Towards a consistent framework for agri-food life cycle assessment in Portugal: inventory adaptation, impact assessment development and application to sown biodiverse pastures

Tiago G. Morais[1]

[1] Instituto Superior Técnico, MARETEC - ACAE/DEM, Av. Rovisco Pais, 1, 1049-001 Lisboa, Portugal

Abstract

One of the most important challenges in Life Cycle Assessment (LCA) is performing regionalized analyses while ensuring comparability between studies. This requires consistently regionalized inventories and impact assessment methods in order to accurately depict supply chain processes and enable the application of an increasing number of geographically explicit impact assessment models. This is particularly important for agri-food products.

This thesis proposes a regionalized LCA framework for the agri-food sector, focused on Portugal, but applicable in general. It starts by performing a comprehensive review of agri-food Portuguese studies. Next, it builds a regional, scale-consistent adapted Life Cycle Inventory (LCI) using international reference guidelines. Afterwards, one Life Cycle Impact Assessment (LCIA) midpoint method for soil quality using soil organic carbon (SOC) is introduced. Finally, these improvements are applied in a case study that performs a comparison of cattle feeding in semi-natural and sown biodiverse pastures.

With this thesis ten new consistent LCI interventions are now available. This is the first step to obtain a complete inventory that can be used in all agri-food LCA studies, a necessity due to the fact that Portuguese studies do not have a systematic and country-scale approach. Concerning LCIA, this thesis presents characterization factors for SOC depletion in Europe that can be nested within characterisation factors suggested by the International Reference Life Cycle Data System the ILCD since our results possess better spatial resolution. The comparison of cattle feed in semi-natural and sown biodiverse pastures highlight the improvements achieved, for one relevant and complex Portuguese case study.

Keywords: Agri-food, Portugal, Life cycle Assessment, Life Cycle Inventory, Life Cycle Impact Assessment

1 Introduction

In the last half-century the world population increased and is expected that reach nine billion by 2050[1]. This population increase creates a demographic pressure on food production. It has been estimated that we will need to produce 70 to 100 per cent more food than we produce presently. At the same time, society must deal with new challenges, namely how to meet the expected demand for food without significant increases in prices, and how this can be possible without dilapidating the natural environment. Productivity will have to be maintained while at the same time reducing the environmental impacts associated with food production[2].

The first step to ensure sustainability in agriculture is to be able to accurately measure environmental impacts. Thereby, many methodologies can be used to assess agricultural environmental impact. The choice of methodology is an important aspect because this choice has repercussions on the type and quality of results. Life cycle assessment (LCA) is now one of the most important frameworks to measure performance of a product or service in every stage of life cycle, particularly at farm or landscape level[3].

The European Commission (EC), within the scope of "A Resource-Efficient Europe", proposed a Product Environmental Footprint (PEF) guide (2013/179/EU) with the aim of providing a methodology to assess product's environmental performance, comparability between them and trustworthy claims of sustainability. Thus, it is expected that the LCA-based PEF guide will enable cost-effective environmental savings. Agriculture and food are featured prominently among the work groups. After the pilot stage is finished, it is expected that legislation will be introduced by the EC to provide incentives for business-to-consumer communications using an eco-labelling program.

An important issue in agri-food LCA is regionalization. More site-specific detail is needed, which translates into a need for regional inventories and spatialized impact assessment models. However, this cannot come at the expense of comparability between studies – which is a risk if inventories and models are built independently for very specific situations. There is thus a pressing need for regionalization methods that are built consistently with international frameworks and which ensure comparability. This is the problem that the present thesis tackles.

The main objective of the present thesis is to propose solutions regarding the ongoing debate regarding regionalization in LCA. We present a proposal of a regionalized LCA scheme for the agri-food sector, focused in Portugal and using Portuguese data but applicable in general, covering all LCA stages. Our scheme aims to balance regionalization with comparability. For that reason, the innovations in this thesis strive to follow international guidelines and standards while at the same time accurately depicting the specificities of regional agri-food production.

2 Method

In this section, we describe the approach followed in order to achieve the objectives laid out previously. The first part of the thesis is a comprehensive review of agri-food Portuguese studies, in order to assess the state of agri-food LCA in Portugal, how practitioners are conducting their studies using which methodological choices and their main data sources. Product coverage is also assessed. This review was the first of its kind in Portugal. Additionally, we compared results from all studies reporting the Global Warming Potential (GWP) impact category with international benchmarks, measured as kg CO_2eq. The goal in this step was to discover if Portuguese results are commonly above or below average and if there are notable outliers or systematic differences.

