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Environmental impacts of barley cultivation under current and future climatic conditions

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A B S T R A C T

The purpose of this work is to compare the environmental impacts of spring barley cultivation in Denmark under current (year 2010) and future (year 2050) climatic conditions. Therefore, a Life Cycle Assessment was carried out for the production of 1 kg of spring barley in Denmark, at farm gate. Both under 2010 and 2050 climatic conditions, four subscenarios were modelled, based on a combination of two soil types and two climates. Included in the assessment were seed production, soil preparation, fertilization, pesticide application, and harvest. When processes in the life cycle resulted in co-products, the resulting environmental impacts were allocated between the main product and their respective by-products using economic allocation. Impact assessment was done using the ReCiPe (H) methodology, except for toxicity impacts, which were assessed using USEtox.

The results show that the impacts for all impact categories, except human and freshwater eco-toxicity, are higher when the barley is produced under climatic circumstances representative for 2050. Comparison of the 2010 and 2050 climatic scenarios indicates that a predicted decrease in barley yields under the 2050 climatic conditions is the main driver for the increased impacts. This finding was confirmed by the sensitivity analysis. Because this study focused solely on the impacts of climate change, technological improvements and political measures to reduce impacts in the 2050 scenario are not taken into account. Options to mitigate the environmental impacts are discussed.

1. Introduction

Life Cycle Assessment (LCA) seeks to identify the potential environmental impacts of a product over the course of its life cycle (ISO, 2006) by assessing all inputs from and outputs to the environmental from the so-called product system. However, environmental impacts may work as a 'feedback' mechanism and in turn have consequences for future product systems. In LCA the focus usually is on how human activities affect the environment, but it must be realized that (man-made) changes to the environment also have an effect on human activities. The burdens mankind has exerted and momentarily exerts on the environment will influence future product systems. The effects of climate change on agriculture can be considered as an example of this feedback on product systems.

As a first consequence of this feedback, increasing levels of atmospheric CO_2 concentrations (hereafter referred to as $[CO_2]$) are known to increase grain yields (Clausen et al., 2011), resulting in lower inputs per mass unit of harvested crop. In case of barley cultivation in Denmark, yields were estimated to increase up to 20% (Saxe, personal communication, 23 May 2013). As a second consequence, a predicted temperature increase, at least under Danish circumstances, has been shown to decrease grain yields as the grain filling time is reduced (Børgesen and Olesen, 2011). An illustration of the combination of these two effects for barley grown in Denmark was provided by Clausen et al. (2011), who compared grain yields under different environmental circumstances. Comparing grain yields under ambient and elevated (700 ppm) atmospheric $[CO_2]$, an increase of 7.6 g/plant to 12.0 g/plant (+56%) was observed. In contrast, barley grown under elevated (+5 °C) day and night temperatures showed a significantly lower yield (−27%)

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compared to barley grown under ambient temperatures. When barley was grown under both elevated atmospheric [CO_2] and temperature, the yield decreased 14% compared to barley grown under ambient conditions. A third example of the effect of climate change on agriculture is that changes in the rainfall patterns, for example caused by man-made climate change (Cook et al., 2013) are expected to result in alterations in the nutrient flows from arable land, as well as to force limitations in some regions to the use of water for irrigation (Jeppesen et al., 2011). As a fourth consequence, changes in temperature and rainfall patterns may change pest populations, leaving some regions unsuitable for certain pests already present in these regions undergoing climate change, whilst new species move in to fill this ecological niche (Gregory et al., 2009). Changes in the pest species prevailing in a certain region will inevitably influence the pest management needed to maintain yields. Therefore the type and amount of pesticides applied to the arable land will be affected by climatic changes.

Changes in atmospheric [CO_2], temperature, rainfall and pest prevalence, each alone or combined will change the environmental impacts of agricultural product systems. The question is to what extent. Even though LCA is a suitable methodology to answer that question, it has, to the best of our knowledge, rarely been applied to do so. Niero et al. (2015) studied the environmental impacts of Danish spring barley under changing climate circumstances. In contrast to these authors' approach, the assumptions for the future climatic circumstances on which this paper is based, are more moderate. We worked with an atmospheric [CO_2] of 530 ppm, and an average temperature increase of 2 °C, whereas Niero et al. (2015) assume a worst-case scenario of 700 ppm and a temperature increase of 5 °C. In addition, this study considers different soils and local climates.

