BIOMASS AND BIOENERGY 54 (2013) 227–238

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Comparing the social costs of biofuels and fossil fuels: A case study of Vietnam

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ARTICLE INFO

Article history:
Received 6 August 2012
Received in revised form
6 April 2013
Accepted 10 April 2013
Available online 10 May 2013

Keywords:
Cassava-based ethanol
Jatropha-based biodiesel
Fossil fuels
Social cost
Cost-effectiveness
Vietnam

ABSTRACT

Biofuel substitution for fossil fuels has been recommended in the literature and promoted in many countries; however, there are concerns about its economic viability. In this paper we focus on the cost-effectiveness of fuels, i.e., we compare the social costs of biofuels and fossil fuels for a functional unit defined as 1 km of vehicle transportation. We base our empirical results on a case study in Vietnam and compare two biofuels and their alternative fossil fuels: ethanol and gasoline, and biodiesel and diesel with a focus on the blends of E5 and E10 for ethanol, and B5 and B10 for biodiesel. At the discount rate of 4%, ethanol substitution for gasoline in form of E5 or E10 saves 33% of the social cost of gasoline if the fuel consumption of E5 and E10 is the same as gasoline. The ethanol substitution will be cost-effective if the fuel consumption of E5 and E10, in terms of L km^{-1}, is not exceeding the consumption of gasoline by more than 1.7% and 3.5% for E5 and E10 respectively. The biodiesel substitution would be cost-effective if the fuel consumption of B5 and B10, in terms of L km^{-1} compared to diesel, would decrease by more than 1.4% and 2.8% for B5 and B10 respectively at the discount rate of 4%.

1. Introduction

The global transportation sector is relying on fossil fuels, which contributed 96.3% of the sector's energy consumption in 2009 [1]. Fossil fuel related CO_2 emissions from the global transportation accounted for 23% of total CO_2 emissions from fuel combustion in 2009 [2]. The interest in biofuels as substitutes for fossil fuels has increased worldwide for three reasons. Firstly, biofuels potentially substitute for fossil fuels in the context of an increase in energy price due to an increase in energy demand and insecurity of supply [3–6]. Secondly, biofuels are suggested as a solution for climate change mitigation [2,5–8]. Thirdly, biofuel production has the potential to foster rural economic development [3,4].

Biofuel substitution has been recommended in the literature and promoted in many countries; however, there are concerns about its economic viability [7–13]. To make biofuels competitive with fossil fuels, subsidies have been

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http://dx.doi.org/10.1016/j.biombioe.2013.04.004

implemented in many countries [10–12]. Nevertheless, a comparison of cost-effectiveness between biofuels and fossil fuels has not yet been conducted properly in many studies [12–15]. In previous studies a functional unit (FU) in terms of MJ or L has been used, but this would be appropriate if biofuels were utilised in form of heating energy or pure fuels [16], but not in form of blends for transportation because the fuel efficiency should be considered. The use of substitution ratios between fossil fuels and biofuels based on the fuel efficiency of fossil fuels and blends (not pure biofuels) is also not appropriate [16–18]. In addition, the external costs and benefits of biofuel production and utilization have often not been considered in previous studies (see e.g Refs. [12–15].), with the exception of e.g. Kovacevic and Wesseler [9]. The GHG emissions associated with the effects of land use change and managed soils in biofuel feedstock plantation are either considered in terms of physical units or overlooked in comparison with fossil fuels [19]. In Le et al. [20] the energy and greenhouse gas balances of ethanol were reported.

In this paper we aim to compare the social costs (i.e. the sum of private and external costs) of biofuels and fossil fuels for an FU which we define as 1 km of vehicle transportation. This FU embodies the fuel efficiency, and it is proper for the comparison of biofuels and fossil fuels in transportation. Our study contributes to the existing literature on the cost comparison of biofuels and fossil fuels by considering both private and non-private costs. We base our empirical results on a case study in Vietnam, where cassava-based ethanol and jatropha-based biodiesel are most promising [21–25]. Our study compares two biofuels and their alternative fossil fuels: ethanol and gasoline, and biodiesel and diesel with a focus on the blends of E5 and E10 for ethanol and B5 and B10 for biodiesel. The blend of E5 is a 5% ethanol (E100) blended with 95% gasoline in volume, and B5 is a 5% biodiesel (B100) blended with 95% diesel. E10 and B10 are 10% biofuels blended with 90% fossil fuels in volume.