Next, a regionally adapted LCI for Portugal is presented, covering 86 products. This LCI was built using international reference guidelines, but the inventory interventions were adapted using a method that is scale-consistent with national-level accounts. The selection of interventions for inclusion in this work was guided by two criteria: (a) availability of data, and (b) applicability in Portugal. To illustrate the difference between an adapted inventory with interventions described and a generic inventory, we carried out a case study consisting in a comparison of three products (barley, maize and wheat) inventories using ecoinvent[4] and the same database updated with Portuguese LCI interventions adapted in this study, for the Alentejo agrarian region, and using the ILCD-recommended impact assessment methods[5] to perform the comparison, using software SimaPro 8.0.4.

Afterwards, one LCIA midpoint method is presented for soil quality in the EU (covering Portugal) thought soil organic carbon (SOC), using[6] method. Land occupation and transformation are particularly important for agriculture as keystone drivers of change in the impact pathway of agricultural processes. This method uses the indicator selected by the EU for soil quality and an internationally accepted method to determine the impacts from land use, using a recent database. It provides for the first time in the literature spatially explicit characterization factors for soil quality using SOC. To determine how the CFs obtained in our study compare with other land use indicators, we compare the CFs obtained in this study with CFs obtained by[7]. By directly comparing CFs, we determined whether there was complementarity or overlap between the results of two methods. To illustrate the differences between our results and prior methods, we carried out a case study consisting in a comparison of land use impact on SOC depletion for one product, calculated according to the ILCD method[5] and our three-scale CFs. We performed this study for a European agricultural product (1 kg maize grain, organic in Switzerland) selected from the ecoinvent 3.0 database. In the life cycle of this product there are 66 transformation and 25 occupation intervening processes.

Finally, these improvements to the LCI and LCIA achieved in the previous sections are applied in a case study that uses a cLCA approach to perform a comparison of cattle feed in semi-natural (SNP) and sown biodiverse pastures (SBPPRL), using method developed by[8]. This analysis tests the value and the limits of the innovations in this thesis, operationalizes these changes for use in standard LCA software (namely SimaPro 8.0) and it also provides important results for the case study in itself. Figure 1 shown the stages of this thesis.

