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Accounting for co-products in energy use, greenhouse gas emission savings and land use of biodiesel production from vegetable oils

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ABSTRACT

Accounting for co-products of vegetable oil production is essential in reviewing the sustainability of biodiesel production, especially since oil crops produce valuable protein-rich co-products in different quantities and qualities. Two accounting methods, allocation on the basis of energy content and system expansion, are compared. Significant differences in results exist between the methods where system expansion is to be preferred because it can take actual use of co-products into account. Results are very sensitive to the choices made in system expansion. Differences can be large, especially between a system expansion where primarily the use of co-products of the oil crops is taken into account and an expansion that also includes direct oil exchange of the vegetable oil used for biodiesel for the marginal oil in the market.

1. Introduction

With the purpose of reducing greenhouse gas (GHG) emission and to ensure a more sustainable energy supply, the EC established targets for the production of renewable energy in the EU for the year 2020 of 20% of the total energy use and 10% of the energy use in the transport sector (EC, 2009). Currently, renewable energy use in the transport sector relies largely on biofuels produced from agricultural crops, a production of which the sustainability is heavily debated. The EC Renewable Energy Directive (RED, EC, 2009) gives criteria for the minimum required GHG emission reduction of biofuels in order to be considered as renewable energy and complying with the target of renewable energy production. A realistic calculation of the GHG emission reduction requires that the production of co-products used for other purposes than energy production is taken into account. The RED (EC, 2009) prescribes allocation on the basis of energy content as accounting method for co-products in the reporting of the Member States on the performance of biofuel production regarding greenhouse gas (GHG) emission reduction. Allocation is a simple technique of dividing, e.g., environmental burdening or costs over main product and co-products. This division is performed in a ratio based on the ratios of mass, energy content or economic value of the different products. Use of this method does not comply with the principles of Life Cycle Assessment (LCA). LCA is an established technique, described in ISO 14040 and 14044 (ECS, 2006a,b), in which the division of environmental burdening takes the real use of co-products into account as much as possible. For this division, LCA prescribes the use of system expansion (substitution method) whenever possible. In system expansion, the products that can be replaced by the co-products of the process described are included in the system, and thus in the LCA analysis. This is acknowledged in the RED, where article 23–4 reads: "*In reporting on greenhouse gas emission saving from the use of biofuels, the Commission shall use the values reported by Member States and shall evaluate whether and how the estimate would change if co-products were accounted for using the substitution approach*". Nevertheless, allocation, being easier to apply, received much more attention in accounting for co-products than system expansion, possibly stimulated by the idea that both methods produce results that are generally comparable (EC, 2009). However, appreciable differences in GHG emission reduction between the methods have been reported, in favor of both allocation and system expansion (Hoefnagels et al., 2010; Wang et al., 2011) and although system expansion for agricultural production can easily lead to complex system descriptions, it is in principle always possible to use system expansion (Weidema, 2001). In this paper we present both system expansion as well as allocation. Moreover, we include energy use and land use as important sustainability

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issues in our analysis. Energy use is important since it determines the efficiency of the biodiesel produced and land use is an important issue because productive arable land is scarce worldwide and oil crops for biodiesel do compete with crops for food production.

Global production of biodiesel from vegetable oil is almost completely based on three oil crops: oil palm, soybean, and rapeseed. In Europe vegetable oil from these three crops makes up over 95% of biodiesel production (Conijn et al., 2009). All three crops have a protein-rich meal as co-product but in very different quantities and qualities. Hence, an increase in biodiesel production from vegetable oil will increase total vegetable oil production, in turn resulting in an increased meal production of which the quantity and quality depends on the oil crop involved. However, in a study focusing on the effects of biodiesel production all other activities are supposed to be left unchanged and the increase in meal production has to be compensated for by a decreased production of other protein-rich feed components. The most logical choice is replacement of a marginal product, i.e., a product that is supposed to function as buffer in the market and the production of which responds strongly to a change in demand. This will involve one of the major oil crops, soybean, since this is an oil crop as well as a protein crop and is in fact currently regarded as the world's marginal protein source (Schmidt and Weidema, 2008). A decrease in soybean production will result in a decrease in (soy) oil production which will be compensated for by an increased production of another oil crop, most likely oil palm, since palm oil is currently regarded as the marginal vegetable oil (Schmidt and Weidema, 2008). This again results in increased meal production and – in the end – establishment of a new equilibrium between oil crops in which more oil production goes together with the production of an amount of feed ingredients from which a comparable amount and quality of feed can be produced as before. However, the three oil crop meals differ in protein content and digestibility and can therefore not simply substitute each other (Lywood et al., 2009). A qualitative equivalent replacement is only possible when a combination is made with an energy-rich feed ingredient like wheat (Lywood et al., 2009) or barley (Dalgaard et al., 2008).

