Biofuel production in Vietnam: greenhouse gas emissions and socioeconomic impacts

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Le Thanh Loan

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Chapter 1

INTRODUCTION

1.1 Background

1.1.1 Biofuel development in the world

The global production of biofuels has been growing rapidly since the year 2000 (Figure 1.1). It increased from 9,164 thousand tonnes of oil equivalent in 2000 to 34,079 and 60,629 thousand tonnes of oil equivalent in 2007 and 2012, reporting an annual growth rate of 17.1% for the period from 2000 to 2012 and 12.2% from 2007 to 2012 [1]. Although the production of biodiesel has been smaller in quantity compared to that of ethanol, it has achieved an annual growth rate of 19.3% for the period from 2007 to 2012, which is higher than that of ethanol for the same period at 9.7% [1]. Biofuel production is led by the United States, Brazil, and the European Union with their contribution of 87.0% of total biofuel production in the world for the period from 2007 to 2012. Ethanol has been mostly produced by the United States with a contribution of 55.3% and by Brazil with 32.5% of the total ethanol production; biodiesel is produced in the EU (50.3%), the USA (13.3%) and Asian countries (14.6%) [1].

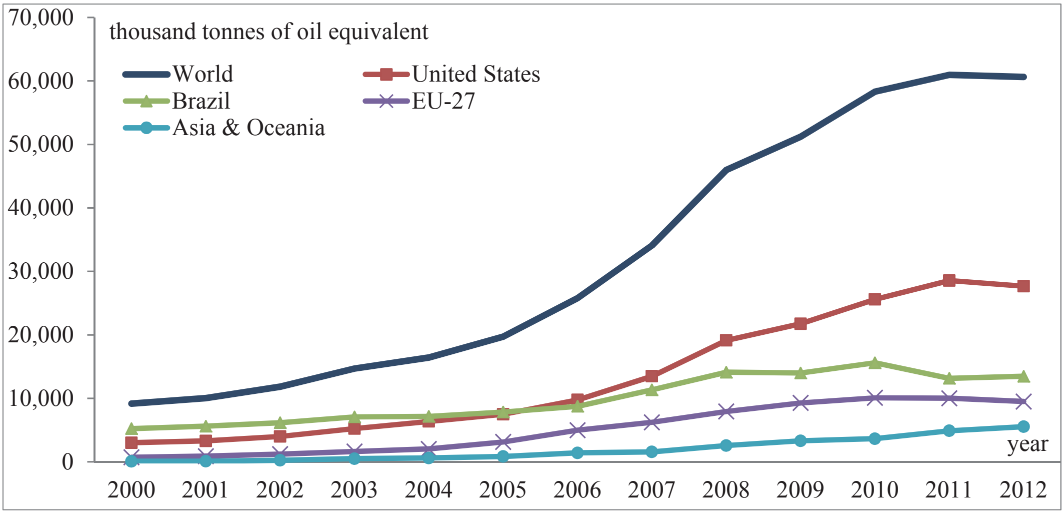

Figure 1.1 Global production of biofuels from the year 2000 to 2012.
Source: [1]

The increase in demand for biofuels is more likely caused by the governments' targets than created by market forces [2,3,5]. The interest in biofuels as substitutes for fossil fuel in transport has increased worldwide and growing targets have been set in the energy policies of many countries for three main objectives: i) reducing the dependency on imported fossil fuels or an increase in the country's energy security, ii) reduction of greenhouse gas (GHG) emissions and climate change mitigation, and iii) creating new markets for the agricultural sector and rural development [2,6-8]. More than fifty countries have implemented biofuel policies, e.g. blending targets, financial incentives, investment supports for research and development and infrastructure, and trade related measures [5,9].

As for the member states of the European Union, the Renewable Energy Directive (RED) 2009/28/EC set a mandatory target of 10% share of renewable energy, including biofuels by the year 2020 in the final energy demand in the EU transport sector [2]. The Fuel Quality Directive (FQD) 2009/30/EC set a target of 6% reduction of greenhouse gas emissions from fuels consumed in the EU transport sector by 2020 [10-12]. To qualify for the targets of both the RED and the FQD, biofuels produced and consumed in the EU have to comply with the sustainability criteria with the requirements of at least 35% GHG emissions savings compared to fossil fuels by 2010, and 60% by 2018 and with the appropriate land use as well as the monitoring requirements for any potential adverse effect [2]. In United States, the 2005 Renewable Fuel Standard set the target of 7.5 billion gallons of biofuels by 2012, which was attained by 2008 [3,4,13]. The 2007 Renewable Fuel Standard set a long-term goal of 36 billion gallons annually by 2022, of which 15 billion gallons are conventional biofuels with more than 20% GHG emission savings and 21 billion gallons are advanced biofuels with more than 50% GHG emission savings [3,4,13]. In Brazil, the Government launched the National Ethanol Program in 1975 and created conditions for the large-scale ethanol industry and incentives for flex-fuel vehicles [5,13]. The program achieved a rapidly rise in ethanol production along with the number of flex-fuel vehicles under the blending requirement of 20% to 25% [5,13]. The national program on biodiesel production and usage set a biodiesel target of 5% demand for diesel from the year 2013 onwards through the supporting schemes of auctioned prices which should be higher than the production cost and tax exemptions for feedstock production [5,13].

In the Asia region, the biofuel production reached 5,540 thousand tonnes of oil equivalent in the year 2012 [1]. Regarding biofuel policies particularly in the ASEAN (the Association of Southeast Asian Nations), the four major biofuel producing countries of Malaysia, Thailand, Indonesia, Philippines have attempted to push their biofuel industries with the major drivers of energy security, social economic development (e.g. income generation and employment for farmers, new agricultural market, and better resource allocation), and environmental concerns. However, different from developed countries, the two former drivers are emphasized while the latter of addressing environmental concerns seems not to be a priority as these countries do not belong to the Annex 1 group and are not required to cap their emissions under the Kyoto Protocol [14]. The mandatory use of biofuels has been established in these countries with the requirements of biofuel blends from 2 to 10%, e.g. blended diesel with 5% palm oil under the Malaysian Biofuel Act 2007, a target of biofuel substitution of 2% for biodiesel and 10% for ethanol under the 2007 Biofuels Act in Philippines, 5% of biofuel substitution by 2025 in Indonesia, and 5% biodiesel blend and 10% ethanol blend under the Alternative Energy Development Plan for the period from 2008 to 2022 in Thailand [5,14,15]. It was indicated that while Thailand and Philippines achieved a steady growth of biofuel production and effective blending mandates, there has been a stagnant growth in Malaysia and Indonesia due to some drawbacks of land suitability and high export duty for biodiesel in Malaysia, and of the use of feedstock of molasses and an increase in crude palm oil in Indonesia [14,15].

1.1.2 Biofuel development in Vietnam

Vietnam has for a long time exploited and exported crude oil and imported refined oil for domestic consumption; the Vietnamese first refinery of Dung Quat has met 30% of the domestic fuel demand [3]. The country is currently a net energy exporter; however, it is projected to be a net energy importer after 2015 [1,2]. The refined oil constituted the highest share of total energy consumption at 42% and its import has grown at an annual rate of 6.0% during the period from 2000 to 2009 [1]. The energy consumption of transport sector increased at an annual rate of 12% and on average accounted for 24% of total energy consumption throughout the period from 2000 to 2009 [1]. The sector's energy consumption is projected to grow at an annual rate of 6.4% for the period from 2010 to 2020 and is expected to account for 22% of total energy demand by 2020 [6]. Such a growth in fossil fuel consumption results in a corresponding increase in CO_2 emissions, contributing to climate change through the greenhouse effect [5,6]. The fossil fuel related CO_2 emissions from transport accounted for 25% of total CO_2 emissions from energy use in 2008 in Vietnam. This figure is expected to increase to 35% in 2020 and 37% in 2030 due to an increase in oil demand and the high emission intensity in the transport sector [5,8]. Therefore, the transport sector is considered as a priority and well suited for the promotion of energy efficiency and cleaner fuels in response to the Vietnam national green growth strategy and the context of climate change [4,9,17].

The interest in biofuels as substitutes for fossil fuels in Vietnam has been driven by three main reasons of diversifying its fuel sources in the context of an increase in energy price and insecurity of supply, potentially fostering rural economic development, and providing a solution for green energy to mitigate climate change. This has promulgated in the Vietnamese government's Decisions No. 177/2007/QD-TTg of 2007 and No. 1842/2008/QD-BNN-LN [9,10] of 2008 for the biofuel development strategy toward the year 2025, the Decision No. 53/2012/QD-TTg of 2012 on the roadmap for compulsory use of biofuels from the year 2015, and the Law on the environmental protection tax effective from the year 2012 [18-21]. Accordingly, the first two decisions set out a biofuel development strategy toward the year 2025 with a focus on two biofuels of ethanol and biodiesel and their utilization in domestic transport and disseminated the incentives for biofuel investments such as research and development projects, tax exemption, and a 20-year land use right for biofuel investors. The third decision formulated the blending mandate of E5 by 2015 and E10 by 2017 and encouraged the use of B5 and B10. 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 fourth decision has provided a relative incentive to biofuel production and consumption through a tax on fossil fuel since the year 2012.

The biofuel production in Vietnam has rapidly developed under the government policies. The biofuel output targets are 250 thousand tonnes per year, equivalent to 1% of projected total fuel demand by 2015; and 1.8 million tonnes per year, equivalent to 5% of projected total fuel demand by 2025 [18]. Regarding biofuel feedstocks, cassava and jatropha are most applicable in Vietnam [18,19]. Jatropha is strategic in the Vietnamese government's planning, whereas cassava is market-driven based on its availability. Up to 2010, eight plants had started with a total annual capacity of 680 million liters of ethanol, of which 420 million liters are for biofuel and the remainder for alcoholic, cosmetic, and pharmaceutics industries and export [22,23]. These plants are located in the Central Highlands, South Central Coastal, and Southeast regions, which contributed 72% of total cassava output in the period from the year 2006 to 2010 [24]. Jatropha has been planted mostly in unused barren land in the North and Coastal regions in compliance with the direction of the Ministry of Agriculture and Rural Development [25-27]. Biodiesel processing experiments were conducted by the Research Institute for Oil and Oil plants, the Institute of Tropical Biology, and by processing plants in 2010. In the private sector, seven companies are investing in biodiesel processing, and most of them are Vietnamese (except for the Eco-Energy Joint Stock Company, which takes 67% of its investment from Ecocarbone in France). Apart from Dai Dong and Khe Sanh Rubber in Ha Noi and Ho Chi Minh cities, the other investors are located in jatropha-supplying provinces. While biodiesel production was at the initial stage of jatropha plantation, processing experiments, and vehicle testing, the blend of E5 has already been sold in Vietnam since August 2010 [28]. The blend stations operated in 4 cities and 22 provinces in 2011 and have been expanded throughout the whole country by 2012 [28].

1.2 Environmental and economic studies of impacts of biofuels

1.2.1 Biofuels and biofuel policies

Biofuel is referring to solid (bio-char), liquid (ethanol, biodiesel, and vegetable oil), or gaseous (biogas, biosyngas, and biohydrogen) fuels that are produced from biological sources (e.g. plants or animal or biomass) [29,30]. These fuels can be used for production of heat, electricity, and transportation services. In this thesis we focus on two liquid biofuels of ethanol and biodiesel as substitutes to fossil fuels for transportation. Ethanol is blended with gasoline, and biodiesel is blended with diesel. The common blends of ethanol include E5, E10, E15, E85, and E100 with 5, 10, 15, 85, and 100 percent of ethanol in the blends, respectively. The common blends of biodiesel are B2, B5, and B20 with respectively 2, 5, and 20 percent of biodiesel in the blends.

Biofuel policies are referring to a mix of regulations or market interventions from the environmental, energy, agricultural and trade legislation [29]. While the main subsidy programs to biofuel producers or consumers directly enhance the biofuel industry, the secondary biofuel policies create a wide-range of incentives including research and development grants for the projects of biofuels and feedstock, financial incentives to biofuels producers, infrastructure subsidies (e.g. subsidies for flexible-fuel vehicles and fueling stations), export subsidies, fuel taxes, and environmental regulations [29].