This paper is thus a comparative case study of barley produced in Denmark under current and future climatic circumstances aiming at answering the following question: How do the environmental impacts of barley cultivation in Denmark change when going from the current (400 ppm) to a future (2050, 530 ppm CO_2) atmospheric [CO_2] with the accompanying changes in the climatic conditions?

2. Methods

Life Cycle Assessment (LCA) is a comprehensive methodology to assess the environmental impacts of a product, service, or system over its entire life cycle. As defined in ISO 14040 (ISO, 2006), LCA consists of 4 phases:

1. Goal & Scope definition, in which the product is described, and the assessment aim and method are defined;
2. Life Cycle Inventory (LCI), in which all flows between the product system and the environment are mapped and quantified,
3. Life Cycle Impact Assessment (LCIA), in which the flows quantified in the LCI are classified and characterized, and possibly normalized.
4. Interpretation, done parallel to the first three phases, in which these phases are critically reflected on, leading to changes in the goal and scope, LCI, or LCIA.

In this paper, the current section covers the goal and scope definition, as well as the LCI. The results of the LCIA are presented in Section 3 and discussed in Section 4.

Within LCA, two modelling approaches are generally recognized: attributional LCA (aLCA) and consequential LCA (cLCA). aLCA focuses on modelling all environmentally relevant flows of energy and materials to and from the life cycle of a product (i.e. barley), whilst the aim of cLCA is to model only those environmentally relevant flows that change as a consequence of a possible decision (Finnveden et al., 2009). aLCA was chosen as the assessment methodology. Since the primary focus of this paper is on how climate change affects the impacts of barley cultivation, and not on how the wider agricultural system changes as a consequence of changes in barley production, aLCA is the most appropriate methodology in this context.

2.1. Goals and scope

The functional unit used here to compare barley cultivation in Denmark under current and future atmospheric CO_2 concentrations ("atmospheric [CO_2]") is 1 kg of spring barley at farm gate (i.e. cradle-to-gate LCA).

The assessed product system includes all activities specifically required to produce barley: production of seeds, soil preparation (ploughing and harrowing), fertilizer and pesticide application, harvesting and drying of the harvested grains. The boundary between the product system and the environment was set as described in Dijkman et al. (2012): the field in which barley is cultivated is part of the product system, including 1 m of soil below and the air column above the field up to 100 m. Once a substance crosses this system border it is considered an emission to the environment.

Process multi-functionalities in the foreground system are resolved using economic allocation. We deviate from the ISO 14040 standard (ISO, 2006) recommendation of system expansion and substitution, because an important by-product of barley production, straw, has different uses, for some of which a substitute is not easily found. Moreover, relying on allocation instead allows for a straightforward sensitivity check of the product system model. There are good arguments to be made both in favour of and against economic allocation (Ardente and Cellura, 2012). Here, it is used for two reasons. Firstly, economic data is available for all co-products to be allocated (barley and straw, pig meat and manure, and various feed crops and meals for pig production), allowing for allocation to be done consistently throughout the study. Secondly, allocating on the basis of properties such as mass and energy content do, in our opinion not reflect the motivation for production of one or more of the co-products to be allocated. Another option for allocation of agricultural products, the Cereal Unit (Brankatschk and Finkbeiner, 2014), could not be applied for all co-products and was therefore excluded.

The product system was modelled in GaBi 4.4.142.1 (PE-LBP, 2008) using the ecoinvent 2.2 database (Ecoinvent Centre, 2007).

2.2. Scenarios

Two scenarios were defined: a 2010 scenario representing current climatic conditions and a scenario with climatic circumstances as they are projected for Denmark by 2050. These scenarios will be referred to as the 2010 and 2050 scenarios.

In the 2010 climate scenario, the average annual temperature is 10.3 °C, with monthly averages between 2.4 °C and 19.1 °C. Annual precipitation is 660–950 mm, depending on the scenario (see Table 1), with June, July and August being the months with most rainfall. In the 2050 scenario it was assumed that the atmospheric [CO_2] has increased from ~400 ppm in 2010 to ~530 ppm in 2050. This is in line with the IPCC A1B scenario (IPCC, 2007), based on economic and cultural globalization, rapid economic growth and a population size which peaks in the middle of the 21st century and decreases hereafter. In the A1B scenario, the focus is on rapid introduction of new technologies. Energy provision in these scenarios is based on a combination of fossil, non-fossil and renewable

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