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Carbon footprint of renewable diesel from palm oil, jatropha oil and rapeseed oil

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A B S T R A C T

This paper examines the carbon footprint of renewable diesel (RD) production from palm oil, jatropha oil and rapeseed oil. Greenhouse gas (GHG) emissions from land use change (LUC), feedstock cultivation processes, and RD production and delivery are studied from a life-cycle assessment perspective. The goal of the paper is to calculate the carbon footprint of RD and recommend ways of decreasing it. Our findings indicate that the key contributors to the carbon footprint of RD are found in the GHG emissions of LUC, feedstock cultivation and oil extraction processes. In the case of palm oil, methane collection from palm oil mill effluent (POME) is one of the main contributors to the carbon footprint. Our calculations demonstrate that the RD production and distribution stages generate relatively low GHG emissions compared to the other life-cycle stages; therefore, attention should be focused on the contributing role of LUC and cultivation processes to the RD carbon footprint. If cultivation requires a land use conversion from forest to cultivated land, the resultant GHG emissions exceed emission levels from fossil fuels. If feedstock cultivation is done with no LUC or if grasslands are the feedstock cultivation site, then cultivation GHG emission reductions are achieved. In some cases, RD production may even act as a sink for GHGs. Due to its quality RD can be used without blend-wall limitations in vehicles; therefore, it offers a higher biofuel potential for the diesel sector than does traditional biodiesel. The article concludes by discussing the implications of the findings for RD in light of GHG emission reductions.

1. Introduction

The intensification of global warming due to greenhouse gas (GHG) emissions has led to a wider use of renewable energy. Approximately 15% of global GHG emissions are released from the transportation sector, and the sector's share of emissions is only expected to grow during the decades to come [1]. To reduce sector GHG emissions, a rapid introduction and utilization of biofuels is needed. According to the biofuel use targets of the European Union, by 2020, 10% of fuels in the transportation sector should be biofuels, and the target for this portion of biofuels will be even higher in the future [2]. Almost half of the new cars sold in the EU use diesel fuel [3]. Vehicles equipped with a diesel engine can use either biodiesel (rapeseed methyl ester (RME), fatty-acid methyl ester (FAME), etc.) or renewable diesel (RD) to replace fossil diesel; consumption of these diesel products is thus expected to grow [4]. RD differs from first generation biofuels and can be used without blend-wall limitations [5]. Blend-wall for biodiesel (FAME) is approximately 5–7% [5]. RD is a pure paraffinic diesel fuel produced by hydrotreatment (hydrotreated vegetable oil (HVO)), whereas biodiesel is produced by transesterification. The GHG emissions from RD production are expected to be lower than emissions from biodiesel production due to the more effective production methods used in RD production [6].

RD may be produced from different kinds of oils. Currently the main feedstock sources are vegetable oils and animal fats. When animal fats or other renewable waste oils can be used, feedstock cultivation and LUC-related problems are avoidable. However, to produce RD on a wide scale, cultivated vegetable-based oils are likely also needed. Some studies show that algae-based oils do have potential as a feedstock source, but thus far they have not been produced on a wide scale; furthermore, the production of algae-based oil is highly GHG intensive, but depends on actual case [7,8].

A considerable amount of studies related to biodiesel production by transesterification have been carried out. Biodiesel studies have identified several principal hotspots affecting GHG emissions

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during the life cycle of RD production. When crude palm oil is used as a raw material source of biodiesel, Wicke et al. (2008) found that biogas collection from palm oil mill effluent (POME) and energy utilization of side products exert a strong positive effect on the GHG balance. They also estimated that biogas and harvested biomasses possess good potential for being sources of bioenergy and should be utilized in order to achieve the best-case scenario [9]. One important factor from an environmental point of view is the use of artificial fertilizers in oil palm cultivation [10]. According to Reinhard and Zah (2009) and Wicke et al. (2008), the most important environmental factor for palm oil (*Elaeis guineensis*) is the land area affected by the increased cultivation of oil palms [11,9]. Currently, the expansion of oil palm cultivation areas is taking place on logged-over forest and on former rubber and coconut plantations, while also rainforests and peatlands have been converted for oil palm-plantation purposes [9,12,13]. Conversion of rainforests and peatlands causes GHG emissions which are higher than the emissions from our fossil fuel reference; i.e., fossil diesel [13]. On the other hand, if production is redirected to degraded lands and production management is improved, this will result in GHG emission reductions or will even turn oil palm plantations into sinks [9].