1.2.2 Environmental impacts of biofuels

A number of studies have dealt with environmental impacts of biofuels with many thematic areas, e.g. GHG emission performance, effects on soil quality, water, and biodiversity related to biofuel production [7,31-33]. Literature review indicated most of studies examined the environmental indicators of biofuels and made a comparison with those of fossil fuels [7,31,34]. Prominent among common used indicators are the energy and GHG balances which are defined as the differences between the energy for and the GHG emissions from the production and utilization of a biofuel and those of its alternative fossil fuel for the same functional unit [7,31,34]. Besides the energy and GHG balances, other environmental impacts of biofuels are found in literature, e.g. the effects of biofuel feedstock production on soil quality and water, and the effects on biodiversity [7,31-33].

As for the analysis of energy and GHG balances, most studies applied the life-cycle assessment (LCA) approach so as to consider the entire life-cycle of production and utilization of biofuels [7,31,34-37]. Although the literature shows several studies on energy and GHG balances, the GHG emissions associated with the effects of land use change particularly in feedstock plantation are often missing [7,35,39]. The use of a functional unit (FU) in terms of mega joule or liter in the comparison between fossil fuel and biofuel has often applied, resulting in difficulties of interpreting results [35]. Some studies indicated the possibility of reducing GHG emissions through soil organic carbon sequestration and the biofuel substitution for fossil fuels; however, others notified conditions on land use change or low temporal imbalance of terrestrial carbon stocks [38,40,41]. The use of biofuels in heat and power generation or in transportation sector results in different emission effects and energy efficiency [42]. Generally, the analysis of these two indicators for a biofuel system much depends on local contexts, e.g. farming practices, land use change for feedstock plantation, the use of fossil fuels in biofuel processing, and the use of biofuels [33,38,42,43].

1.2.3 Economic viability of the biofuel industry

Biofuels would probably not have been viable without the government's intervention; there have been concerns about economic viability of biofuels [44-49]. Subsidies have been implemented in many countries to make biofuels competitive with fossil fuels [46-48]. Many studies have conducted the cost-effectiveness analysis of biofuels in various indicators, e.g. a production cost per unit of energy (British Thermal Units) compared to that of fossil fuel [49], a retail price per liter of soybean-based biodiesel as the sum of all the direct and indirect cost, tax and profit in comparison with that of diesel [49], the costs of biofuels compared to the forecasted price on fossil fuel per GJ [50], a production cost per liter of jatropha-based biodiesel [51]. Nevertheless, a comparison of cost-effectiveness between biofuels and fossil fuels has not yet been conducted properly in many studies [48-51]. The common use of a functional unit (FU) in terms of liter or unit of energy (Joule or British Thermal Units) would be appropriate if biofuels were utilized in form of heating energy or pure fuels [35], 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 [35,52,53]. In addition, the external costs and benefits of biofuel production and utilization have often not been considered in previous studies (see e.g. [48-51]), with the exception of e.g. Kovacevic and Wesseler [45]. 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 [39].

In a broader view, the cost analysis or budget modeling helps to pinpoint the key economic variables or cost drivers during the production chain. However, this approach is better supplemented with another analysis for policy purpose and a broader view of the whole economy due to the following shortcomings [7]. Firstly, prices in the costing analysis may not be real social value of resources due to policies, distortion, externalities in production and use. Second, the role of market structure is overlooked as the analysis focuses on one specific industry; and the analysis ignores the effects of general equilibrium in the whole economy. The approach is suitable for analyzing the industries with low production levels in comparison with the whole size of the economy [7]. The equilibrium analysis in the next section has been suggested as a supplemental approach regarding the economy-wide impacts.

1.2.4 Economic impacts of biofuels

In the biofuel economics literature, the two common equilibrium models are often utilized to investigate impacts of biofuels, namely partial equilibrium models and general equilibrium models. In partial equilibrium models, the analysis focuses on a part of the economy; only one or few sectors are represented under the assumptions that the endogenous changes only affected the explicitly modeled sectors, not the whole economy, and that the rest of the economy remained unaffected [54]. As for the analysis of biofuels, partial equilibrium models have often focused on agricultural sectors and represented in details the agricultural production and biofuel sectors under the restriction of land use, but these models have not accounted for the linkages to non-agricultural sectors [55]. In the literature, the partial equilibrium models considered the effects of biofuel production policy at national level, e.g.

in Refs. [56-61] or at the regional or global level, e.g. in Refs. [62-68] on specific aspects of land use change in Refs. [56,58,59,67], on food supply or the agricultural market in Refs. [62-64,66], and on prices of fossil fuel in Refs. [57,65].

Different from partial equilibrium model, general equilibrium models describe the entire economy as all economic agents are taken into account and behave according to the neo-classical microeconomic theory [54]. As biofuels are produced from agricultural sources for energetic purposes, the biofuel policies have not only impacts on agricultural and energy markets but also implications across the economy, e.g. production and consumption of other industries, trade balance, and households' welfare. The general equilibrium models can address the impacts of biofuels policies due to the economy-wide characteristics and the linkage among production, consumption, and trade in the models [7,55,69]. The general equilibrium modeling applied to biofuels mainly has three approaches. First, in the implicit modeling approach, the biofuel sectors and biofuel commodity are not explicitly modelled, but modelled through the adjustments of data on biofuel crops, e.g. grain, sugar, and oilseeds instead [55,63,70]. Since modeling the biofuel crop inputs in this approach captures a part of production technology and because it is impossible to look into the government support and welfare implications, some authors have moved to the second approach of modeling biofuels as latent technologies with the requirement of data on inputs and cost structures of biofuels [55,71-73]. With the explicitly modeled biofuel production technologies, the representation of biofuels becomes more realistic with the processing stage and the consideration of the linkages between biofuel sectors and other sectors in the economy; however, there exists a shortcoming with the assumption of biofuel trade. The third approach of disaggregating biofuel sectors from the Social Accounting Matrix has been adopted with the availability of reliable data on biofuel sectors in recent studies, e.g. Taheripour et al. [74,75], Britz and Hertel [76], Hertel et al. [77], and Birur et al. [78]. Besides the equilibrium models, some authors have shifted the focus on time series econometrics with the availability of biofuel time-series data to investigate the price transmission and interactions among biofuel-related markets, e.g. Ciaian and Kancs [79, 80]; Kristoufek et al. [81,82], Zhang et al. [83,84], Serra et al. [85], and Serra and Zilberman [86].

Regarding the general equilibrium models, though there exists a large literature on impacts of biofuels, most of studies focus on the global and regional effects of biofuels or biofuel production in developed countries [7,55,69,87]. While the biofuel impacts are greatly different between developed and developing countries due to the consumption and production structures, technology, trade openness, fuel substitutability, and institutional arrangements, previous studies for developed countries either assumed the existence of the country's market power and/or a perfect substitution between biofuel and fossil fuel with all consumers owning flexible-fuel vehicles [87-92]. There are few studies for developing countries [7,38,55,69]. In the case study for the group of Greater Mekong Subregion (GMS) countries, Yang et al. simply took the difference between two scenarios with and without GMS countries in the group of three main producers, namely the USA, EU, and Brazil neither considering environmental effects nor a more detailed differentiation by country and household income group [93]. In the studies for Mozambique and Tanzania, the authors assumed land abundance, biofuel production from foreign sectors, biofuel export, and its profit repatriation in their model [94,95]. Another study in Argentina developed a model with the assumptions that the labor force and real wage are constant, and that there is no investment in the economy [96]. These are not common features in developing countries, particularly for Vietnam without land abundance, its biofuel production from both public and private sectors for the local transport sector, and its projected increases in labor force and investment [97,98].

Previous studies considered the biofuel impacts on specific aspects, e.g. land use change in Refs. [56,58,59,67,78], food supply or the agricultural market in Refs. [62-64,66], prices of fossil fuel in Refs. [57,65], international trade in Refs. [62,100,101], and by-products in Ref. [74]. Few studies examined the effects of the biofuel on welfare or economic growth, e.g. in Europe in Refs. [69,99], and in Mozambique and Tanzania in Refs. [94,95]. There have been concerns about the negative impacts on wefare, especially in developing countries without proper policies on locations, feedstocks, agricultural innovations, and social measures [69,102,103]. The welfare impact is crucial as it incorporates many factors, e.g. the share of food and energy expenditure, changes in technology, infrastructure and services, and policies, reflecting integrated effects of food and energy markets, agricultural diversification, employment generation, and so on. Yet, the welfare impact of biofuels has been limited in the literature. Besides, the environmental impacts have been mostly land use change, but many studies have not considered the emissions from the biofuel production and combustion. The impact on food security has received limited attention in a general equilibrium analysis [34-36]. The analysis of new biofuel feedstock, particularly jatropha has not been fully examined in many perspectives of energy, environment, economic viability, and impacts on the economy.

1.3 Objectives and research questions

The overall objective of this thesis is to study the energy efficiency, GHG emission savings, and the economic viability of biofuels as energy for transportation and to examine the impacts of biofuel policies on food production, welfare, and emission in Vietnam. To achieve the research objective, the following four research questions will be addressed.

1. What are the energy and GHG balances of cassava–based ethanol and jatropha–based biodiesel as substitutes for fossil fuels for transportation in Vietnam?
2. What is the cost effectiveness of biofuels in comparison with fossil fuels in Vietnam?
3. What are the impacts of biofuel production policy on welfare, food production, and emission in Vietnam?

4. What are the impacts of the tax on fossil fuel and subsidy for biofuels on welfare in Vietnam?

1.4 Methodology

Three main methodologies are applied in this study. Life-cycle assessment is used to answer reseach question 1. On the basis of the results of GHG and non-GHG emissions from the production and utilization of biofuels, the study applied the cost-effectiveness analysis to compare the social costs of production and utilization of alternative fuels (ethanol with gasoline, and biodiesel with diesel) for a functional unit in reseach question 2. An applied general equilibrium model is utilised to answer reseach questions 3 and 4.

1.4.1 Life-cycle assessment

Life-cycle assessment (LCA) is a method to compile and evaluate the inputs, outputs and the potential environmental impacts of a product system throughout its life-cycle [104]. Although it is regulated under the ISO 14040:2006 and 14044:2006 standards which provide the principles, framework, and guidelines for conducting an LCA study, the LCA application is not always straight forward and possibly leads to different results for a similar product [104]. LCA is used in many thematic areas such as environmental management systems and environmental performance evaluation, certification of greenhouse gas emissions, integration of environmental aspects into product design, waste prevention and recycling, and sustainable use of natural resources.

As for biofuel development, the LCA methodology has been increasingly used to assess the effects of biofuels in the consideration of all stages of biofuel production and utilization. Literature shows that the LCA is widely used to consider the energy balance, GHG balance, and other life-cycle environmental impacts of biofuel chains [35-37]. For the first two purposes, a comparative LCA has been applied to compare biofuel production and consumption and its alternative fossil fuel in order to see the difference in energy efficiency and environmental performance. Without the comparison with fossil fuels, the other use of LCA aims to obtain the environmental impacts related to biofuels or to identify main hotspots in the chain so that policymakers and companies can pursue further improvements, research and development activities for sustainability [36,37]. Literature on the energy and GHG balances under the LCA approach reveals a variety of results due to i) different data sources, key input parameter values, agricultural managements, different feedstocks in different climates and cultivation, ii) methodological issues, e.g. definition of system boundaries, allocation methods, different functional units, the effect of biomass removal from soils, and iii) other indirect effects such as land-use change [37,105].