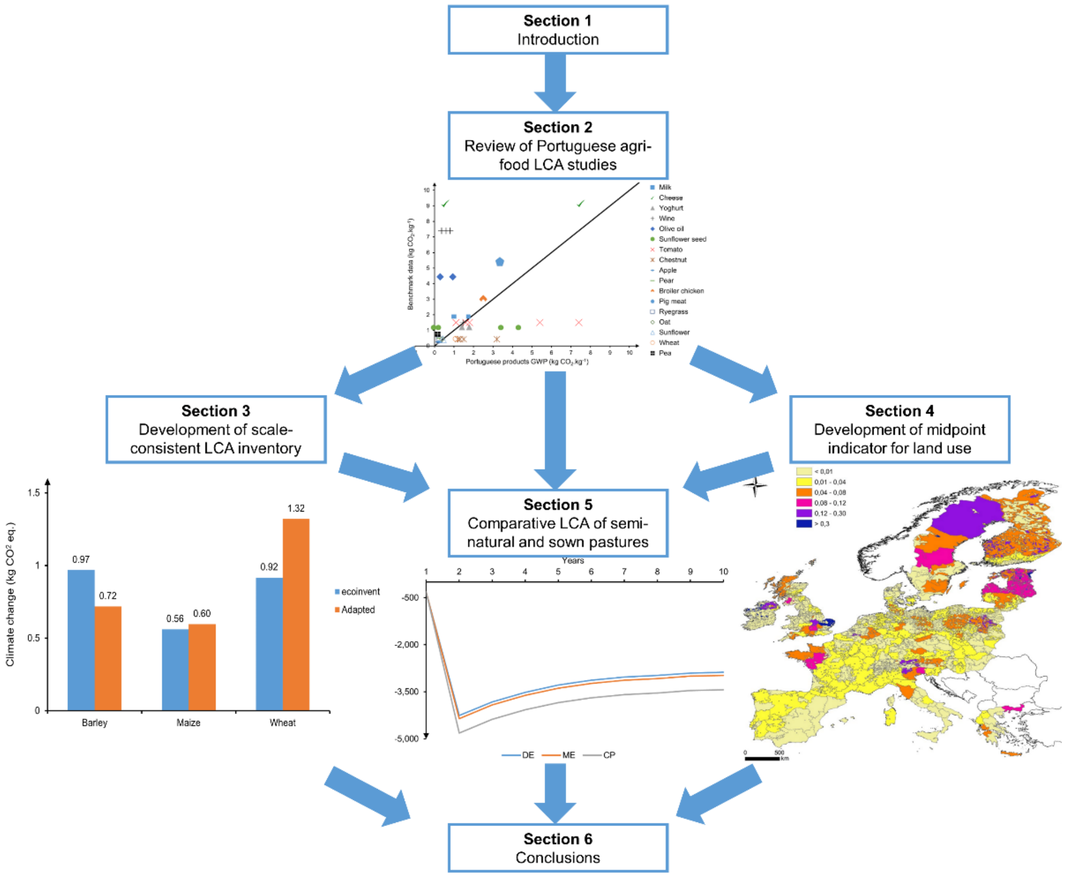

Figure 1. Organization of the sections within this thesis.

3 Results

3.1 Review of Portuguese agri-food LCA studies

We found a relatively small number of agri-food LCA studies in Portugal in our search (twenty two), which cover only twenty two different products. There is some repetition of products among studies, since these often focus on more than one different product each. The products covered are several dairy products, wine, olive oil, sunflower seed, chestnut, tomato, apple, pear, broiler chicken, pig meat and cow/calf feed.

The objective and goals were similar in most studies. LCA is used from a practitioner's perspective, aiming in most cases to determine or improve the environmental impacts of the products of interest rather than to advance or use new methods, propose models or use innovative frameworks of analysis. Geographic boundaries are different between studies, going from the micro scale of one production unit[9] to the entire country[10]. System boundaries are cradle-to-gate in most studies, only[9] is cradle-to-grave.

For activity data, many studies use on-site production data (e.g. production quantity)[9–18]. However, the LCI in all studies is composed of either local or average Portuguese data as foreground data and different versions of the ecoinvent database as background data. No study uses a geographically regionalized LCI or complementary modelling tools for impact assessment beyond the models commonly offered in LCA software.

Allocation divides studies into two major groups, mass and economic, and only one study [19] uses also protein-based allocation. For LCIA, most studies use mainly CML 200[20] and ReCiPe[21] methods, while Eco-indicators 95[22] and 99[23] are common among older studies. However no study used the recent ILCD recommendations for impact assessment indicators[5]. In results interpretation the common procedure is to quantify results in each impact category, and benchmark them using published results for the same product type. However, studies rarely present complete uncertainty analyses. Studies often resort to different versions of SimaPro as the software tool while GaBi 4.0 is also an option in other studies [13,24]. Finally, only one study performs consequential LCA[8].

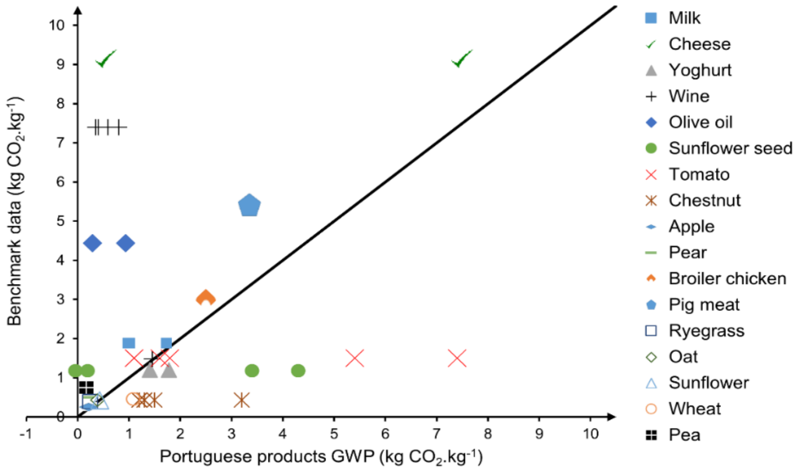

Figure 2. Relation between Portuguese studies' Global Warming Potential (GWP) and international data. The line shows where GWP reported in Portuguese studies would be equal to average international GWP, excluding two outliers (sunflower seed in perennial land use).

