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Life cycle assessment of five vegetable oils

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ABSTRACT

The purpose of this study is to evaluate and compare the environmental performance of five different vegetable oils, including the relevant market responses induced by the oils' by-products. The oils under study are palm oil, soybean oil, rapeseed oil, sunflower oil and peanut oil. These oils are to a large extent substitutable and they are among the largest oils in terms of global production. Besides evaluating the environmental performance of each oil individually, the effect of reducing each one of the oils and replacing it with a mix of the others is also evaluated. The life cycle inventory is carried out using a consequential approach, which implies that co-product allocation is avoided by use of substitution, and that marginal market mixes are generally applied. The environmental performance is evaluated by focussing on global warming, land use and water consumption. With respect to global warming, rapeseed oil and sunflower oil are the best performing, followed by soybean oil and palm oil, and with peanut oil as the least good performing. For land use, palm oil and soybean oil are the oils associated with the smallest contribution, followed by rapeseed oil, and with sunflower oil and peanut oil as the oils with the largest net occupation of land. When focussing on water consumption (using the water stress index), sunflower oil had the smallest impact, followed by rapeseed oil, palm oil and soybean oil, and with peanut oil as the oil with the largest contribution.

1. Introduction

The aim of this study is to generate life cycle assessment (LCA) results on a number of the major vegetable oils, and to generate evidence to inform consumers, industry and policy-makers of the potential environmental consequences of replacing any particular vegetable oil at the expense of another. The latter includes considerations of the market responses of taking out different vegetable oils from the market.

The study compares the environmental impacts of palm oil, soybean oil, rapeseed oil, sunflower oil and peanut oil. These five oils are among the six largest oils in the world in terms of global production volume, which is illustrated in Fig. 1. Palm kernel oil is produced in larger volumes than peanut oil, but since this oil is a joint co-product of palm oil, it is not considered separately. The considered vegetable oils are fully or partly substitutable for a large number of applications (Gunstone, 2011; Clay, 2004; In and Inder, 1997). The study only considered comparisons of the oils within the general market for unspecified vegetable oils, and hence the findings are not applicable for special applications where the oils are not substitutable.

Different vegetable oils systems are associated with different quantities of co-products, mainly oil meals which are used as animal feed. When studying market responses related to changes in demand for the different oils and when substituting different oils, it is a challenge to address the interactions among oils and with the feed markets. The studied product systems are identified using a systems perspective where likely market responses and substitution effects are considered. To achieve this, consequential modelling in life cycle inventory is used (Ekvall and Weidema, 2004; Weidema et al., 2009).

Previous research on comparative life cycle information on vegetable oils is relatively limited. Examples are Arvidssona et al. (2013) and Schmidt (2010). A larger number of studies exist within the field of biodiesel (e.g. Menichetti and Otto, 2009) which however are most often limited to focus only on GHG emissions compared to mineral diesel, and almost all of them use attributional modelling (Mentena et al., 2013) which is not relevant for the purpose of the current study.

2. Material and methods

The study generally follows the provisions set out in ISO 14040 and 14044 (ISO, 2006a,b).

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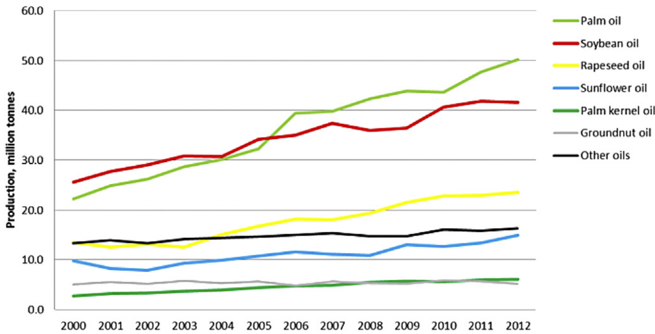

Fig. 1. The world's production of vegetable oils (FAOSTAT, 2013a).

2.1. Goal and scope and functional units

The purpose of the study is twofold:

1. to obtain environmental information on different major substitutable vegetable oils, and
2. to assess the market responses and environmental consequences of removing different vegetable oils from markets, and replacing with a defined average mix of other oils.