1.4.2 Cost-effectiveness analysis

Cost-effectiveness analysis is to compare alternatives in terms of the ratio of their costs and a single quantified effectiveness measure, which is not in monetary terms [106]. Different from cost benefit analysis, which includes all social costs and benefits, the cost-effectiveness analysis is based on social costs and takes into account social benefits, which are included in the effectiveness measure. Cost-effectiveness analysis seeks the lowest-cost option among different measures for a given target. It measures technical efficiency, not allocative efficiency; that is, it does not necessarily signify an optimal resource allocation because the predetermined target may not be efficient [106]. This approach has been successful used in health economics and increasingly in environmental issues [107-109]. In the environmental aspects, several studies have used this approach to assess an environmental policy, e.g. Refs. [110,111], greenhouse gases mitigation measures, e.g. Refs. [109,112] or an environmental solution and biofuel production, e.g. Refs. [45,113,114].

1.4.3 An applied general equilibrium model

Applied general equilibrium (or computable general equilibrium) models have been wisely used to analyze economy-wide effects of biofuels [7,55,69]. Different from a partial equilibrium model, which focuses on specific sectors without considering the full economy, the general equilibrium model is suitable for analyzing the economic-wide impacts of exogenous shocks or policies because it is able to capture the entire economy, relationships between economic agents, the international trade effects. The model endogenously represents the agents' behavior and response to the change in prices through their consumption and production patterns [54]. The AGE models have a sound microeconomic foundation as the economic agents including consumers, producers, the government and other countries are assumed to behave according to neo-classical microeconomic theory [54].

Most of general equilibrium models are represented under different formats, of which the two common are the computable general equilibrium format (the equation system) and the Negishi format. Though the former is widely used in the empirical applications of general equilibrium models, the latter is an elegant formulation of the applied general equilibrium models and properly applicable in the environmental economic topics for the following advantages. First, the Negishi format can deal with non-convexity of production technology and preference set. Second, it can directly discuss the welfare issue through an explicit welfare program, which is to maximize the welfare function and to solve for a Pareto-efficient equilibrium. From the literature, several studies have applied the general equilibrium models to examine the impacts of biofuel targets and policies on the economy (see Section 1.2.4).

1.4.4 Application of methodologies to the research questions

For research question 1, the energy and GHG balances are used to measure energy efficiency and effects on GHG emissions of biofuel production and utilization. The analysis of energy and GHG balances follows the LCA and comparative analysis suggested by Gnansounou et al. [35]. In the comparative analysis, the energy and GHG balances are the differences between the energy for and the GHG emissions from the production and utilization of a biofuel (e.g. ethanol and biodiesel) and those of its alternative fossil fuel (gasoline and diesel) for the same functional unit of 1 km of road transportation. To calculate energy input for and GHG emissions from the production and utilization of ethanol, a well-to-wheel LCA is chosen since the utilization phase is significantly affected by fuel consumption and GHG emissions from combustion. To calculate the energy input and GHG emissions for a functional unit (FU), we calculate the energy use in terms of mega joule and GHG emissions in terms of gram of CO_2 equivalent (CO_2e) for 1 MJ of biofuels, and we then convert them for an FU.

For research question 2, 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 at a certain efficiency level of blend. Social cost includes the private cost and external cost of GHG and non-GHG emissions. 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 terms as an external cost.

For research questions 3 and 4, we use an applied general equilibrium (AGE) model to investigate the economy-wide impacts of biofuel production and incentive policies in Vietnam on welfare in Vietnam and its main trading partners, on food production, and on emissions of greenhouse gases. An AGE model represents the interaction between policies and economic activities by taking into account the behaviors of all economic agents, and their implications for consumption, production, trade flows and welfare [54]. Its nature permits the assessment of new phenomena, such as the biofuel policies in Vietnam. The model will be an open-economy model including Vietnam and its main trading partners (MTP). For research question 3, we identify the impacts of the biofuel production policy by comparing the reference scenario without any biofuel production policy with the scenarios for the biofuel production targets of ethanol, biodiesel and both biofuels. A sensitivity analysis of the elasticity of substitution between biofuel and fossil fuel is conducted to evaluate the effects of the elasticity of substitution on the model results.

For research question 4, we extend the AGE model in research question 3 with the biofuel incentive policies, particularly a 10% tax on fossil fuel and/or a 10% subsidy for biofuels in

Vietnam. To investigate the impacts of biofuel incentive policies, we compare the reference scenario without biofuel incentive policies with the scenarios for the implementation of a tax on fossil fuel and/or a subsidy on biofuels. The biofuel production targets are included in these scenarios. A sensitivity analysis of the tax rate is conducted to address the implication of the optimal tax.

In the application of the AGE model for Vietnam and its main trading partners we have made a number of assumptions based on the actual biofuel policies of the Government of Vietnam and on the use of the biofuels produced in Vietnam. These assumptions are discussed in the Chapters 4 and 5, and the limitations of the AGE analysis related to these assumptions are also discussed in the conclusions of Chapters 4 and 5 and in the synthesis of the thesis in Chapter 6.

1.5 Contribution of this research

The novel contributions of this study lies in the life-cycle assessment approach with three distinguishable features for the assessment of biofuel industry and the applied general equilibrium model for the impacts of biofuel policies with explicit welfare function and in the context of a developing country. First, the study assesses the energy and GHG balances and cost-effectiveness of biofuels for a functional unit of one kilometer of vehicle transportation. The previous study used a functional unit of megajoule or liter; however, this is not approriate for the case of using biofuels in form of blends for transportation without the explicit consideration of fuel efficiency. This study embodies the fuel efficiency in the assessment using the functional unit of 1 kilometer of vehicle transportation and conducts the sensitivity analysis on the fuel efficiency of blends. This functional unit is proper for the comparison of biofuels and fossil fuels in transportation. Second, the research contributes to the existing literature on energy and GHG balance accounting for biofuels by considering the effects of LUC and change in soil management in feedstock plantation. Third, the study is distinguished from previous studies on the cost comparison of biofuels and fossil fuels by considering both private and non-private costs with an empirical case of Vietnam for cassava-based ethanol compared to gasoline and jatropha-based biodiesel compared to diesel.

Regarding the general equilibrium model for the economy-wide impacts of biofuel policies, the literature has shown several previous studies focusing on specific aspects of land use change in Refs. [56,58,59,67,78], food supply or the agricultural market in Refs. [62-64,66], prices of fossil fuel in Refs. [57,65], international trade in Refs. [62,100,101], and by-products in Ref. [74]. Few studies examined the effects of the biofuel mandate on welfare or economic growth (e.g. in Europe in Refs. [69,99], and in Mozambique and Tanzania in Refs. [94,95]). Besides, studies on biofuel incentive policies mostly in developed countries have assumed the country’s market power and/or a perfect substitution between biofuel and fossil fuel with all consumers owning flexible-fuel vehicles [87-92]. Other studies focused on some aspects of the taxation, e.g. the Suits Index to measure the progressivity of taxes [115], the effect on producers' profits [116], the effect on gasoline demand as a response to carbon tax [117], and the analysis based on a theoretical framework [87,118,119]. An applied general equilibrium model in this study contributes to the existing literature by considering the impacts of biofuel mandate in Vietnam on welfare and incorporating emissions of greenhouse gases, not only because of feedstock production but also from the production and utilization of biofuels as substitutes for fossil fuels in transportation. The study extends the model with policy incentives of a tax on fossil fuel and a subsidy for biofuel under the adoption of the biofuel mandate in Vietnam. Finally, the study also provides an empirical equilibrium model for the case of biodiesel from non-edible feedstock of jatropha and with the consideration of the co-products of biofuels.

1.6 Outline of the thesis

The thesis follows a publication-based format in which the four empirical chapters are the articles addressing the research questions outlined in Section 1.4. Following this introduction, Chapters 2 and 3 examine the performance of biofuel industry concerning the energy efficiency, emission savings, and economic viability. Chapter 2 analyses the energy and GHG balances of biofuels as substitutes for fossil fuels in the consideration of the effects of LUC in feedstock plantation and changes in fuel efficiency of blends affecting energy and GHG balances. Chapter 3 investigates cost-effectiveness of biofuels under efficiency levels of blends by comparing the social costs of biofuels and fossil fuels for a functional unit of 1 km of vehicle transportation. The chapter also identifies the required fuel consumption levels of blends to make biofuels cost-effective compared to fossil fuels keeping other factors constant.

Chapters 4 and 5 model the interaction between biofuel policies and economic activities in the economy to investigate the economy-wide impacts of biofuel policies in Vietnam. Chapter 4 demonstrates how an exogenous increase in the biofuel production and consumption results in changes in food production, greenhouse gas emission, and welfare by simulating the biofuel production target in an applied general equilibrium model. Chapter 5 extends the applied general equilibrium model with a tax on fossil fuel and a biofuel subsidy in the context of adopting the biofuel mandate to investigate the impacts of the government's incentive policies on the economy and welfare in Vietnam. Finally, Chapter 6 highlights the main finding of the thesis, discusses policy implications, limitations of the study, suggestion for further research and draws general conclusions.

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RỪNG CỘNG ĐỒNG
BON BU NƠ (A-B)
S: 1016 Ha.

Chapter 2

Energy and greenhouse gas balances of biofuels in Vietnam

Biofuel production has been promoted to save fossil fuels and reduce greenhouse gas (GHG) emissions. However, there have been concerns about the potential of biofuel to improve energy efficiency and mitigate climate change. This paper investigates energy efficiency and GHG emission saving of cassava-based ethanol as energy for transportation. Energy and GHG balances are calculated for a functional unit of 1 km of road transportation using life-cycle assessment and considering effects of land use change (LUC). Based on a case study in Vietnam, the results show that the energy input for and GHG emissions from ethanol production are 0.93 MJ and 34.95 g carbon dioxide equivalent per mega joule of ethanol respectively. The use of E5 and E10 as a substitute for gasoline results in energy savings, provided that their fuel consumption in terms of liter per kilometer of transportation is not exceeding the consumption of gasoline per kilometer by more than 2.4% and 4.5% respectively. It will reduce GHG emissions, provided that the fuel consumption of E5 and E10 is not exceeding the consumption of gasoline per kilometer by more than 3.8% and 7.8% respectively. The quantitative effects depend on the efficiency in production and on the fuel efficiency of E5 and E10. The variations in results of energy input and GHG emissions in the ethanol production among studies are due to differences in coverage of effects of LUC, CO_2 photosynthesis of cassava, yields of cassava, energy efficiency in farming, and by-product analyses.

This chapter is supplemented from the publication: Le TL, van Ierland EC, Zhu X, Wesseler J, Ngo G. Energy and greenhouse gas balances of cassava-based ethanol. Biomass and Bioenergy 2013;51:125-135.

2.1 Introduction

Vietnam is currently a net energy exporter; however, it is projected to be a net energy importer after 2015 [1,2]. The refined oil constituted the highest share of total energy consumption at 42% and its import has grown at an annual rate of 6.0% during the period from 2000 to 2009 [1].

Like most rapidly developing countries, the contribution of transport sector to total energy consumption and CO_2 emissions in Vietnam is increasing [3,4]. The sector's energy consumption increased at an annual rate of 12% and on average accounted for 24% of total energy consumption throughout the period from 2000 to 2009 [1]. The sector's energy consumption is projected to grow at an annual rate of 6.4% for the period from 2010 to 2020 and is expected to account for 22% of total energy demand by 2020 [5]. Such growth in fossil fuel consumption results in corresponding increases in CO_2 emissions, contributing to climate change through the greenhouse effect. In Vietnam, fossil fuel related CO_2 emissions from transport accounted for 25% of total CO_2 emissions from energy use in 2008. This figure is expected to increase to 35% and 37% in 2020 and 2030 respectively due to an increase in oil demand and the high emission intensity in the transport sector [3,6]. Therefore, the transport sector is considered as a priority and well suited for the promotion of energy efficiency and cleaner fuels in the context of climate change [3,7].