The products that should have priority in future studies are vegetable oil, olive oil, tomato, pig meat, cow milk, pears, animal feed, butter and sunflower. The criteria was export value, and area in Portugal (data shown as electronic supplementary material S2).

Figure 2 is a graphic representation of the benchmark exercise performed. We can observe that products studied more than one time (e.g. wine) have similar values. Cheese and wine are the products with higher GWP impact in international data but relatively reduced impact in Portuguese studies, in contrast with sunflower seed that display (for some farms) low GWP in international studies but high impact in Portuguese studies. Note, however, that in this case only a very small sample is available for the comparison.

3.2 Development of scale-consistent LCA inventory

The interventions surveyed were: yield, land use (LU), land transformation, soil loss, fertilizers, pesticides, greenhouse gas (GHG) emissions (including carbon dioxide (CO_2) emissions after urea or lime applications), electricity and carbon dioxide (CO_2) emissions after urea or lime applications, water use and animal feed. To exemplify one intervention adapted, Figure 3 shows crop yield for fodder maize.

Fertilizers and pesticides required correction of the quantity used per crop, using national aggregated consumption. Extrapolating from regional fact sheets[25] to national aggregates results in an overestimation for all fertilizers and pesticides, mainly P, K and manure. N fertilizer estimation is more accurate. The extrapolation for manure according to regional fact sheets[25] is particularly higher than national totals, in comparison with national aggregated, probably due to the fact that the quantities applied are more variable.

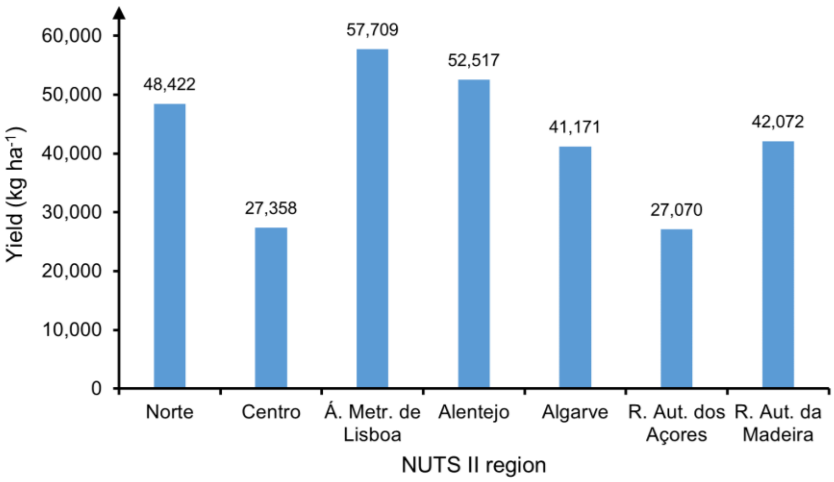

Figure 3. Fodder maize yield by Portuguese NUTS II region.

Concerning the comparison with the ecoinvent database v3.0, computing relative deviations (one minus results for ecoinvent divided by adapted results) for all impact categories and all products, we find significant differences between ecoinvent and regionalized Portuguese products, in the range 2%-355%. The average deviation is approximately 29.0% (95% confidence interval: 6.5-51.5%). This means that in most impact categories the deviation is in favour of the regionalized processes having higher impacts. There is enough variability to demonstrate that using secondary surrogate data (such as ecoinvent processes) is insufficient and that regionalizing the LCI before conducting studies is essential.

The main contribution to GHG emissions is fertilizer application. Differences in fertilizer use explain most of the differences between the processes. Land use (expressed in SimaPro as "Occupation") and respective farming activities, which in the LCI are also expressed in m^2 yr, are also particularly relevant to explain the differences in Figure 5 among the adapted interventions with relevance for the climate change impact category. This is due to the mechanized agricultural activities (e.g. tillage, harrowing and harvesting). Thereby, higher land use area involves higher GHG emissions.

3.3 Development of midpoint indicator for land use

The first outcome of this section is average SOC per land use and region. The regions with higher SOC content are Northern Europe and the British Isles, which can be explained by the combination of two factors: cool temperate with moist climate and spodic soils, which are typically high in SOM[26].