For both purposes, the study was intended for decision support in situations where oils replace each other or the used quantity of oils is changed. The study only applies to small scale changes in demand for the oils, i.e. changes in demand that will not change the overall market trends of the oils. This corresponds to decision context A as defined in the ILCD Handbook (JRC, 2010). The study presents the results of two different analyses, see Table 1. The second purpose intends to provide decision support in situations where industry/retail NGOs or governments consider to reduce (or locally eliminate) the use of a specific vegetable oil, where the reduction will be compensated by an average mix of other vegetable oils. It should be stressed that this average does not necessary represent actual responses to an isolated decision to reduce a specific oil, and that the results of this analysis is only for illustrative purposes. The results from the first analysis (see Table 1) can be used to calculate the effect of any other mix of compensating oils.

For both purposes of the study, the functional unit is defined as one tonne of edible fats and oils as defined in CODEX STAN 19-1981 (2013). For the included oils, the reference flow was one tonne refined (Neutralised, Bleached and Deodorised; NBD) vegetable oil at refinery gate. The reference flows for the two analyses of the study are described in Table 1. The reason for using refined oil and not crude oil for the functional unit is that the different crude oils contain different levels of impurities and free fatty acids that are removed in the refinery stage. Hence, the crude oils are not substitutable in a one to one ratio.

2.2. Consequential modelling

Generally there are two different approaches to modelling in life cycle inventory: consequential modelling and attributional modelling. According to Sonnemann and Vigon (2011, p 132), attributional modelling is defined as: "*System modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule.*" Often attributional modelling is carried out by assuming that the products are produced using existing production capacity (current or historical market average), and multiple-output activities are dealt with by applying allocation factors based on economic value (and other allocation principles). Consequential modelling is defined as a: "*System modelling approach in which activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit.*" (Sonnemann and Vigon, 2011, p 133). Hence, in consequential modelling it is generally a change in demand for the product under study that is modelled. A cause-effect relationship between a change in demand and the related changes in supply is intended to be established. This implies that the product is produced by additional capacity, when the market trend is increasing. This additional production capacity must be from unconstrained technologies. Co-products are always dealt with using substitution, which is also the preferred approach in ISO 14044. The consequential modelling principles are comprehensively described in Ekvall and Weidema (2004) and Weidema et al. (2009). The consequential approach was consistently applied throughout the study. The attributional approach would fail to comply with the purpose of the study which focuses on predicting the environmental impacts of choosing different oils.

The production of refined vegetable oils is characterised by several by-products where the major ones are the protein-rich meals from the oil mills and free fatty acids (FFA) from the refining process. Both the protein meals and the FFA are used as animal feed. Schmidt and Weidema (2008) identify two major segments of the global generic animal feed market; namely feed protein and feed energy. Therefore a change in supply of oil meals and FFA will substitute these two products in proportion with their protein and energy content. Since the attributional approach only estimate/approximate the effects from downstream processing of by-products and product substitutions by applying an allocation factor on the upstream effects, this approach does not reflect actual cause-effect mechanisms in the market. The technique for performing the substitution calculations for vegetable oil systems is demonstrated in several studies, e.g. Dalgaard et al. (2008), Schmidt and Weidema (2008), Schmidt et al. (2009), Schmidt (2010), and it is also implemented in ecoinvent v3 (ecoinvent Centre, 2013).

Table 1
Analyses and reference flows.

Analysis	Description of the outcome of the analyses	Reference flows
1	Results per tonne of each of the included vegetable oils.	1 tonne NBD oil.
2	Results per tonne of each of the oils reduced and compensated by a market mix of oils.	Reduction of 1 tonne specific NBD oil and compensation by 1 tonne NBD oil from relevant market mix.

2.3. System boundaries

The inventories are established to represent the most recent point in time for which data were available. The decisive data in this respect the FAOSTAT data on crop yields which were available for 2011. The production functions for oil mill and refinery operations are regarded as being relatively constant over time, so data for 2005–2010 are used to represent 2011.

With two exceptions, the study follows the same cut-off practises as the ecoinvent v3 database (ecoinvent Centre, 2013). This implies that inputs of services (such as cleaning, accounting, lawyers, marketing, business travelling), research and developing (laboratories, equipment, offices etc.), and overhead (overhead energy, office equipment etc.) are not included. The two exceptions representing differences from ecoinvent v3 are the use of