Biofuel production has been supported by the Government of Vietnam under the Decision No. 177/2007/QD-TTg of 2007 [8]. The decision sets out a development strategy until 2015 and a broader vision toward 2025. It disseminates the incentives for biofuel investments such as research and development projects, tax exemption, and a 20-year land use right for biofuel investors. The policy has focused on two biofuels: ethanol and biodiesel. Blends of E5 for gasoline and B5 for diesel are utilized in domestic transport in the period from 2010 to 2015, and E10 and B10 are proposed after 2015 [9]. The biofuel output targets are 250 kt per year (kt y^{-1}), equivalent to 1% of projected total fuel demand by 2015; and 1.8 Mt y^{-1}, equivalent to 5% of projected total fuel demand by 2025 [8].

Although there is diversity in feedstocks, cassava and jatropha are most promising in Vietnam [8-12]. Jatropha is strategic in the government's plan, whereas cassava is market-driven based on its availability, soil suitability, and conversion efficiency. Accordingly, as of 2010, four ethanol plants have been built with an annual capacity of 420 million liters in the provinces of Phu Tho, Quang Nam, Quang Ngai, and Binh Phuoc [10]. While biodiesel production is currently at the initial stage of jatropha plantation and processing experiments, the blend E5 has been sold in Vietnam since August 2010.

Biofuel substitution has, in one respect, been recommended in the literature and promoted under the policy; there are, however, some uncertainties and concerns about its energy efficiency and GHG emission saving [7,13]. Energy and GHG balances are commonly used to measure biofuel energy efficiency and effects on GHG emissions. However, GHG emissions associated with the effects of LUC are often missing [14,15]. Further, a functional unit (FU) in terms of mega joule or liter has often been applied in the comparison between fossil fuel and biofuel, resulting in difficulties of interpreting results [15].

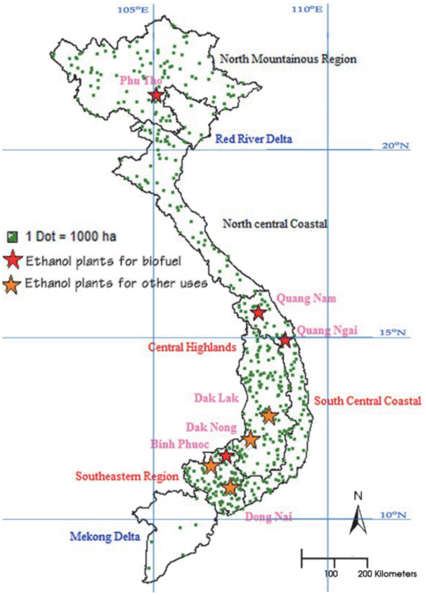
This paper aims to fill this gap in the literature by investigating the energy and GHG balances of cassava-based ethanol in the form of blends (E5 and E10) as substitutes for gasoline. The research contributes to the existing literature on energy and GHG balance accounting for biofuels by considering the effects of LUC in feedstock plantation in particular. The analysis is based on an FU of 1 km of transportation by road vehicles. A sensitivity analysis on the efficiency of E5 and E10 blends has been conducted to identify threshold values for minimum technical requirements and to compare with available technical solutions.

The structure of the paper is as follows: Section 2.2 presents the status of ethanol production in Vietnam. Section 2.3 describes the methodology for establishing energy and GHG balances in this study. The results and discussion of energy and GHG balances are presented in Section 2.4, and Section 2.5 contains our conclusions.

2.2 Cassava-based ethanol production in Vietnam

2.2.1 Cassava-based ethanol industry in Vietnam

Cassava-based ethanol production has rapidly developed in Vietnam. Up to 2010, eight ethanol plants had started with a total annual capacity of 680 million liters, of which 62% is for biofuel and the remainder for alcoholic, cosmetic, and pharmaceutics industries and export [10,12]. Seven among the eight plants are located in the Central Highlands, South Central Coastal, and Southeast regions, which contributed 72% of total cassava output in the period from 2006 to 2010 (Map 2.1). The blend stations operate in the whole country by 2012 [17].



Map 2.1 Cassava areas and ethanol plants in Vietnam.
Source: [16]

2.2.2 Cassava-based ethanol production

The process of cassava-based ethanol production includes three phases: cassava production, ethanol conversion, and ethanol distribution and blending.

Cassava production

Cassava is cultivated in less developed provinces in Vietnam (Map 2.1). Farmers start cultivating cassava in the beginning of the rainy season and harvest after 7-10 months. They conduct land preparation using tractors and manually perform stem cutting, land hoeing, and seeding. Farmers cultivate cassava under rain fed conditions. They apply synthetic and organic fertilizers, and low levels of disease control. Weeding and harvesting are also done manually. After the harvest, cassava is sliced and dried in the sun before delivery to ethanol plants in the form of dried chips. The conversion ratio of fresh root to dried chips is 2.4 kg kg^{-1}, which is derived from the survey (see Section 2.3.2 for details on the survey) and verified by other studies [12,18,19].

Ethanol conversion

There are four sub-processes to convert dried chips to ethanol: 1) milling, 2) liquefaction, 3) saccharification and fermentation, and 4) distillation and dehydration. Besides ethanol, by-products include dried distillers grains sold for animal feed production, biogas used as a supplemental energy, and CO_2 collected for sale. The conversion ratio of dried chips to ethanol in this study is 2.6 kg L^{-1}, which is derived from the survey and verified by other studies [12,18,19].

Ethanol distribution and blending

The ethanol is sold to the oil company and delivered to blending stations by trucks. At the blending stations, the tank blending process uses pumping machines to deliver gasoline and ethanol into one tank and to perform recirculation within this storage tank. Blends are then transported to gas stations for domestic consumption.

2.3 Methodology

2.3.1 Methodological issues of LCA applied to biofuels

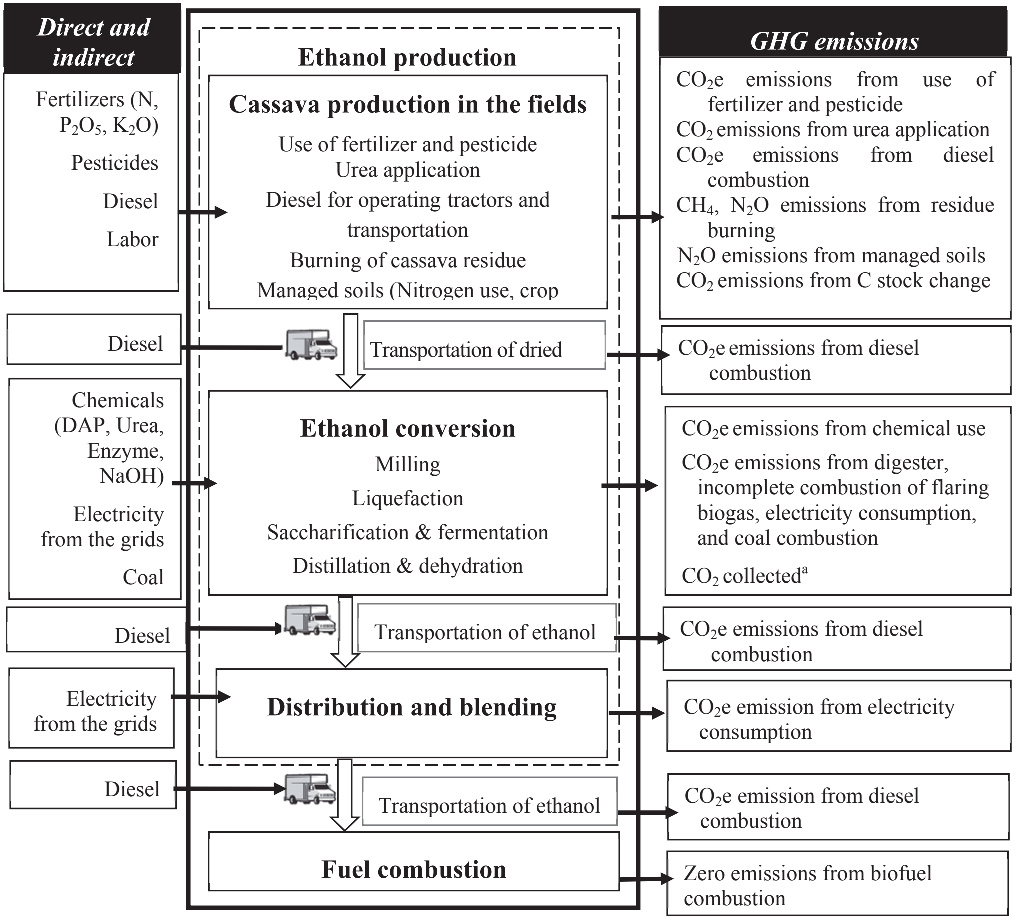
The analysis of energy and GHG balances in this paper follows the LCA and comparative analysis suggested by Gnansounou et al. [15]. In the comparative analysis, the energy and GHG balances are the differences between the energy for and the GHG emissions from the production and utilization of ethanol and those of gasoline for the same functional unit. To calculate energy input for and GHG emissions from the production and utilization of ethanol, a well-to-wheel LCA is chosen since the utilization phase is significantly affected by fuel consumption and GHG emissions from combustion.

Description of the system

Figure 2.1 shows the life-cycle system of ethanol production and utilization applied in this study. To calculate the energy input for and GHG emissions from four phases in Figure 2.1 for an FU, we calculate the energy use in terms of megajoule and GHG emissions in terms of gram of CO_2 equivalent (CO_2e) for 1 MJ of ethanol, and we then convert them for an FU.

For the cassava production, the energy use and GHG emissions are first calculated for one hectare of cassava and then converted to 1 MJ of ethanol using the cassava yield for the period from 2010 to 2025 which is projected based on the annual growth rate of 7.2% and the cassava yield in 2010 of 17.2 t ha^{-1}, the conversion ratio of fresh root to ethanol, and the lower heating value (LHV) of ethanol. For the ethanol conversion, distribution and blending, the energy use and GHG emissions are calculated for 1 L and converted to 1 MJ using the LHV of ethanol.

The energy input and GHG emissions associated with transportation are calculated from transportation distances, truck capacity, and diesel consumption (see Appendix 2.2). Three stages of transportation include transporting 1) dried chips from cassava areas to ethanol plants, 2) ethanol from processing plants to blending stations, and 3) ethanol from blending stations to gas stations. Each national distance is the average of three regional distances with the weights of corresponding capacities.



a A GHG emission saving

Figure 2.1 Life cycle system of ethanol production and utilization.

Functional unit and sensitivity analysis

Following the suggestion by Gnansounou et al. [15], this study applies the FU of travelling 1 km using gasoline or ethanol as mechanical energy for road vehicles in the comparison between ethanol and gasoline. To compare the life-cycle energy and GHG emissions of ethanol to those of gasoline, this study separates the fuel efficiency of ethanol (E100) from the obtainable efficiencies of gasoline and the blends of E5 and E10. It assumes that the efficiency of the gasoline component in the blends is the same as its own and that the efficiency of ethanol is explained by its contribution to the blends after deducting that of the gasoline component [15].

Table 2.1 Properties of gasoline, E5, and E10.

Properties	Unit	Gasoline	Ethanol	E5[a]	E10[a]
Density	$g\ L^{-1}$	743.00	790.00	745.40	747.70
LHV	$MJ\ L^{-1}$	32.17	21.10	31.62	31.06

a The properties of blends are calculated from those of gasoline and ethanol and the volume shares [15].
Source: [20]

Table 2.1 provides the fuel properties as a base to convert from fuel consumption to efficiency indicator. Table 2.2 presents the experimental results concerning the fuel consumption of blends with respect to (w.r.t) gasoline. Following these results, it is argued that the lower LHVs of blends cause higher fuel consumption, while their higher octane values and compression ratios improve the thermodynamic properties, and thus may reduce the fuel consumption [15,18,21-26]. But fuel efficiency is affected not only by these properties but also by other factors such as vehicle speed and gear, vehicle models, and road conditions.

Table 2.2 Percentage change in fuel consumption of blends w.r.t gasoline.