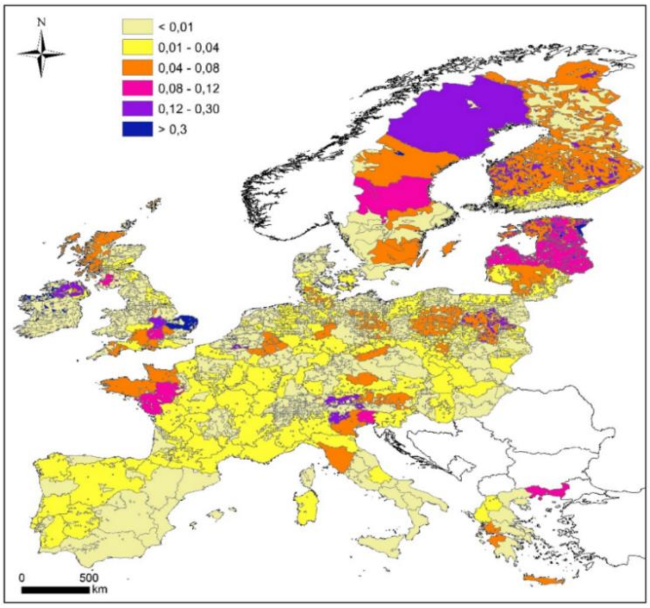

Figure 4. Occupation characterization factors (per NUTS II region), for the land class "cultivated and managed vegetation" (kg C yr m^{-2} yr^{-1}).

Next, the characterization factors (CF) of occupation and transformation for SOC depletion. As an example of the trends observed, Figure 4 represents occupation CFs for the land cover "cultivated and managed vegetation", which includes agricultural land use. This map shows that northern Europe, namely Sweden's NUTS II regions, are where the highest occupation CFs for this land use can be found, explained by high values of SOC_{pot} (pristine SOC concentrations in boreal forests) and low SOC_{LU2} (land with agricultural uses), which translate into high differences using this model.

The results obtained also show that biophysical aggregation displays relatively lower uncertainty when compared to aggregating at an administrative level. However, most of the effect is offset by the fact that there are more territorial units at NUTS II scale.

The results for the scenarios assessed regarding the case study. The main differences are noted in occupation impacts, which, as noted by [6], are overrepresented relative to transformation impacts. The application of region-blind ILCD CFs results in a higher overall impact, compared to the application of the regional CFs from our study.

3.4 Comparative LCA of semi-natural and sown pastures

The analysis used 254 impact categories to show that, in the first year, 27 have a negative value, i.e. in the second situation (SBPPRL and SNP) the impact is lower than in the baseline situation (SNP and commercial feed). From the second year on, 213 have a negative value. Next we highlight some important cases within this set of indicators. The climate change impact category (from

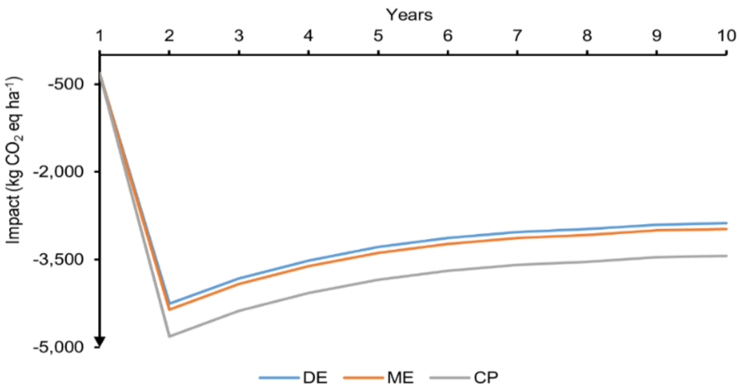

Figure 5. Impact difference in impacts between situations for climate change impact category, according ILCD method.
DE – Digestible energy; ME – Metabolizable energy; CP – Crude Protein.

ILCD method) was analysed with and without the inclusion of CO_2 sequestration. Figure 5 shows the evolution of impacts along the 10 years studied, according to the three equivalence types used, and including CO_2 sequestration. The impact difference, for the three equivalences established, is always negative with a spike in the second year due to maximum carbon sequestration taking place during that year. For the first year the difference of impacts between scenarios is also negative, although in this year commercial feed is used in both situations, so it does not have any influence. The reason for this negative result is the fact that first-year SBPPRL also sequester carbon, and the amount sequestered compensates for the emissions due to the installation of the pasture. Using DE and ME exhibits a similar trajectory, but CP equivalence amplifies the environmental effects because commercial feeds are more protein-rich. This is particularly important because commercial feeds, on a nutritional unit basis, have much higher impacts than SBPPRL and SNP.

