electricity, production mix photovoltaic, at plant	0	0	0	0.0001	0.0003	0.0214
Electricity, at wind power plant	0	0	0.0042	0.0302	0.0726	0.1287
Electricity, at cogen ORC 1400kWth, wood, allocation exergy	0	0.0001	0.0068	0.0163	0.0286	0.0134
Electricity, at cogen with biogas engine, allocation exergy	0	0	0	0	0	0
Electricity, production mix FR	0.0233	0.0365	0.0007	0.026	0.0233	0.057
Electricity, production mix PT	-0.0387	-0.0264	-0.0203	-0.0013	-0.0243	0
TOTAL	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*

2.4. Allocation assumptions

The function of the analyzed system was not linked directly to a specific final product, such as harvested grapes or wine bottles. Moreover, it is important to consider that numerous additional products, co-products or residues are formed throughout the winemaking process. However, given the surface-based perspective and the limitation of the system boundaries to the viticulture stage of wine production, the derived environmental impacts were not disaggregated between different material flows. Hence, allocation between co-products was not necessary.

2.5. Life Cycle Impact Assessment

ReCiPe is the assessment method selected for the computation of the environmental impacts. The rationale behind this selection is due to the vast range of environmental impacts that it considers and the possibility of providing a single score weighted endpoint average for the results, which allows tackling priority impact categories based on the values obtained.

3. Results

While the results for this study are still under computation, and will be presented in full at the LCA of Foods 2014 Conference, at this point in the analysis is was possible to anticipate to a certain extent some of the main drivers of environmental impact in the appellation under study. On the one hand, as can be observed in Figure 1, the biogenic GHG emissions for the appellation were computed based on the IPCC guidelines for the entire assessment period. The results show a steady tendency toward a higher potential of carbon storage in the appellation as surface land destined to viticulture decreases. In fact, by year 2008 the carbon storage potential of the land was found to be superior to the biogenic GHG emissions occurring in the area studied.

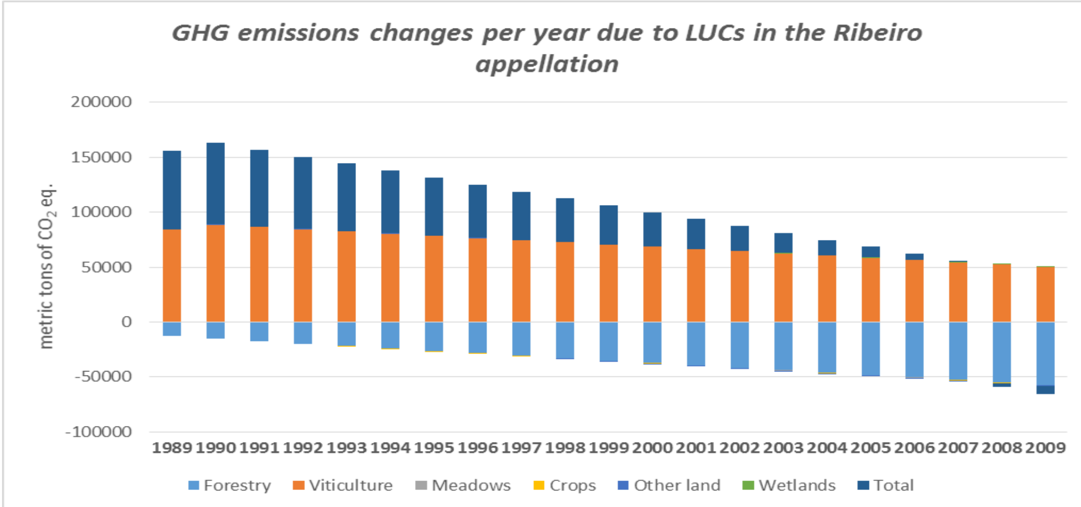

Figure 1. Biogenic greenhouse gas emissions (metric tons of CO2eq) and storage potential of the *Ribeiro* appellation in the period 1989-2010 (Results referred to the FU).