Blends	E5		E10		Source
Fuel consumption indicators	L km^{-1}	g kW h^{-1}	L km^{-1}	g kW h^{-1}	
Vehicle					
- Ford Laser Ghia 1.8		-5.18[a]		-4.19	[21]
- Honda Super Dream 100 cc		-6.37		-5.41	[21]
- 1.4i SI engine	5.20[b]	2.80-0.20[c]	5.50[b]	3.60-1.50[c]	[22,23]
- Ford Focus	-1.20[d]				[15]
- Renault Megane	-0.60				[24]
- Various car models			-5.63[d]		[15,25]
- Toyota 1.6 L/2000			1.13		[18]
- XU7JP/L3 engine			5.07		[26]

a A minus sign means the lower fuel consumption of blends w.r.t gasoline.

b Ref. [23].

c Ref. [22], these two values are measured at the vehicle speeds of 80 km h^{-1} and 100 km h^{-1} respectively.

d These are averaged from the figures in Ref. [15].

For this reason, a sensitivity analysis is conducted to evaluate the effects of different fuel consumption of blends w.r.t gasoline and to provide a general assessment on energy and GHG balances of ethanol. The percentage change in fuel consumption of blends w.r.t gasoline is considered at three levels, formulating 6 scenarios: S1, S2, and S3 are the cases of E5 with 5% higher, the same, and 5% lower levels of fuel consumption respectively; S4, S5, and S6 are the cases of E10 with 5% higher, the same, and 5% lower levels of fuel consumption respectively. The efficiency of the ethanol component in blends is separated in the column 8 of Table 2.3. Accordingly, the energy use and CO_2e emissions are calculated for 1 km and compared to the equivalent values of gasoline in the analysis of energy and GHG balances.

Table 2.3 Fuel efficiency of ethanol component in blends.

Indicator	Blend			Gasoline component		Ethanol component		
	Fuel consumption	Fuel efficiency		Percentage of gasoline energy in blend (%)	Fuel efficiency	Percentage of ethanol energy in blend (%)	Fuel efficiency	
	(L km^{-1})	(MJ km^{-1})	(km MJ^{-1})		(km MJ^{-1})		(km MJ^{-1})	(MJ km^{-1})
	(1)	(2)	(3) = 1: (2)	(4)[f]	(5) = (3) for gasoline	(6)[g]	(7) = ((3) x 100 – (4) x (5)) : (6)	(8) = 1: (7)
Gasoline	0.080[b]	2.56[a]	0.39	100.00	0.39			
- S1 (E5, +5%)	0.084[c]	2.65	0.38	96.66	0.39	3.34	0.03	35.32
- S2 (E5, 0%)	0.080[d]	2.52	0.40	96.66	0.39	3.34	0.59	1.68
- S3 (E5, -5%)	0.076[e]	2.39	0.42	96.66	0.39	3.34	1.22	0.82
- S4 (E10, +5%)	0.084[c]	2.60	0.38	93.21	0.39	6.79	0.31	3.21
- S5 (E10, 0%)	0.080[d]	2.48	0.40	93.21	0.39	6.79	0.59	1.68
- S6 (E10, -5%)	0.076[e]	2.35	0.43	93.21	0.39	6.79	0.91	1.10

a Ref. [15].

b This figure is calculated from 2.56 MJ km^{-1} and the LHV of gasoline.

c These figures equal the consumption of gasoline multiplied by 1.05 respectively.

d These figures equal the consumption of gasoline multiplied by 1 respectively.

e These figures equal the consumption of gasoline multiplied by 0.95 respectively.

f These figures equal the volume share of gasoline in blends (0.95 for E5 and 0.9 for E10) multiplied by the LHV of gasoline and divided by the LHV of blend.

g These figures equal the volume share of ethanol in blends (0.05 for E5, and 0.1 for E10) multiplied by the LHV of ethanol and divided by the LHV of blend.

2.3.2 Data collection

Except for secondary data from the literature, the primary data are collected through the survey that was done in the harvesting season of cassava from January to April in 2011. We selected four of the top ten cassava producing provinces: Binh Phuoc, Tay Ninh, Dong Nai and DakNong. We interviewed 102 farmers, 8 managers in 4 ethanol plants, 32 other stakeholders (starch processors, input suppliers, and hired labourers), and 24 key informants to obtain data on 1) farm inputs, 2) on-site conversion ratios of fresh root to dried chip and to ethanol, 3) ethanol conversion inputs, 4) LUC estimation, and other information.

2.3.3 Energy balance analysis

The energy balance compares the energy input for the production and utilization of ethanol with that of gasoline for the same FU. The energy input is calculated at the primary energy level using the energy input efficiencies from GREET [27] and Biograce [28]. The energy input of gasoline is 1.1375 MJ MJ^{-1} [27]. For the ethanol, we calculate both direct and indirect energy inputs (Figure 1.1). The former includes diesel for operating tractors and transportation, coal for ethanol conversion, and electricity for ethanol conversion and blending. The latter is embodied in other inputs including fertilizers, pesticides, labor, chemicals, plant construction, machine, and vehicles. Labor in farming is converted into energy using the most popular method of "Total Food Consumed" with a ratio of 2.3 MJ h^{-1} [29-32]. The indirect energy inputs for plant construction, machine, and vehicles are not considered in this study due to the lack of data and their trivial amounts [18,30,33]. The LHVs and energy input efficiencies are presented in Table 2.5. In addition to these parameters, we collected the energy inputs for ethanol production from the survey. The details have been provided in the Appendix 2.3.

2.3.4 GHG balance analysis

The GHG balance compares the GHG emissions from production and utilization of ethanol with that of gasoline for the same FU. The three GHGs consisting of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are aggregated to the CO_2 equivalent (CO_2e) using the global warning potential (GWP) factors [28,34]. The GHG emissions from the production and combustion of gasoline are 83.8 g MJ^{-1} [28,35]. The emission from ethanol combustion is zero according to the Renewable Energy Directive (RED) [35]. The GHG emissions from ethanol production are calculated using the guidelines from the IPCC, RED, and Biograce [28,34-36]. The emissions from plant construction and production of equipment and vehicles are not taken into account under the cut-off criteria suggested in the literature [28,35,36].

Details are presented in the Appendix 2.4. The emission sources and emission factors (EFs) are listed in Figure 1 and Table 2.8 respectively.

In the cassava production phase, seven emission sources are considered, namely fertilizer use, pesticide use, diesel consumption, urea application, burning cassava residue, N_2O emissions from managed soils, and carbon stock (CS) change caused by LUC. The first three emissions are calculated by multiplying the EFs and corresponding amounts of these inputs per liter of ethanol. The emissions from manure application are taken to be zero [28]. The fourth is calculated from the amount of urea per ha and its EF.

For the emissions from burning cassava residue, the weight of cassava residue is estimated from the harvest index reported by Hoang et al.[37]. 79% of cassava residue is burnt, and 21% is returned to soil according to the survey. For N_2O emissions from managed soils, we need the EF of volatilized and re-deposited nitrogen, the EF of nitrogen lost through leaching from [34], and the amounts of nitrogen in synthetic fertilizers, organic fertilizers, and cassava residue. The nitrogen contents of cassava residue and manure as organic fertilizers are 0.016 and 0.0032 kg kg^{-1} respectively [38,39]. The nitrogen associated with the loss of soil carbon stock (SOC) due to LUC is calculated from the SOC change, percentages of LUC, and carbon nitrogen ratios (Appendix 2.5).

Table 2.4 Projection of cassava area and LUC for cassava production expansion.

- Ethanol production in 2009	kt	2	- Cassava yield in 2010	t ha^{-1}	17.17[b]
- Ethanol production in 2025	kt	600[a]	- Annual growth rate of cassava yield	% y^{-1}	7.20[b]

	Total	Forest land	Grassland[c]	Annual cropland	Perennial cropland
- Mono-cropped cassava (%)	87.83	11.68	31.15	26.09	18.92
- Inter-cropped cassava (%)	12.17	-	-	2.46	9.71
Percentage in total area (%)	100.00	11.68	31.15	28.55	28.63
Area in 2025 (ha)	94086	10989	29305	26856	26936

a Ref. [8].
b Ref. [16].
c The barren land and denuded hills in Vietnam are considered as grassland.

Concerning the LUC due to cassava expansion, the ethanol industry could use cassava from newly cultivated areas and other sources. With a focus on the impact of GHG emissions from cassava cultivation, this study assumes that cassava for biofuel feedstock comes wholly from newly domestic cultivation as a result of LUC. Table 2.4 shows the projection of cassava area for the targeted ethanol volume of 600 kt in 2025, and LUC estimation from the fourteen leading cassava producing provinces with a contribution of 66% to the total cassava area in the period from 2005 to 2009 (Appendix 2.6). The survey indicated that 88% newly-cultivated cassava would be expanded as a mono-crop, and 12% as an intercrop with other perennial crops. To meet the targeted volume, a cassava area of 94,086 ha is required by the year 2025, equivalent to 19% of the cassava area or 1.5% of the arable land in 2009 [16].

For the emissions from CS change caused by LUC, the CS is the sum of SOC and the vegetation carbon stock (C_{VEG}) reflecting change in plant carbon sequestration. The CO_2 emission from CS change is calculated by multiplying the CS change and corresponding percentage of LUC.

For the ethanol conversion phase, the emissions from the ethanol conversion with an anaerobic digester are collected from the document published by the UNFCCC [40]. The advanced technology supports to collect CO_2 from the fermentation process for further use in food and chemical industries. Therefore, the eventual effect is the GHG emission minus the CO_2 collected. For the distribution and blending, GHG emissions from electricity and diesel consumption are calculated by multiplying the EFs of electricity and diesel and their amounts described in Section 2.3.3.

2.4 Results and discussion

2.4.1 Energy balance analysis

Energy input for cassava-based ethanol production

The direct energy inputs include coal, electricity, and diesel; the indirect are chemical, fertilizers, pesticide, and labor in farming (Table 2.5). The biogas by-product in form of methane is used in the conversion process itself. In terms of energy inputs, coal is the most important, accounting for 81.0% of total energy. Electricity and diesel contribute 8.2% and 5.0% of total energy respectively. Indirect inputs have the portion of 5.9%. Regarding the three phases, the most energy consuming phase is ethanol conversion which accounts for 89.8% of total energy. This is followed by cassava production (8.1%) and the distribution and blending phase (2.1%). The total energy input is 19.71 MJ L^{-1} or 0.94 MJ MJ^{-1}, which is lower than that of gasoline.

Table 2.5 Energy input for cassava-based ethanol production in Vietnam.

Inputs	Unit	Energy content[b] (MJ per unit)	Energy input efficiency (MJ MJ^{-1} or MJ per unit)[a]	Input (unit per L)	Energy input	
					MJ L^{-1}	%
Cassava production					*1.60*	*8.13*
Fertilizers and pesticides					0.75	
N	kg		48.99[c]	0.010	0.51	
P_2O_5	kg		15.23[c]	0.009	0.13	
K_2O	kg		9.68[c]	0.010	0.09	
Pesticides	kg		268.40[c]	0.00004	0.01	
Labor	h		2.30[d]	0.118	0.27	
Diesel for operating tractors	L	35.87	1.14[e]	0.003	0.11	
Diesel for transportation	L	35.87	1.14	0.012	0.48	
Ethanol conversion					*17.69*	*89.77*
Chemicals					0.14	
NaOH	kg		10.22[c]	0.003	0.03	
Urea	kg		22.78[e]	0.003	0.07	
DAP	kg		8.60[f]	0.003	0.03	
Enzyme	kg		15.00[f]	0.001	0.02	
Electricity	kW h	3.60	1.57[g]	0.281	1.59	
Coal	kg	24.44	1.09[c]	0.600	15.96	
Distribution and blending					*0.41*	*2.10*
Diesel for transportation	L	35.87	1.14	0.010	0.39	
Electricity for blending	kW h	3.60	1.57	0.004	0.02	
Total					19.71	100.00

a MJ MJ^{-1} for the direct energy inputs, and MJ per unit for the indirect.
b Ref. [20].
c Ref. [28].
d Ref. [29-32].
e Ref. [27].
f Ref. [42].
g Ref. [1].