If CO_2 sequestration is omitted the initial situation continues with higher environmental burden due to the impact of commercial feeds except during the first year (SBPPRL installation), where no concentrate feed is being replaced. This means that, even if carbon sequestration is disregarded as a temporary storage of carbon in soils and removed from the impact assessment, SBPPRL still avoid GHG emissions due to the replacement of the feed. This effect, in terms of avoided emissions, is not negligible. The categories where CO_2 sequestraion do not intervene results shown that the system with SBPPRL has a lower impact than the system with commercial feed, except in the first year. This effect, in terms of avoided emissions, is 2,8, 2,9 or 3,6 t CO_2e ha^{-1} (depending on the equivalence indicator) are avoided by replacing feeds. This number is similar to the average year for carbon sequestered by SBPPRL.

Comparing ILCD CFs and adapted CFs, in the first year results are similar, however in the following years land use impacts using ILCD CFs are higher. This happens due to the weight of commercial feed impacts in results, since that commercial feed is composed by ten ingredients most of which are crops, which amplifies the results due to the fact that croplands have higher land use impacts (measured as SOC depletion) than grasslands.

4 Conclusion

The main lesson that can be drawn from the review of Portuguese agri-food studies is the lack of a systematic country-scale approach. This is particularly important for the LCI stage. Inter-study comparability is difficult due to very different assumptions, including data sources, involved in the establishment of study-specific inventories. This demonstrated the importance of inventory adaption section, which proposed such a prototype of a consistent regional LCI. We also observed from the twenty-two products assessed in twenty-two studies that only seven are published in international journals. Mass-based reference units were used in most studies, which does allow for comparability between studies, but this is a functionless unit that does not express the true purpose of food products, which is to provide nutrition. Because of this observation, comparison between SBPPRL and SNP included several nutrition-based functional units to test the sensitivity of results. In LCIA, impact categories varied between studies and were often calculated according to methods pre-implemented in software applications, some of which are now outdated and most of which do not reflect the biophysical impacts of agriculture on soil, biodiversity and water, for example. For this reason the comparison between SBPPRL and SNP included ILCD, a compilation of LCIA models currently recommended by the European Commission that includes state-of-the-art impact modelling. It was also observed that practitioners never applied regionalized LCIA models, which justified the proposal of a first ILCD-compatible model for land use with characterization factors for Portugal.

We also concluded that there is enough Portuguese data available to compile a systematic database (which in my thesis can be found in multiple SI tables, available in https://fenix.tecnico.ulisboa.pt/homepage/ist170313/thesis---supplementary-material) for most interventions required for a complete LCI, at the country or a regional scale. This thesis provides inventory flows for 10 interventions adapted for Portugal. These interventions were then used as foreground data in the comparison between SNP and SBPPRL to build the inventory for each pasture type and commercial feed. The inventory adaption contributed to the general objectives of the thesis because the data compiled can be used consistently in future Portuguese agri-food studies (or international studies where the life cycle contains Portuguese agricultural materials), and it also laid down some indications that may help a future research effort to adjust reference values for other interventions. Future Portuguese studies should rely on these LCI interventions to accurately depict foreground processes that take place in the country.

Following the general objectives of the thesis, this thesis also provides regionalized CFs for occupation and transformation depending on scale (NUTS II, eco and climate region), both of which can be applied in impact assessment in Portuguese studies. Data is provided for the European Union using a method consistent with ILCD – which means that these CFs obtained here can be nested within ILCD CFs providing more detail for the EU countries. The method used to calculate CFs is very well established in LCIA. However, it suffers from shortcomings related to data availability that even a study using very detailed field measurements is unable to solve. For example, regeneration time is one relevant aspect to improve, as Brandão and Milà previously mentioned. The implications of using a constant regeneration time (20 years), suggested by [27] are relevant because it is at the root of the diminished significance of transformation impacts.