Another difference between the RED prescriptions and the substitution method regarding biodiesel production is found in the accounting for glycerine, a co-product of the hydrolysis of vegetable oil. According to the RED no allocation to glycerine should be made because of its current low value. In system expansion all co-products should be taken into account, and when no current product can be replaced waste disposal is eventually part of its life cycle.

A problem in the use of vegetable oil not addressed in system expansion is the exchangeability of the different vegetable oils: system expansion only accounts for the use of co-products. However, since different vegetable oils are equally suitable for major applications (e.g., cooking) an increased demand for one oil could be compensated for by an increased production of another. This means that the use of rapeseed or soy oil for biodiesel production could be expected to cause an increase of the use of palm oil, currently the world's marginal vegetable oil, for other purposes.

The two methods of accounting for co-products for the production of biodiesel from palm oil, soy oil and rapeseed oil for the impact categories GHG emission, energy use and land use will be quantitatively compared in this paper. A variant of system expansion, where the vegetable oil used for biodiesel production can be directly replaced by an increased production of the marginal vegetable oil, will be used as well. In the calculations primarily palm oil is assumed to be the marginal vegetable oil; results of an alternative calculation with rapeseed oil as marginal vegetable oil are also presented.

Table 1
Outputs of crop production systems relevant for biodiesel production in the EU (from: BioGrace (2011) and Corré and Conijn (2015)).

Product output in kg ha^{-1}	Oil palm	Soybean	Rapeseed	Wheat[a]
Yield seeds	–	2800	3550[b]	7200[b]
Fresh fruit bunches	19,000[c]	–	–	–
Moisture content	34%	15%	10%	13%
Yield (dry matter)	12,540	2380	3195	6264
Oil content in dry matter	34.4%	22%	45.5%	–
Crude vegetable oil	4314	524	1454	–
Biodiesel	4008	487	1351	–
Glycerine (pure)	401	49	135	–
Meal content in dry matter	3.75%	78%	54.5%	–
Meal (dry matter)	470	1860	1740	–
Moisture content in meal	18%	18.3%	17%	–
Crude protein content in meal (dry matter)	16.5%	48%	34%	–

[a] Wheat is selected as feed compound to be replaced by oil crop meals.
[b] Values refer to varieties of both crops sown in late autumn.
[c] Average yield level over the life cycle of oil palms.

2. Materials and methods

2.1. Crop production systems

The analysis is based on representative production systems, relevant to biodiesel production in Europe, which reached just over 10 Mt in 2013 (EBB, 2015). Palm oil is produced in South-East Asia, soybean in Brazil, and rapeseed and wheat in Western Europe. Yield levels and associated (co-) products are presented in Table 1. All products are transported to and processed in the Netherlands.

Palm oil is produced in perennial plantations. Annual production reaches its maximum five years after planting and a life cycle of approximately 25 years provides optimal total production. Fresh fruit bunches of oil palm are harvested and transported to a palm oil mill where the fruits are separated from the bunches. The empty fruit bunches are composted and recycled to the oil palm fields. The fruits are separated from the kernels and oil is extracted from both fruits and kernels. The remainders of the fruits are separated into a solid (fibers) and a liquid (palm oil mill effluent, POME) fraction. The solid fraction is, together with the kernel shells, used for energy supply to the palm oil mill, which is supposed to follow best practices and to use no external energy (BioGrace, 2011). POME is treated as waste water avoiding methane emission. The meal of the kernels (Palm Kernel Expeller, PKE) is used in animal feed. The crude oil, mostly fruit oil and kernel oil mixed, is transported to a harbor, refined, and shipped.

Soybean is an annual crop, in Brazil partly grown in a double cropping system with maize in winter and soybean in summer and partly grown in a single cropping system. Since only a minor proportion of the soybeans in Brazil is grown in a double cropping system (Babcock and Carriquiry, 2010) and information on the effects of other crops in system expansion is lacking, this complication in land use is not included in the analysis; this means that the results in this paper are limited to soybean grown in a single cropping system. After harvest soybeans are transported to a harbor and mostly shipped as whole beans. Oil is extracted and refined in importing countries and the remaining meal is used in animal feed.

Rapeseed and wheat are annual crops, in Europe grown in rotation with other arable crops in single cropping systems. After harvest, rapeseed is transported to a processing plant where the oil is extracted and refined; the remaining meal is used in animal feed. After harvest wheat is transported to locations where it is processed into animal feed. Yield levels (Table 1) of rapeseed and wheat were calculated as the average data for production in the period 2007–2009 in Germany and France, the main West European rapeseed- and wheat-producing countries (Eurostat, 2015).