Energy balance of cassava-based ethanol

Different fuel consumption of blends leads to the different efficiency of ethanol and thus energy balances noting that the six scenarios are described in Section 2.3.1. All scenarios achieve energy savings except for scenarios S1 and S4 (Table 2.6). For instance, the ethanol substitution for gasoline in form of E5 would save 1.4 MJ or 46.1% of primary energy input for every km in scenario S2. The energy balances are positive in scenarios S1 and S4, meaning that the ethanol substitution for gasoline would not save energy input. Seeking for breakeven points, we find a zero energy balance if the fuel consumption of E5 and E10 is respectively 2.4% and 4.5% higher than the consumption of gasoline per kilometer. This means that the use of E5 and E10 as a substitute for gasoline achieve energy savings, provided that their fuel consumption in terms of liter per kilometer of transportation is not exceeding the consumption of gasoline by more than 2.4% and 4.5% respectively.

Table 2.6 Energy balance of cassava-based ethanol in Vietnam.

Fuel	Energy input (MJ MJ^{-1})	Fuel efficiency (MJ km^{-1})	Energy input per FU (MJ km^{-1})		Energy balance	
			Ethanol	Gasoline	MJ km^{-1}	%
	(1)	(2)[a]	(3) = (1) x (2) for ethanol	(4) = (1) x (2) for gasoline	(5) = (3) - (4)	(6) = ((5) : (4)) x 100
Gasoline	1.138	2.56		2.9166		
Ethanol						
- S1 (E5, +5%)	0.934	35.32	32.99	2.9166	30.07	1031.12
- S2 (E5, 0%)	0.934	1.68	1.57	2.9166	-1.35[b]	-46.14
- S3 (E5, -5%)	0.934	0.82	0.77	2.9166	-2.15	-73.76
- S4 (E10, +5%)	0.934	3.21	3.00	2.9166	0.08	2.83
- S5 (E10, 0%)	0.934	1.68	1.57	2.9166	-1.35	-46.14
-S6 (E10, -5%)	0.934	1.10	1.03	2.9166	-1.89	-64.71

a These values are from the column 8 of Table 2.3.

b A minus sign means an energy saving. The breakeven point is achieved if the fuel consumption of E5 and E10 is respectively 2.4 and 4.5% higher than the consumption of gasoline. These are equivalent to 0.0816 and 0.0833 L km^{-1} for E5 and E10 respectively using the gasoline consumption of 0.0797 L km^{-1} [15].

As for the ethanol targeted volume of 600 kt in 2025, the savings would reach from 13 to 42 PJ of primary energy input depending on the efficiency of blends, equivalent to 2.6-8.6% of fuel consumption in the transport sector in 2009 (Appendix 2.7). The ethanol plants are well located around cassava areas to shorten transportation distances, and almost all ethanol plants utilize biogas by-products. Opportunities for reducing energy input lie in the improvements of cassava yield, more sustainable cultivation (shifting from chemical to organic fertilizers), and a higher energy-efficient substitute for coal. In addition to the efforts from the cassava and ethanol producers, the energy balance can be improved through adaptation of vehicle engines to increase the efficiency of blends.

Energy input of cassava-based ethanol: a comparison with other studies

Due to different concepts of energy balance in the studies, this comparison focuses on the energy input of ethanol (Table 2.7). The energy input variation is explained by 1) the feedstock, 2) feedstock yields, 3) the application of energy inputs in feedstock production, and 4) the energy intensity of ethanol industry [41]. This study focuses on cassava-based ethanol, keeping the first element constant.

Table 2.7 Energy input of cassava-based ethanol: a comparison with other studies.

Cases	Dai et al. [30]	Leng et al. [19]	Nguyen et al. [18]	This study
Energy input (MJ L^{-1})	13.71	16. 59	12.06	19.71

Regarding the three remaining elements, our study applied the average projected yield of 33 t ha^{-1} for the period from 2010 to 2025, while the others used different yields from 27 to 39 t ha^{-1} [18,19,30]. Given constant farm energy inputs, the higher the yield applied, the lower the amount of energy spent per liter of ethanol. For energy input of labor, our study applied 648 h ha^{-1} while 1920 and 433 h ha^{-1} are used in Refs [30] and [18] respectively. The ratio of 2.3 MJ h^{-1} is mostly used while 12.1 MJ h^{-1} is applied in Ref. [18]. The different fertilizer and pesticide application, truck capacity, and transportation distance all contribute to the energy input variation. For the ethanol conversion, this study includes the indirect energy inputs of chemicals, but others do not. The direct energy inputs are similar in the four studies with the anaerobic digester installation and biogas utilization.

2.4.2 GHG balance analysis

GHG emissions from cassava-based ethanol production

The literature has mentioned the lack of explicit attention to the effects of LUC and change in soil management in feedstock plantation on GHG emissions, causing an increasing doubt about the GHG emission saving attributed to biofuels [7,14]. These effects are considered in our study following the guidelines from the IPCC, RED, and Biograce [28,34-36].

The ethanol production would result in a GHG emission in terms of CO_2e of 738 g L^{-1} or 35 g MJ^{-1} (Table 2.8). The cassava production contributes an emission of 1068 g L^{-1}, of which 66 and 15% are from carbon stock change caused by LUC and N_2O emissions from managed soil respectively. These are followed by the emissions from the fertilizer application and burning residue (14%) and the emissions from diesel consumption (4%).

Table 2.8 GHG emissions from cassava-based ethanol production in Vietnam.

Emission source	Unit	Emission factor (g per unit)	Input (unit per L)	CO_2e emissions (g L^{-1})
Emissions from cassava production				*1067.73*
Fertilizer and pesticides				75.54
- N	kg	5880.60[a]	0.0104	61.43
- P_2O_5	kg	1010.70[a]	0.0085	8.56
- K_2O	kg	576.10[a]	0.0096	5.55
- Pesticides	kg	10971.30[a]	0.00004	0.46
Diesel consumption				43.24
- Diesel for operating tractors	L	3005.91[a]	0.0027	8.17
- Diesel for transportation of dried chip	L	3005.91[a]	0.0117	35.07
Urea	ha	37227.05	0.0002	6.75
Emissions from burning cassava residue	ha	415826.09	0.0002	75.39
N_2O emissions from managed soil	ha	886552.24	0.0002	160.73
- Direct emissions	ha	689456.71	0.0002	125.00
- Indirect emissions	ha	197095.53	0.0002	35.73
Annualized emissions from carbon stock changes caused by LUC	ha	3892012.58	0.0002	705.62
Emissions from ethanol conversion				*-361.26*[c]
CO_2 collected				-490.00
Chemicals				16.57
- DAP	kg	1527.00[a]	0.0030	4.59
- Urea	kg	3167.00[a]	0.0030	9.52
- Enzyme	kg	1000.00[b]	0.0011	1.05
- NaOH	kg	469.30[b]	0.0030	1.41
Other emissions				112.17
Emissions from distribution and blending				*31.07*
- Electricity for blending	kW h	565.20[a]	0.0037	2.08
- Diesel for transportation	L	3005.91[a]	0.0075	28.99
Total				737.55

a Ref. [28].

b Ref. [42].

c A minus sign means a GHG emission saving.

The ethanol conversion with the anaerobic digester induces a GHG emission of 129 g L^{-1}, of which 87% comes from facilities, e.g. CH_4 emission from the digester and incomplete combustion of flaring biogas, CO_2e emissions from electricity and coal consumption, and 13% is attributed to chemical use. However, they collect 490 g L^{-1} from the fermentation process for further use in other industries. The eventual effect is the net GHG emission saving of 361 g L^{-1}. The distribution and blending contributes 31 g L^{-1}.

GHG balance of cassava-based ethanol

Table 2.9 GHG balance of cassava-based ethanol in Vietnam.

Fuel	CO_2e emissions (g MJ^{-1})	Fuel efficiency (MJ km^{-1})	CO_2e emissions per FU (g km^{-1})		GHG balance	
			Ethanol	Gasoline	g km^{-1}	%
	(1)	(2)[a]	(3) = (1) x (2) for ethanol	(4) = (1) x (2) for gasoline	(5) = (3) - (4	(6)=((5) : (4)) x 100
Gasoline	83.80	2.56		214.86		
Ethanol						
- S1 (E5, +5%)	34.95	35.32	1234.46	214.86	1019.60	474.53
- S2 (E5, 0%)	34.95	1.68	58.78	214.86	-156.08[b]	-72.64
- S3 (E5, -5%)	34.95	0.82	28.64	214.86	-186.22	-86.67
- S4 (E10, +5%)	34.95	3.21	112.22	214.86	-102.64	-47.77
- S5 (E10, 0%)	34.95	1.68	58.78	214.86	-156.08	-72.64
- S6 (E10, -5%)	34.95	1.10	38.51	214.86	-176.35	-82.08

a These values are from the column 8 of Table 2.3.

b A minus sign means a GHG emission saving. The breakeven point is achieved if the fuel consumption of E5 and E10 is respectively 3.8 and 7.8% higher than the consumption of gasoline. These are equivalent to 0.0827 and 0.0859 L km^{-1} for E5 and E10 respectively using the consumption of gasoline of 0.0797 L km^{-1} [15].

Different fuel consumption of blends leads to different GHG balances noting that the six scenarios are described in Section 2.3.1 (Table 2.9). All scenarios result in emission savings except for scenario S1. For example, the ethanol substitution for gasoline in form of E5 would save an emission of 156 g or 72.6% of GHG emissions from the combustion of the equivalent amount of gasoline for every km in the scenario S2. The GHG balance is positive in scenario S1, meaning that the substitution would cause an increase in emissions. Seeking for the breakeven points, we find a zero balance if the fuel consumption of E5 and E10 is respectively 3.8% and 7.8% higher than the consumption of gasoline per kilometer. This means that the use of E5 and E10 as a substitute for gasoline would achieve an emission saving, provided that their fuel consumption is not exceeding the consumption of gasoline per kilometer by more than 3.8% and 7.8% respectively.

As for the ethanol targeted volume of 600 kt in 2025, the emission saving would reach from 512 to 3643 kt depending on the efficiency of blends, equivalent to 1.4-10.1% of the emissions from gasoline production and combustion in the transport sector in 2009 (Appendix 2.7). The opportunities for further emission savings lie in improved agricultural practices, particularly a reduction of burning residue, a lower nitrogen application, and more sustainable cultivation to minimize the effects of LUC and soil management.

GHG emissions from cassava-based ethanol: a comparison with other studies

Due to different concepts of GHG balance in the studies, this comparison focuses on the GHG emissions from ethanol production (Table 2.10). The emission variation is explained by 1) three elements discussed in Section 2.4.1 with the most significant being conversion technology and by-product utilization, 2) the effects of LUC and soil management, and 3) the consideration of CO_2 photosynthesis of cassava [15,44-47].

Table 2.10 GHG emissions of cassava-based ethanol: a comparison with other studies.

Case study	Leng et al. [19]	Hu et al. [43]	Nguyen et al. [18]	Silalertruksa and Gheewala [44]	This study
CO_2e emissions (g L^{-1})	15,483	21	964	1328 – 6437[a]	738

[a] This study results in GHG emissions from 1328 to 6437 g L^{-1} for scenarios with the alternative LUC and utilization of by-product.

Firstly, the emissions are reduced by the advanced technology and by-product utilization [45-47]. The study [44] and our study both consider the utilization of biogas. The electricity generating biogas is assigned to earn the emission credit equal to life-cycle GHG emissions from the production of electricity in Ref. [44]. In our study, the biogas utilization reduces the energy input and thus the corresponding attributed emissions; the advanced technology supports to collect CO_2. Therefore, the ethanol conversion attains an emission saving in our study. Regarding the emissions attributed to energy consumption, the diesel consumption of 109 L ha^{-1} is used for farm activities in Ref. [44], which is twice higher than the amount in our study. The transportation distances of dried chip and ethanol in Ref. [19] are 250 and 350 km respectively, which are 1.5 and 7 times longer than those in our study.