During the case study application, inventory detail was precisely one of the main challenges faced. Life cycle inventories do not possess yet enough information regarding the exact location of processes apart for countries or large-scale administrative regions, since they are intended to be used as generic, background data or as blueprints to build foreground processes using primary data. This is an obstacle mostly when CFs are aggregated according to biophysical units. This fact demanded the aggregation of CFs intended for use within climate or eco-regions for entire countries (weighing by area), which introduced a new source of uncertainty in the final CF used. The correlations between CFs using different aggregation strategies are far from perfect (e.g. Pearson correlation for herbaceous vegetation eco-climate region is 0.563 and 0.495 to NUTS II-climate region) , which means that if cell-level CFs are aggregated into larger units to match inventories then this process may decrease the quality of the LCIA method. It is thus urgent for LCIs to introduce more detailed, spatialized information, so they can keep up with new progress in impact modelling – which also justifies the work done in inventory adaptation.

The comparative LCA study involving pastures applied all the previous results to one relevant and complex Portuguese case study. SBPPRL are a Portuguese innovation whose complete environmental life cycle consequences were thus far undetermined. The results of this provide a basis for assessment and comparison of the environmental burdens of SBPPRL and its alternative baseline system, which are concentrate feeds, using an innovative approach[8]. The system with SBPPRL generates lower environmental impacts due to the replacement of commercial feeds and carbon sequestration. For example, for GHG emissions, replacing feeds avoids the emission of about 3 t CO_2e ha^{-1}, which is similar to the amount sequestered in SBPPRL except in early years. In respect to the equivalence method, it is possible to conclude that DE and ME equivalences provide similar impact values in contrast with CP equivalence, due to the fact that SBPPRL have higher nutritional quality and therefore a nutritional indicator, such as CP, expresses that more feed is needed to equal the amount provided by pasture plants. Comparing result for DE and CP, the impact indicators using CP to establish the equivalence of scenarios is about 12% higher in the second year (first where commercial feed are unnecessary) and range between 20 % and 40% in the following years. Finally, the comparison of results of using adapted CFs calculated with ILCD for land use impact category showed that the adapted indicator shows the difference of impacts between systems in the case study is 85% lower.

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References

(1) Pretty, J.; Sutherland, W. J.; Ashby, J.; Auburn, J.; Baulcombe, D.; Bell, M.; Bentley, J.; Bickersteth, S.; Brown, K.; Burke, J.; et al. The top 100 questions of importance to the future of global agriculture. **2011**.

(2) Godfray, H. C. J.; Beddington, J. R.; Crute, I. R.; Haddad, L.; Lawrence, D.; Muir, J. F.; Pretty, J.; Robinson, S.; Thomas, S. M.; Toulmin, C. Food security: the challenge of feeding 9 billion people. *Science* **2010**, *327* (5967), 812–818.

(3) van der Werf, H. M. .; Tzilivakis, J.; Lewis, K.; Basset-Mens, C. Environmental impacts of farm scenarios according to five assessment methods. *Agric. Ecosyst. Environ.* **2007**, *118* (1-4), 327–338.

(4) Weidema, B. P.; Bauer, C.; Hischier, R.; Mutel, C.; Nemecek, T.; Reinhard, J.; Vadenbo, C. O.; Wernet, G. Overview and methodology. Data quality guideline for the ecoinvent database version 3. Ecoinvent Report 1(v3). Swiss Centre for Life Cycle Inventories: St. Gallen 2013.

(5) European Commission - Joint Research Centre; Institute for Environment and Sustainability. *International Reference Life Cycle Data System (ILCD) Handbook - Recommendations for Life Cycle Impact Assessment in the European Context*; Publications Office of the European Union: Luxemburg, 2011.

(6) Brandão, M.; Milà i Canals, L. Global characterisation factors to assess land use impacts on biotic production. *Int. J. Life Cycle Assess.* **2012**, *18* (6), 1243–1252.

(7) Alvarenga, R. A. F.; Erb, K.-H.; Haberl, H.; Soares, S. R.; van Zelm, R.; Dewulf, J. Global land use impacts on biomass production—a spatial-differentiated resource-related life cycle impact assessment method. *Int. J. Life Cycle Assess.* **2015**, *20* (4), 440–450.

(8) Teixeira, R. F. M. Sustainable Land Uses and Carbon Sequestration: The Case of Sown Biodiverse Permanent Pastures Rich in Legumes, Dissertation, Instituto Superior Técnico, 2010.

(9) González-García, S.; Castanheira, É. G.; Dias, A. C.; Arroja, L. Environmental life cycle assessment of a dairy product: the yoghurt. *Int. J. Life Cycle Assess.* **2012**, *18* (4), 796–811.

