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# Do greenhouse gas emission calculations from energy crop cultivation reflect actual agricultural management practices? – A review of carbon footprint calculators

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ABSTRACT

A wide range of calculators have been developed to assess the greenhouse gas (GHG) emissions of agricultural products, including biomass for bioenergy production. However, these calculators often fail in their ability to take into account the differences in pedoclimatic conditions, agricultural management practices and characteristics of perennial crops and crop rotations. As a result, the predictions of GHG emissions by these calculators are characterized by a high level of uncertainty, and calculators may fail in their ability to detect mitigation options along the production chain. The aim of this study was to analyze the available calculators for calculating GHG emissions from energy crop cultivation based on Carbon Footprint (CFP) approaches according to the goal and scope of the calculator, the methodology used to account for GHG emissions from energy crop cultivation, energy crop cultivation management practices and the ability to model crop rotation. Out of 44 environmental assessment calculators for agricultural products, we identified 18 calculators which are capable of assessing GHG emissions from energy crop cultivation. These calculators differ in their goal and scope and which farming operations related to crop management are taken into account; this makes it difficult to compare and interpret the results from these CFP assessments. Only seven calculators out of 18 can calculate GHG emissions from energy crop rotations. At the moment, none of these calculators are able to consider actual effects from energy crops in rotation in the context of nutrient shifts, reductions in the use of agricultural operating needs, or the sequence and composition of crop rotations. However, by expanding the system boundaries of the CFP study, by taking the whole energy crop rotation and local agricultural management practices into account, the opportunity to identify more GHG mitigation options increases.


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## 1. Introduction

Human influence on climate change was again confirmed by the latest report from the Intergovernmental Panel on Climate Change (IPCC) [1]. Anthropogenic greenhouse gas (GHG) emissions from fossil fuel combustion and industrial processes contributed about 78% to the total increase of GHGs in the atmosphere over the last 40 years [1]. Furthermore, the Agriculture, Forestry and Other Land Use sector (AFOLU) accounted for about a quarter of anthropogenic GHG emissions [1]. In response to this, a growing number of governments have begun introducing renewable energy policies in an effort to reduce GHG emissions by replacing non-renewable fossil fuels with renewable energy sources. The European Commission has committed itself to increase the proportion of renewable energy to 20% of the overall share of the energy consumption and to 10% of transportation-related energy consumption by 2020 [2]. In 2008, 12.9% of the total global primary energy supply had already originated from renewable energy sources, of which bioenergy contributed the dominant share (80%) [3]. This implies that the production and use of biomass to generate power, heat and fuel has significantly increased in recent years [4].

Biomass for the supply of energy is traditionally obtained from fuelwood. However, in the last decade, the use of crop residues and dedicated energy crops delivering the demanded biomass increased. Energy crops are agricultural crops solely cultivated for energy-related use. Several food crops (e.g. maize or sugar beet) can also be grown as energy crops if they have high yields and, preferably, a low demand for agrochemical inputs [5].

Energy generation from energy crops has an almost-closed $CO_2$ cycle (in which the combustion of biomass releases the same amount of $CO_2$ as was captured by the crop during growth). However, it is not carbon neutral over its whole production chain, since GHG emission occurs during the production stage, e.g. through production of fertilizer, pesticides, farming machinery or fuel combustion from machinery used [5]. Agricultural management practices have a considerable effect on the amount of GHG emissions from energy crop production and, correspondingly, on the entire biomass energy production chain [6]. Consequently, agriculture, including energy crop cultivation, holds significant potential for reducing GHG emissions [7].

However, appropriate assessment tools are required to identify the GHG emission benefit of bioenergy compared to its fossil alternatives. The most widely used approach is the Life Cycle Assessment (LCA) defined by ISO Standards 14040 [8] and 14044 [9,10].

LCA is defined as a method for compiling and evaluating all inputs, outputs and the potential environmental impact of a production system throughout its life cycle. It enables the user to measure and quantify the environmental impacts of a product. Furthermore, it helps to identify hot spots where the most significant impacts occur, giving the user the opportunity to develop strategies for improving the product's environmental performance [8].

In addition to the LCA guidelines, the Carbon Footprint (CFP) defined by ISO Standard 14067 [11] provides requirements and guidelines for the quantification and communication of GHG emissions in a production chain. The CFP is a specific method within the LCA approach and summarizes all GHG emissions and removals occurring within the established product system boundaries, expressed as $CO_2$ equivalents. There are a considerable number of tools working with the CFP approach for calculating the GHG emissions from agricultural products [12,13]. An overview of currently available tools for quantifying GHG emissions at landscape scale from AFOLU was provided by Denef et al. [13]. They divided those tools into three categories: (1) calculators, (2) protocols and guidelines, and (3) process-based models. Based on these results a review of these tools was conducted by Colomb et al. [14,12] to evaluate the methodological differences between these tools, to promote transparency and to provide guidance for the user to choose the most appropriate tool. As distinct from Colomb et al. [14], our review focuses only on calculators, including web-based and software-based calculation tools, which are able to quantify GHG emissions from energy crop cultivation at farm scale. For this subset we provide an extended analysis of the complex crop cultivation system, including an evaluation of the calculators for their ability to take energy crop production specific characteristics, crop rotation effects and farm specific management practices into account.

CFP calculators are used by farmers, agricultural suppliers and scientists to identify the potential for GHG mitigation in their local agricultural production chains [15]. In order to be able to detect these GHG emission mitigation potentials, however, calculators should account for local agricultural management practices on the farm and especially for energy crop specifications by taking into account differences in pedoclimatic conditions, farming practices, farming technologies [16], the characteristics of perennial crops [17], and crop rotations (sequence and composition of crops) [18]. Diversification of crop rotation patterns is one option for GHG emission reduction in cropping systems [19], but CFP studies from crop cultivation typically only take into account one vegetation period of one single crop [18]. Accordingly, as agriculture systems are highly complex, not all underlying material flows can be quantified when the assessment is limited to such a short time period. As result, calculation systems leave out crop rotation effects, including all interactions between the previous crop and the assessed crop, such as nutrient shifts, reduction in the use of agricultural operating needs, different intensity and the timing of farming activities [18]. Furthermore, CFP studies frequently fail to adequately consider the specifics of energy crop cultivation, such as differences in the timing of sowing and harvesting dates, the allocation of byproducts (e.g. the production of digestate and its reuse as fertilizer), and cultivation management (e.g. increased fuel use for the whole plant harvest, tillage frequency, and