Secondly, the emissions from the effects of LUC and soil management are considered in our study and the study [44] but overlooked in the other studies. The high effect of residue burning causes a high emission in Ref. [19]. Thirdly, while a direct measure of CO_2 photosynthesis during cassava cultivation is assumed to equal the CO_2 emission from the combustion of blends in Ref. [44] or an emission saving in Ref. [43], it is considered as the change in plant carbon sequestration in the LUC effect in our study. The saving of CO_2 photosynthesis reduces the emissions in Ref. [43].

2.5 Conclusions

This study analyses the energy and GHG emission balances of cassava-based ethanol production and utilization as a substitute for gasoline. The energy balance analysis shows that the energy input of ethanol is 0.93 MJ MJ^{-1} and that the use of E5 and E10 as a substitute for gasoline results in energy savings, provided that their fuel consumption in terms of liter per kilometer of transportation is not exceeding the consumption of gasoline per kilometer by more than 2.4% and 4.5% respectively. The analysis of GHG balance shows that ethanol production results in a GHG emission of 35 g MJ^{-1} and that the use of E5 and E10 would achieve a GHG emission saving, provided that fuel consumption of E5 and E10 is not exceeding the consumption of gasoline per kilometer by more than 3.8% and 7.8% respectively. Testing results for vehicle engines for Vietnam show that the required fuel consumption of blends is feasible and that actually higher efficiencies can be obtained. The sensitivity analysis illustrates that the further adaptation of vehicle engines to reduce fuel consumption of blends compared to gasoline would lead to higher achievements of ethanol substitution. Even better results can be obtained through improvement of energy input efficiency in ethanol production by using a more energy-efficient substitute for coal, an improvement of cassava yield, and more sustainable cultivation. The further GHG emission saving are achieved by an increase in residue returned to soil and more sustainable cultivation of cassava.

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Appendices

Appendix 2.1 Energy and GHG balances of jatropha-based biodiesel

Appendix 2.1.1 Jatropha-based biodiesel production

The process of jatropha-based biodiesel production includes three phases, namely jatropha production, biodiesel processing, and biodiesel distribution and blending.

Jatropha production

Data on plantation was obtained from the experiments of Forest Science Institute of Vietnam and the survey and cross-checked with literature [48-52]. Jatropha is planted in the beginning of rain seasons from seedlings. Farmers use tractors for land preparation and manually perform hoeing, planting, applying fertilizers and pesticide, weeding, pruning, harvesting and seed husking. Irrigation is applied for three months in dry season. Fruits are manually harvested, dried under the sun and husked to obtain dried seeds for delivery to biodiesel plants.

Jatropha-based biodiesel production

Data on biodiesel processing was obtained from the experiments of biodiesel plants, the Research institute for Oil and Oil Plant, the Institute of Tropical Biology and cross-checked with other studies [49,53,54] (Figure 2.A1). Mechanical extraction is applied in Vietnam. The average seed oil content is 0.35, the extraction and transesterification efficiencies are 0.80 and 0.95 respectively.

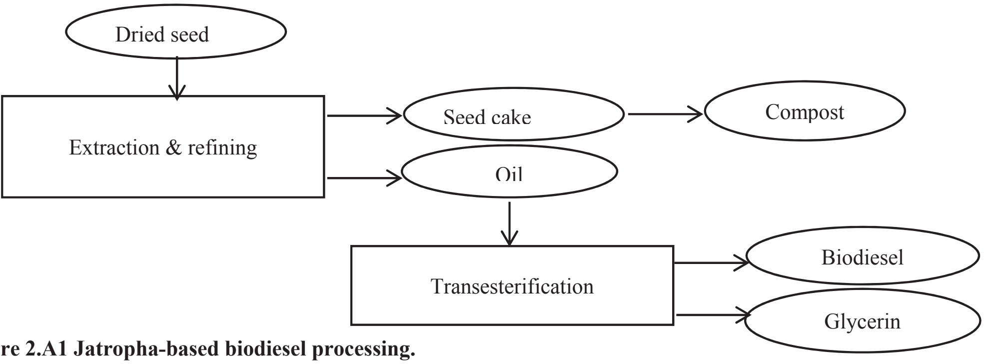

Figure 2.A1 Jatropha-based biodiesel processing.
Source: Survey (2011)

Biodiesel distribution and blending

The distribution and blending of biodiesel are the same as those of ethanol with the sale to oil companies, delivery to blending stations, and the tank blending process.

Appendix 2.1.2 Energy balance of jatropha-based biodiesel

Table 2.A1 Energy input for jatropha-based biodiesel production in Vietnam.

Inputs	Unit	Energy content [b] (MJ per unit)	Energy input efficiencies ($MJMJ^{-1}$ or MJ per unit)[a]	Input (unit per L)	Energy inputs	
					$MJ\ L^{-1}$	%
Jatropha production					*5.89*	*40.21*
Fertilizers and pesticides					1.95	
- N	kg		48.99[c]	0.028	1.37	
- P_2O_5	kg		15.23[c]	0.028	0.43	
- K_2O	kg		9.68[c]	0.014	0.14	
- Pesticides	kg		268.40[c]	0.00004	0.01	
Labor	h		2.30[d]	1.007	2.32	
Diesel for farming	L	35.87	1.14[e]	0.020	0.80	
Diesel for seed transportation	L	35.87	1.14	0.020	0.83	
Biodiesel processing					*8.38*	*57.20*
Chemical					7.51	
- NaOH	kg		10.22[c]	0.009	0.09	
- Methanol	kg		33.02[c]	0.225	7.42	
Electricity	kW h	3.60	1.57[f]	0.154	0.87	
Distribution and blending					*0.38*	*2.59*
Electricity for dispensing	kW h	3.60	1.57	0.004	0.02	
Diesel for transportation	L	35.87	1.14	0.009	0.36	
Total					14.65	100.00

a $MJ\ MJ^{-1}$ for the direct energy inputs, and MJ per unit for the indirect.
b Ref. [20].
c Ref. [28].
d Ref. [29-32].
e Ref. [27].
f Ref. [1].

The total energy input of biodiesel production is 14.65 $MJ\ L^{-1}$ or 0.4490 $MJ\ MJ^{-1}$ (Table 2.A1). In terms of energy inputs, the indirect energy inputs amount to 80.4% of total energy, of which the most energy input of methanol accounts for 50.7%; labour and fertilizer contribute 15.8% and 13.3% respectively. The direct energy inputs of diesel and electricity contribute 19.7% of total energy. In view of the three phases, the biodiesel processing phase accounts for 57.2%, which is followed by the jatropha production phase (40.2%) and distribution and blending phase (2.6%).

Concerning energy balance at different fuel efficiency levels of biodiesel, except for scenario S8, all other scenarios achieve an energy saving (Table 2.A2). For example, the biodiesel substitution for diesel in form of B5 would save 1.41 MJ or 64.06% of primary energy input for every km in scenario S7. In scenario S8 with 5% higher fuel consumption of B5 w.r.t diesel, the energy balances are positive, meaning that the substitution would not save energy input. The breakeven points with a zero energy balance are found at 3.31% and 6.85% higher fuel consumption of B5 and B10 compared to diesel, respectively. This means that the biodiesel substitution for diesel in form of B5 or B10 would achieve an energy saving, provided that the fuel consumption of B5 and B10, in terms of liter per kilometre of transportation compared to diesel, is not exceeding the consumption of diesel by more than 3.31% and 6.85% respectively.

Table 2.A2 Energy balance of jatropha-based biodiesel in Vietnam.

Fuel	Energy input (MJ MJ^{-1})	Fuel efficiency (MJ km^{-1})	Energy input per FU (MJ km^{-1})		Energy balance	
			Biodiesel	Diesel	MJ km^{-1}	%
	(1)	(2) [a]	(3)=(1)x(2) for biodiesel	(4)=(1)x(2) for diesel	(5)=(3)-(4)	(6)=((5):(4))x100
Diesel	1.137	1.94		2.2019		
Biodiesel						
- S7 (B5, 0%)	0.449	1.76	0.79	2.2019	-1.41[b]	-64.06
- S8 (B5, +5%)	0.449	37.01	16.62	2.2019	14.42	654.71
- S9 (B10, 0%)	0.449	1.76	0.79	2.2019	-1.41	-64.06
- S10 (B10, +5%)	0.449	3.36	1.51	2.2019	-0.69	-31.39

a These values are from column 8 of Table 3.3.

b A minus sign means an energy saving.

The biodiesel target of 250 kt would achieve from 1.8 to 7.1 PJ, equivalent to 0.4 to 1.4% of fuel consumption in the transport sector in 2009. Almost all of biodiesel plants are located in jatropha-producing areas to minimize transportation distances. Opportunities for reducing energy input lie in the improvements of jatropha yield due to nearly half of total energy attributed to this phase, more sustainable cultivation, e.g. shifting from chemical to organic fertilizers, an improvement of chemical utilization in biodiesel processing, and a reduction in the use of human labor in dried seed production by using the mechanical husking. Beside the efforts from biodiesel producers, the energy balance could also be further improved by adapting vehicle engines to biodiesel use.

Appendix 2.1.3 GHG balance of jatropha-based biodiesel

The biodiesel production would result in a GHG emission saving in terms of CO_2e of 2143 g L^{-1} or 65.65 g MJ^{-1} (Table 2.A3). The jatropha production results in an emission saving of 2615.5 g L^{-1} owing to an increase in carbon stock changes caused by LUC following the jatropha production. Biodiesel processing phase contributes a GHG emission of 443.8 g L^{-1}, of which 80.4% derives from chemical use and 19.6% from electricity consumption. The distribution and blending phase accounts for 28.7g L^{-1}.

The biodiesel target of 250 kt would achieve from 617 to 1391 thousand tonnes of CO2e, equivalent to 1.7 to 3.9% of the emissions from fuel consumption in the transport sector in 2009. As the production and utilization of biodiesel produce a GHG emission saving, the biodiesel substitution for diesel achieves a GHG emission saving in all scenarios (Table 2.A4). However, its consumption should be considered other aspects of positive contribution of biodiesel to blends, energy efficiency, and cost effectiveness.

Table 2.A3 GHG emissions from jatropha-based biodiesel production in Vietnam.

Emission source	Unit	Emission factor (g per unit)	Input (unit per L)	CO_2e emissions (g L^{-1})
Emissions from jatropha production				*-2615.45*[a]
Fertilizer and pesticides				202.07
- N	kg	5880.60[b]	0.0280	164.82
- P_2O_5	kg	1010.70[b]	0.0280	28.33
- K_2O	kg	576.10[b]	0.0140	8.07
- Pesticides	kg	10,971.30[b]	0.00004	0.43
Diesel consumption				120.05
- Diesel for operating tractors	L	3,005.91[b]	0.01951	58.63
- Diesel for seed transportation	L	3005.91[b]	0.02043	61.42
Emissions from burning of jatropha residue	ha	74,982.84	0.00097	72.72
N_2O emissions from managed soils	ha	61,938.08	0.00097	60.07
- Direct emissions	ha	34,589.42	0.00097	33.55
- Indirect emissions	ha	27,348.66	0.00097	26.52
Annualised emissions from carbon stock changes caused by LUC	ha	-3,165,362.51	0.00097	-3069.94[a]
Emissions from biodiesel processing				*443.82*
Chemical				356.81
- NaOH	kg	469.30[b]	0.00880	4.13
- Methanol	kg	1569.73[b]	0.22467	352.68
Electricity for processing	kWh	565.20[b]	0.15395	87.01
Emissions from distribution and blending				*28.72*
Electricity for blending	kWh	565.20[b]	0.003675	2.08
Diesel for transportation				26.64
- B100	L	3005.91[b]	0.00667	20.06
- Blends	L	3005.91[b]	0.00219	6.58
Total				-2142.92

a A minus sign means a GHG emission saving. b Ref. [28].

Table 2.A4 GHG balance of jatropha-based biodiesel in Vietnam.