(10) Rosa, D. Avaliação de Ciclo de Vida da castanha e do tomate em Portugal, Dissertation, Faculdade de Ciências e Tecnologia - Universidade de Coimbra, 2014.

(11) González-García, S.; Castanheira, É. G.; Dias, A. C.; Arroja, L. Environmental performance of a Portuguese mature cheese-making dairy mill. *J. Clean. Prod.* **2013**, *41*, 65–73.

(12) González-García, S.; Castanheira, É. G.; Dias, A. C.; Arroja, L. Using Life Cycle Assessment methodology to assess UHT milk production in Portugal. *Sci. Total Environ.* **2013**, *442*, 225–234.

(13) Caldeira, B. A pegada de carbono do vinho alentejano: exemplo de valorização da sustentabilidade. SEMINÁRIO “Bens públicos e serviços ambientais” Feira Nacional de Agricultura – CNEMA. Santarém 2011.

(14) Santos, A. M. S. M. N. dos. Avaliação do Ciclo de Vida do Vinho Verde, Dissertation, Universidade do Porto, 2010.

(15) Mateus, A. Avaliação de Ciclo de Vida do Azeite e do Vinho em Portugal, Dissertation, Faculdade de Ciências e Tecnologia - Universidade de Coimbra, 2012.

(16) Neto, B.; Dias, A. C.; Machado, M. Life cycle assessment of the supply chain of a Portuguese wine: from viticulture to distribution. *Int. J. Life Cycle Assess.* **2013**, *18* (3), 590–602.

(17) Figueiredo, F.; Castanheira, É. G.; Ferreira, A.; Trindade, H.; Freire, F. Greenhouse gas assessment of wine produced in Portugal. In *Energy for Sustainability 2015 – Designing for People and the Planet, May 14-15*; Coimbra, Portugal, 2015.

(18) Rosado, M. Contributo para a integração da componente ambiental na avaliação económica de sistemas de produção agro-pecuários. Dissertation, Universidade de Évora, 2009.

(19) Castanheira, É. G. Avaliação do ciclo de vida dos produtos lácteos fabricados em Portugal continental, Dissertation, Universidade de Aveiro, 2008.

(20) Guinée, J.; Gorrée, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; de Koning, A.; van Oers, L.; Wegener, A.; Suh, S.; Udo de Haes, H. *Life cycle assessment. An operational guide to the ISO standards*; Centre of Environmental Science: Leiden, 2001.

(21) Goedkoop, M. J.; Heijungs, R.; Huijbregts, M. A. J.; De Schryver, A. M.; Struijs, J.; Van Zelm, R. *ReCiPe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First Edition (version 1.08) Report I: Characterisation*; 2013.

(22) Goedkoop, M.; Demmers, M.; Collignon, M. *The eco-indicator 95 Manual for Designers*; PRé Consultants, 1995.

(23) PRé Consultants. *Eco-indicator 99 Manual for Designers*; PRé Consultants, 2000.

(24) González-García, S.; Belo, S.; Dias, A. C.; Rodrigues, J. V.; Costa, R. R. da; Ferreira, A.; Andrade, L. P. de; Arroja, L. Life cycle assessment of pigmeat production: Portuguese case study and proposal of improvement options. *J. Clean. Prod.* **2015**, *100*, 126–139.

(25) GPP. *Contas de Cultura das Actividades Vegetais, Ano 1997 - Modelo de Base Microeconómica (“Crop Sheets 1997 – Microeconomic Base Model”, in Portuguese)*; Ministério da Agricultura, do Desenvolvimento Rural e das Pescas - Gabinete de Planeamento e Política Ago-Alimentar: Lisbon, 2001.

(26) Jones, R. J. A.; Hiederer, R.; Rusco, E.; Loveland, P. J.; Montanarella, L. *The map of organic carbon in topsoils in Europe, Version 1.2, September 2003: Explanation of Special Publication Ispra 2004 No.72 (S.P.I.04.72). European Soil Bureau Research Report No.17, EUR 21209 EN, 26pp. and 1 map in ISO B1 format*; Office for Official Publications of the European Communities: Luxembourg, 2004.

(27) IPCC. *2006 IPCC Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies (IGES) for the Intergovernmental Panel on Climate Change.*; The Intergovernmental Panel on Climate Change (IPCC): Kanagawa, 2006.