A second issue of interest, was the analysis of the electric mix evolution in Spain in the timeframe analyzed (see Figure 2). As can be seen below, the GHG emissions associated with the production of electricity in Spain ranged from 0.5-0.6 kg CO_2eq per 1 kWh between 1989 and 2005, depending mainly on the proportion of coal used for electricity production, as well as on the hydroelectric power available. However, in 2005, led by the increase in installed power of some renewable energies, namely wind power, but also photovoltaic to a lesser extent, and to an important reduction in the use of coal, the GHG emissions associated with the production of 1 kWh of electricity were down to 0.3-0.45 kg CO_2eq for the period 2009-2011.

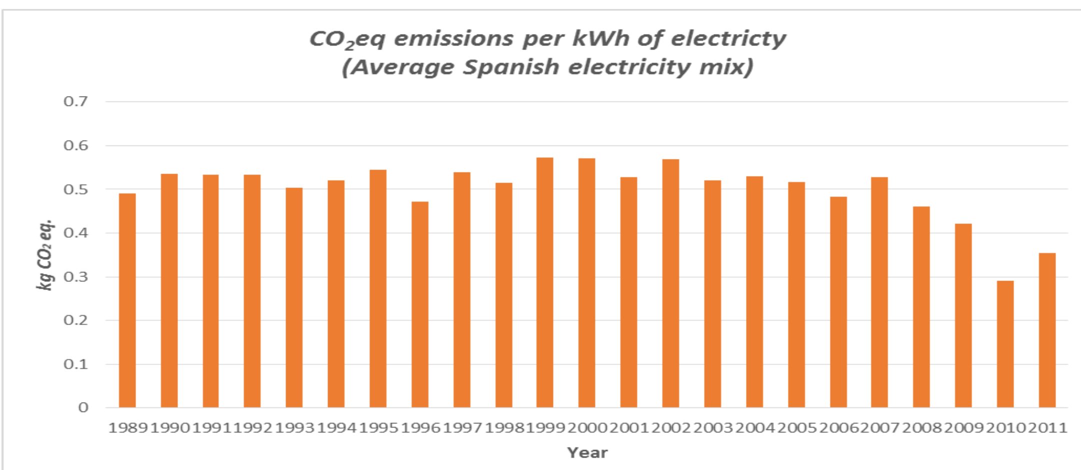

Figure 2. Greenhouse gas (GHG) emissions per kWh produced in the Spanish electricity mix (1989-2011). Data referred to 1 kWh produced, including pumping and international exchanges.

4. Discussion and conclusions

The partial results presented in this paper demonstrate substantial increases in carbon storage in the *Ribeiro* appellation in the past two decades due to LUCs. This is attributable to the lower surface area destined to winemaking, a phenomenon that can be linked to the demographic crisis in the area, but also to a more specialized and technological production system, in which the average producer cultivates more viticulture land than in the late 80s. While these results can seem positive, it is also important to bear in mind that most of the land that has been abandoned in the past 20 years has not received adequate management, but has been absorbed without any human monitoring by the surrounding habitat conditions. Therefore, risks linked to forest fires, as well as a lack of understanding of the optimized carbon storage potential of abandoned land, are two issues that remain essentially unexplored.

In this preliminary analysis of the results, and based on the results gathered in Figure 2, it may appear that the anthropogenic GHG emissions regarding electric production in Spain would also contribute to enhance the trend shown by biogenic emissions. However, this interpretation can be highly biased due to the increase in technological use in viticulture activities. Therefore, while the total GHG emissions per kWh have decrease in this period, especially linked to the higher proportion of renewable energy in the mix (mainly wind power) in recent years, viticulture practices are also using more energy intensive materials in trellis (e.g. concrete or granite slabs, rather than *Acacia dealbata*) or fertilizers (more widespread use of inorganic fertilizers in recent years).

While this results are still partial and preliminary, they do present some promising tendencies for the environmental profile of the appellation. However, numerous issues remain open from an LCI and LCIA perspective. In the first place, the uncertainties in the LCI appear to increase as we go back in the year of assessment, linked to the increasing difficulty to retrieve data. Secondly, the preliminary results advances in this paper have also focused on GHG emissions, ignoring other impact categories used in ReCiPe. While this decision is justified in the fact that both energy and land use are of extreme importance in the assessment of climate change, future updates of this work will have to analyze in depth the trade-offs between impact categories linked to the dynamic changes occurring in the appellation.

Finally, while the results presented already allow certain interpretations from a policy-making approach, the expected final outputs of the study will permit a broad discussion on how different policy decisions can steer the dynamic environmental impact changes in the near future.

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