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Different palm oil production systems for energy purposes and their greenhouse gas implications

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ABSTRACT

This study analyses the greenhouse gas (GHG) emissions of crude palm oil (CPO) and palm fatty acid distillate (PFAD) production in northern Borneo (Malaysia), their transport to the Netherlands and their co-firing with natural gas for electricity production. In the case of CPO, conversion to biodiesel and the associated GHG emissions are also studied. This study follows the methodology suggested by the Dutch Commission on Sustainable Biomass (*Cramer Commission*). The results demonstrate that land use change is the most decisive factor in overall GHG emissions and that palm oil energy chains based on land that was previously natural rainforest or peatland have such large emissions that they cannot meet the 50–70% GHG emission reduction target set by the *Cramer Commission*. However, if CPO production takes place on degraded land, management of CPO production is improved, or if the by-product PFAD is used for electricity production, the emission reduction criteria can be met, and palm-oil-based electricity can be considered sustainable from a GHG emission point of view. Even though the biodiesel base case on logged-over forest meets the *Cramer Commission*'s emission reduction target for biofuels of 30%, other cases, such as oil palm plantations on degraded land and improved management, can achieve emissions reductions of more than 150%, turning oil palm plantations into carbon sinks. In order for bioenergy to be sustainably produced from palm oil and its derivatives, degraded land should be used for palm oil production and management should be improved.

1. Introduction

Over the past decade, many industrialised countries have sharply increased the amount of biomass they import. This is primarily due to the fact that such countries introduced policies to stimulate renewable energy use and that imported biomass is often more cost-efficient than domestic biomass. Increasing global trade and consumption of bioenergy has been accompanied by a growing concern about the environmental, ecological, and social impacts of bioenergy production. This concern has been spurred by reports about bioenergy crop production causing deforestation and the associated loss of biodiversity, greenhouse gas (GHG) emissions, displacement of forest people and related land conflicts, to name just a few. Southeast Asian palm oil, in particular, has been associated with major problems such as clear-cutting of natural rainforest, destruction of ecologically valuable peatland and instigation of social conflicts, and its sustainability has been intensely debated in many countries [1–4]. As a result of these unintended and undesired effects of bioenergy production, various initiatives have attempted to develop sustainability criteria in order to ensure sustainable bioenergy trade [5–9]. In Europe, such efforts began in Belgium where an energy company developed its own

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certification system that is widely accepted by Belgian authorities [5,6]; in the UK where, as part of the renewable transport fuel obligation, reporting guidelines on carbon and sustainability are being developed [7]; and in the Netherlands where the so-called *Cramer Commission* on sustainable production of biomass has recently finished its work [8]. The European Commission is also working on legislation to guarantee the sustainable production of biomass [9].

In all of these initiatives, the GHG balance is an important sustainability criterion because the presumed GHG emission savings compared to fossil energy are a key driver of increasing bioenergy consumption. However, it cannot simply be assumed that bioenergy results in GHG emission savings since both the land use change (LUC) associated with biomass production and inputs needed for such LUC like fossil fuels for machinery, fertiliser, and pesticides can generate GHG emissions [10,11]. LUC in particular has been found to strongly affect the GHG balance either by emissions from, for example, the net loss of standing biomass when natural rainforest is converted to other uses, or by sequestration of carbon from, for example, a net increase of soil carbon when degraded land is converted to bioenergy production [11–14].

Although methods for calculating GHG balances have been developed for the Belgian, British, and Dutch initiatives [5,15,16], several aspects of implementation and verification of this sustainability criterion remain debatable. Such unsettled aspects include the method of allocating emissions to by-products, the allocation period over which LUC emissions should be amortised and the choice of the fossil electricity reference system. Moreover, these methodologies have not yet been tested on specific production cases. Therefore, the main objectives of this study are (1) to analyse the GHG balance of specific palm-oil-based energy chains and (2) to study the effects on the GHG balance of the three abovementioned unresolved methodological issues, as well as the effects of different reference land use systems and of different management options. In order to do so, the following chains are considered:

(1) *CPO electricity chain*: production of crude palm oil (CPO) in northern Borneo, Malaysia, transport to the Netherlands and co-firing at a natural gas power plant in the Netherlands;
(2) *PFAD electricity chain*: production of the palm oil derivative palm fatty acid distillate (PFAD) in northern Borneo, Malaysia, transport to the Netherlands and co-firing with natural gas for electricity production in the Netherlands; and
(3) *Biodiesel chain*: using the CPO for the production of biodiesel in Malaysia and transporting the biodiesel to the Netherlands for use in vehicles [17].

The GHG emission calculations are based on the methodology developed by the *Cramer Commission* since, in order for the analysed chains to be considered sustainable, they will have to meet the *Commission*'s criteria.

The remainder of the study is organised as follows: The methodology applied for calculating the GHG emission reductions of bioenergy compared to fossil reference systems is described (Section 2), and the data input is presented (Section 3). Then, the results of the GHG analysis of the three chains, of their various cases and of the effects of the methodological choices are presented in Section 4, followed by a discussion of the results and the methodological choices (Section 5). Section 6 presents the study's final conclusions.

2. Methodology

This study determines the GHG emissions from CPO and PFAD-based electricity and CPO-based biodiesel production according to the Dutch *Cramer Commission* methodology for GHG calculations [16], which is based on a life cycle inventory and accounts for all GHG emissions that arise between initial land use conversion through final use of the palm-oil-based energy.

The three most important GHGs, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), are included. For comparing the emissions of these three gases, the concept of global warming potential (GWP) is applied following the guidelines of IPCC, allowing for a comparison of the radiative forcing of the different gases [18]. The other main GHGs (hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride) are not taken into account as they are insignificant in the bioenergy production chains.

The GHG emissions of by-products, which are used outside the system boundaries, are calculated on the basis of system extension. This approach assumes that the by-product generated can replace the same or a similar product that was produced from another feedstock. Due to this replacement, an emission credit for the avoided GHG emission from the original production of the product can be assigned.

The percentage of GHG emission reduction is calculated by dividing the difference in GHG emissions from the fossil and bioenergy chain by the emissions of the fossil reference system. The reduction percentage is measured against the standards set by the Cramer Commission, which requires an emission reduction of 50–70% for bioelectricity and 30% biodiesel in order for these to be considered sustainable [8]. A negative percentage of emission reduction refers to a bioenergy system that has larger emissions than the fossil energy system. A positive percentage of emission reduction refers to a bioenergy system that reduces GHG emissions compared to the fossil reference system. A percentage of emission reduction of more than 100% refers to a bioenergy system that sequesters more CO_2 than is emitted in terms of CO_2 equivalent throughout the production chain. The functional units are defined as production of 1 kWh of electricity for the electricity chains and 1 MJ fuel for biodiesel.

In addition to the percentage of GHG emission reduction, the emissions from palm oil energy chains are also expressed in terms of carbon payback time. This is the period of time that the bioenergy feedstock needs to be grown before the LUC emissions have been offset [19]. The carbon payback period is determined by dividing the net carbon loss from LUC per hectare by the amount of carbon saved per hectare and per year by the use of bioenergy (excluding LUC emissions).

For this study, case-specific data from a field visit of two plantations, two mills and one refinery in the Sandakan