In contrast to biodiesel, little research into RD production related GHG emissions has been conducted. Huo et al. (2009) have compared biodiesel and RD production from a life-cycle assessment perspective [6]. According to their study, GHG emission reductions are higher with RD, but the differences are relatively small. In the case of soy oil-based diesel, the GHG reductions may exceed 57% compared to fossil fuels. According to Pleanjai et al. (2007), electricity consumption is much higher in transesterification than in hydrotreatment [14]. Knowledge concerning carbon footprint differences between the various RD feedstocks is still lacking, which raised two questions for us: Could rapeseed (*Brassica rapa*) provide a feedstock that could compete with palm oil? And could jatropha (*Jatropha curcas*) provide a potential feedstock exerting a low impact on land use?

We have conducted this study to fill in some of the gaps in our knowledge concerning the applicability of RD. The main goal of this paper is to answer the following questions: What is the carbon footprint of RD produced from palm oil, jatropha oil or rapeseed oil? What are the key factors affecting these carbon footprints, and how should the RD production chain be developed to gain the highest GHG emission reductions? Is it realistic to expect GHG reductions in wide-scale RD production?

2. Materials and methods

2.1. Basic assumptions

Production of both biodiesel and RD production is estimated to increase rapidly over the years to come, and vegetable oils are predicted to play the most important role in the total growth of alternative diesel fuels [15]. Rapeseed, soy and palm oil are currently most widely used in biodiesel production [16], but another potential vegetable oil suggested as a feedstock is jatropha oil. Therefore, in this study, only vegetable oils (palm oil, rapeseed oil and jatropha oil) have been chosen as feedstock sources for RD production. Soy oil is not studied because it has been already done by Huo et al. (2009).

Oil palms are cultivated in tropical zones (see Fig. 1). Jatropha can be cultivated on non-agricultural and marginal lands not suitable for food production [17]. (However, there is a risk that jatropha will not produce enough seeds on poor land [18].) Rapeseed is mainly grown in more temperate climates (Fig. 1).

For purposes of estimating the average transportation distances for the biomass sources, palm oil was assumed to be cultivated in Malaysia, Central Africa or Brazil; jatropha in Central Africa or Brazil; and rapeseed in Europe or the U.S.A.

In our research, we compared RD production in two different plants. One is located in Finland within the temperate or boreal climate zone (Köppen climate classification *Dfb* and *Dfc*), where the thermal growing season (marked by an absence of snow cover and by an average daily temperature permanently over +5 °C) lasts approximately six months [21]. The other production plant is located in Singapore, where one of the world's largest RD production plant is located. Singapore has a tropical rainforest climate (Köppen climate classification *Af*), and the nearby areas possesses large oil palm plantations. The scenario of RD plants operating in Finland and Singapore is sound and economically feasible, as there are existing RD plants in both countries. Process information data published in Nikander (2008) on a hydrotreatment RD plant in Finland is used in this study [22]. The markets for the RD produced are assumed to be in Finland, Germany, Japan and the U.S.A.

2.2. Life-cycle assessment

The life-cycle assessment (LCA) method may be used to estimate the environmental effect of emissions. We used the GaBi 5.0 LCA

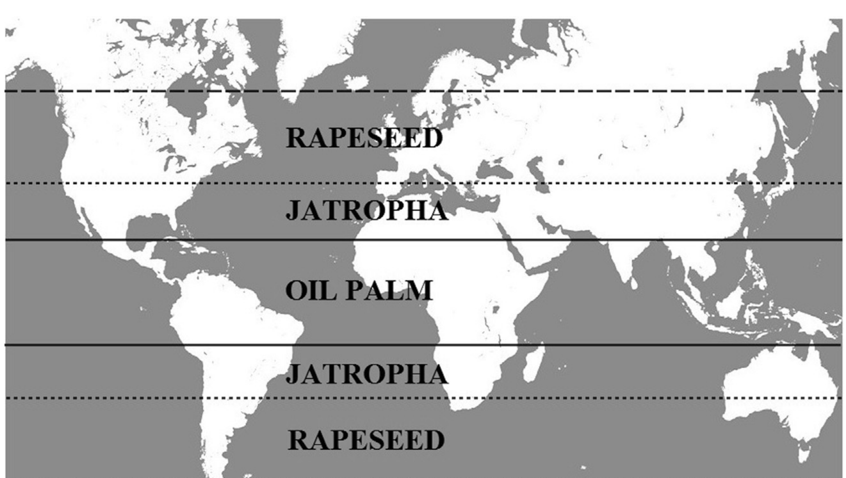

Fig. 1. Locations of potential cultivation areas for renewable diesel feedstock [17,19,20].