The structure of the paper is as follows. Section 2 presents the methodology for establishing the cost-effectiveness analysis. Section 3 describes the case study in Vietnam. The results of the social costs of fuels and the cost-effectiveness comparison between fossil fuels and biofuels are presented in Section 4. Section 5 contains our conclusions.

2. Methodology

2.1. Description of the systems

The life-cycle assessment is used in this study to estimate the GHG and non-GHG emissions from the production and utilization of biofuels, which are then expressed in monetary term as an external cost. Fig. 1 shows the life-cycle systems of production and utilization of biofuels.

2.2. Functional unit and sensitivity analysis

Following the suggestion by Gnansounou et al. [16], this study applies the FU of travelling 1 km using biofuels or fossil fuels as energy for road vehicles. The efficiencies in terms of MJ km^{-1} of biofuel components in blends are separated from the efficiencies of the fossil fuel components and those of the blends. We assume that the efficiencies of gasoline and diesel components in the blends are the same as their own standard efficiencies, and that the efficiencies of ethanol and biodiesel are explained by their contributions to the blends after deducting those of the gasoline and diesel components respectively [16].

Table 1 provides the properties of fuels as a base to convert from fuel consumption (L km^{-1}) to fuel efficiency (MJ km^{-1}). Table 2 presents the fuel consumption of blends with respect to (w.r.t) gasoline and diesel. Accordingly, it is argued that the lower low heating values (LHVs) of ethanol blends cause higher fuel consumption, while their higher octane values and compression ratios improve the thermodynamic properties and may reduce the fuel consumption [16,18,26–31]. The higher fuel consumption of biodiesel blends is explained by their lower LHVs and higher viscosity causing lower atomization and combustion properties [32–38]. In reality, the fuel efficiency is affected by not only fuel properties but also other factors such as vehicle speed and gear, vehicle models, and road conditions.

For this reason, a sensitivity analysis is conducted in this study to evaluate the effects of different blends of biofuels and their fuel consumption. On the basis of the testing results, the percentage change in fuel consumption of ethanol blends w.r.t gasoline is considered at three levels, formulating six scenarios: S1, S2, and S3 are the cases of E5 with 5% higher, the same, and 5% lower levels of fuel consumption per kilometer respectively; S4, S5, and S6 are the cases of E10 with 5% higher, the same, and 5% lower levels of fuel consumption per kilometer respectively. The testing results show that the percentage changes in fuel consumption of the blends of B5 and B10 w.r.t diesel range between 0 and 5%. We therefore formulate four scenarios for biodiesel: S7 and S8 are the cases of B5 with the same and 5% higher levels of fuel consumption compared to diesel respectively; S9 and S10 are the cases of B10 with the same and 5% higher levels of fuel consumption respectively. The efficiencies of biofuel components in blends are separated in Table 3. Accordingly, we compare the social costs of the fuels in terms of US Dollar for a functional unit of 1 km ($ km^{-1}) in Section 2.3.

2.3. Cost-effectiveness analysis

In this study, the cost-effectiveness analysis aims to compare alternative fuels (ethanol with gasoline, and biodiesel with diesel) in terms of their social costs of production and utilization for an FU. To calculate the social cost for an FU, the social cost of 1 GJ of fuel ($ GJ^{-1}) is first calculated and then multiplied by the amount of GJ needed for an FU (GJ km^{-1}) in each scenario in Table 3.

2.3.1. Break-even price calculation

The social costs of fuels are calculated as the break-even price which is identified by setting the net present values of fuel projects equal to zero at a given discount rate. These break-even prices are the average costs for every GJ of fuels produced and utilised. This study follows Kovacevic and Wesseler [9] by considering both private and non-private costs and benefits in the social cost calculation.