Items	CO_2e emissions (g MJ^{-1})	Fuel efficiency (MJ km^{-1})	CO_2e emission per FU (g km^{-1})		GHG balance	
			Biodiesel	Diesel	g km^{-1}	%
	(1)	(2)[b]	(3)=(1)x(2) for biodiesel	(4)=(1)x(2) for diesel	(5)=(3)-(4)	(6)= ((5):(4)) x100
Diesel	83.80	1.9370		162.32		
Biodiesel	-65.65[a]					
- S7 (B5, 0%)	-65.65	1.7626	-115.72	162.32	-278.04	-171.29
- S8 (B5, +5%)	-65.65	37.0137	-2,430.07	162.32	-2,592.39	-1,597.10
- S9 (B10, 0%)	-65.65	1.7626	-115.72	162.32	-278.04	-171.29
- S10 (B10, +5%)	-65.65	3.3649	-220.92	162.32	-383.23	-236.10

a A minus sign means a GHG emission saving.

b These values are from column 8 of Table 3.3.

Appendix 2.2 Transportation distances, truck capacities, and fuel consumption

Table 2.A5 Transportation distances, truck capacities, and diesel consumption.

Items	By region			Vietnam
	North	Central	South	
Ethanol processing capacity (%)	23.8	52.4	23.8	100
Regional distance (km)				
- Dried chip	100	100	100	100
- Ethanol from plants to blending stations	120	180	200	170
- Ethanol from blending to gas stations	50	50	50	50

Items	National distance (km)	Truck capacity (L per truck)	Diesel consumption (L km^{-1})
Dried chip	100	15000[a]	0.35
Ethanol from plants to blending stations	170	16000	0.35
Ethanol from blending to gas stations	50	16000	0.35

a kg per truck

Appendix 2.3 Fertilizer and pesticide application

Appendix 2.3.1 Energy inputs for ethanol production

For the cassava production phase, 81 days per ha (8 h per day) are spent on farm activities. The average amounts of fertilizers per ha are 58 kg of N, 47 kg of K_2O, 53 kg of P_2O_5, and 5 tonnes of farm yard manure, and the average amount of pesticides is 0.23 kg ha^{-1}. The diesel consumption for tractors is 15 L ha^{-1}. For the ethanol conversion phase, the amounts of electricity, coal, and chemicals per liter of ethanol are calculated from the total amounts for the production capacity of 10^8 L y^{-1}. For the distribution and blending phase, the electricity for pumping is calculated based on the capacity of 10,884 L kW h^{-1}.

Appendix 2.3.2 Projection of growth rate of cassava yield

The average amounts of fertilizers per ha (58 kg of N, 47 kg of K_2O, 53 kg of P_2O_5, and 5 tonnes of farm yard manure) and pesticides (0.23 kg ha^{-1}) are applied in this study for the period from 2010 to 2025 assuming the growth rate of cassava yield as the technological growth. This assumption is justified by the studies [55,56]. The study [55] shows that the genetic technology was prominent among factors contributing to cassava yield improvement in Vietnam. As the current variety is KM94 which was released from the year 1995, the adoption of advanced varieties will improve the yield in the coming years. The study [56] has additionally provided the techniques to improve yield such as 1) to rotate cassava with other crops to maintain soil fertility, 2) to grow a living fence of Gliricidia sepium or Leucaena as a source of green manure from their leaves, 3) to adjust the seeding time, density, and methods, and 4) to apply organic fertilizers. The application of these techniques has showed an increase in yield with the same fertilizer application [56].

Table 2.A6 Current varieties in Vietnam in 2008.

Variety	Year of release	Adoption rate (%)	Yield (t ha^{-1})	
			Mean	On farm trial
KM98-5	2008	4.50	20.60	34.50
KM140	2007	5.40	20.00	35.00
KM98-1	2005	3.24	20.30	32.20
KM94	1995	75.54	16.90	33.00
SM937-26	1995	2.70	19.80	32.20
KM98-7	1998	1.44	17.00	31.60
HL23		1.08	13.50	16.50
XVP		2.70	12.00	15.10
Others		3.42	6.50	14.90

Source: [37]

Table 2.A7 Advanced varieties in Vietnam in 2009.

Variety	On farm trial yield (t ha^{-1})
KM316	49.00
KM414	45.70
KM325	43.67
KM397	43.40
KM228	39.10
KM140[a]	39.20
HB60	38.73
KM7	38.67
KM419	37.72

a This KM140 is a hybrid bred from crossing between KM140 and KM140.
Source: [37,56]

Appendix 2.4 Calculation of GHG emissions in biofuel production and combustion

$$E = E_{ec} + E_l + E_p + E_{td} + E_u - E_{ccr} - E_{sca} - E_{ccs} - E_{ee} \qquad (1)$$

E = Total CO_2e emissions from production and utilization of biofuels (g L^{-1});
E_{ec} = CO_2e emissions from feedstock production (g L^{-1});
E_l = Annualised CO_2e emissions from carbon stock changes caused by LUC (g L^{-1});
E_p = CO_2e emissions from biofuel processing (g L^{-1});
E_{td} = CO_2e emissions from transport and distribution (g L^{-1});
E_u = CO_2e emissions from the fuel in use (g L^{-1});
E_{ccr} = CO_2e emission saving from carbon capture and replacement (g L^{-1});
E_{sca} = CO_2e emission saving from soil carbon accumulation via improved agricultural management (g L^{-1});
E_{ccs} = CO_2e emission saving from carbon capture and geological storage (g L^{-1}); and
E_{ee} = CO_2e emission saving from excess electricity from cogeneration (g L^{-1}).

Notes:

- E_u is zero for the ethanol component in fuel blends according to the Renewable Energy Directive, Annex V [35].
- E_{ccr} is the amount of CO_2 collected from the fermentation process and sold to food or chemical industries for further use. This amount is considered in the ethanol conversion phase (E_p).
- E_{sca}, E_{ccs}, E_{ee} are not applicable in this study.

1.1 GHG emissions in feedstock production phase

$$E_{\text{phase-1}} = E_{ec} + E_{l} \tag{2}$$

$$E_{ec} = E_{\text{fertilizer}} + E_{\text{pesticide}} + E_{\text{diesel-1}} + E_{\text{urea}} + E_{\text{burning}} + E_{N2O}$$

$E_{\text{fertilizer}}$ = CO_2e emissions from fertilizer use (g L^{-1});
$E_{\text{pesticide}}$ = CO_2e emissions from pesticide use (g L^{-1});
E_{diesel} = CO_2e emissions from diesel consumption (g L^{-1});
E_{burning} = CO_2e emissions from burning of feedstock residue (g L^{-1});
E_{N2O} = CO_2e emission from N_2O emissions from managed soils (g L^{-1}); and
E_{urea} = CO_2 emissions from urea application (g L^{-1}).

a. CO_2e emissions from fertilizer use

$$E_{\text{fertilizer}} = EF_N \text{ x } Amount_N + EF_{P2O5} \text{ x } Amount_{P2O5} + EF_{K2O} \text{ x } Amount_{K2O}$$

Note: The GHG emissions from manure application are taken to be zero according to Biograce [28].

EF_N = CO_2e emission factor of N (g kg^{-1});
EF_{P2O5} = CO_2e emission factor of P_2O_5 (g kg^{-1});
EF_{K2O} = CO_2e emission factor of K_2O (g kg^{-1});
$Amount_N$ = Amount of N (kg L^{-1});
$Amount_{P2O5}$ = Amount of P_2O_5 (kg L^{-1}); and
$Amount_{K2O}$ = Amount of K_2O (kg L^{-1}).

b. Additional CO_2 emissions from urea application

$$E_{UREA} = 10^6 \text{x } P^{-1} \text{ x } \frac{44}{12} \text{ x } M_{UREA} \text{x } EF_{UREA}$$

P = Productivity of feedstock production (L ha^{-1})
EF_{urea} = Carbon emission factor of urea (t t^{-1})
M_{SF} = Amount of urea (t ha^{-1})

c. CO_2e emissions from pesticide use

$$E_{\text{pesticide}} = EF_{\text{pesticide}} \text{ x } Amount_{\text{pesticide}}$$

$EF_{\text{pesticide}}$ = CO_2e emission factor of pesticide (g kg^{-1});
$Amount_{\text{pesticide}}$ = Amount of pesticide (kg L^{-1}).

d. CO_2e emissions from diesel consumption

$$E_{\text{diesel-1}} = EF_{\text{diesel}} \text{ x LHV x } Amount_{\text{diesel-1}}$$

EF_{diesel} = CO_2e emission factor of diesel (g MJ^{-1});
LHV = Low heating value of diesel (MJ L^{-1}).
$Amount_{\text{diesel-1}}$ = Amount of diesel consumption for operating tractors and feedstock transportation (L L^{-1})

e. CO_2e emissions from burning of residue

$$E_{\text{burning}} = 10^6 \text{ x } P^{-1} \text{ x } M_B \text{ x } C_{f\text{-}B} \text{ x } (EF_{\text{N2O, Agri. residue}} \text{ x } GWP_{N2O} + EF_{\text{CH4, Agri. residue}} \text{ x } GWP_{CH4})$$

M_B = Weight of dry matter (DM) of feedstock residue available for burning (t ha^{-1});
$C_{f\text{-}B}$ = Proportion of feedstock residue actually burnt (79% for cassava and 40% for jatropha);
$EF_{\text{N2O,Agri. residue}}$ = N_2O emission factor of burning of dry matter (t t^{-1});
$EF_{\text{CH4, Agri. residue}}$ = CH_4 emission factor of burning of dry matter (t t^{-1});
GWP_{N2O} = Global Warming Potential (CO_2e) of nitrous oxide (t t^{-1}); and

GWP_{CH4} = Global Warming Potential (CO_2e) of methane (t t^{-1}).

f. N_2O emissions from managed soils

$$E_{N2O} = 10^6 x\, P^{-1}\, xGWP_{N2O} x \frac{44}{28}(E_{N2O-N,dir} + E_{N2O-N,ind})$$

$E_{N2O-N,dir}$ = Direct N_2O-N emissions (t ha^{-1}); and
$E_{N2O-N,ind}$ = Indirect N_2O-N emissions (t ha^{-1}).

Direct N_2O-N emissions: $\mathbf{E_{N2O-N,dir} = (F_{ON}+ F_{SN}+ F_{CR}+ F_{SOM})\ x\ EF_{N2O-N,dir}}$

F_{ON} = Amount of organic nitrogen applied (t ha^{-1});
F_{SN} = Amount of synthetic nitrogen (t ha^{-1});
F_{CR} = Amount of N in crop residues returned to the soil (t ha^{-1});
F_{SOM} = Amount of N mineralized in association with loss of soil C due to LUC and managed soil (t ha^{-1}); and
$EF_{N2O-N,dir}$ = Emission factor for direct nitrous oxide emissions from N inputs (t t^{-1})

F_{SN} = M_{SF} xW_{N-SF} F_{ON} = M_{OF} xW_{N-OF}
F_{CR} = M_B x C_{f-R} x$W_{N, AG}$

$$F_{SOM} = \left[\sum_{i=1-4,j=1-2} \frac{SOC_{historic-i} - SOC_{PJ-j}}{T} x\, R_{PJ-i}\right] x \frac{1}{R}$$

W_{N-SF} = weight fraction of nitrogen in synthetic fertilizer (t t^{-1});
W_{N-OF} = weight fraction of nitrogen in organic fertilizer (t t^{-1});
M_{SF} = Amount of synthetic fertilizer (t);
M_{OF} = Amount of organic fertilizer (t);
C_{f-R} = Proportion of feedstock residue returned to the soil (21% for cassava and 60% for jatropha); and
$W_{N, AG}$ = N content in dry matter of feedstock residue (t t^{-1}).
R = C:N ratio of the soil organic matter
$SOC_{historic-I}$ = Soil carbon stock of land use case i before feedstock cultivation (t ha^{-1})

There are four cases of land use before feedstock plantation including forest land, grass land, other annual crop land, and perennial crop land.

SOC_{PJ-j} = Soil carbon stock under feedstock plantation case j (t ha^{-1})
R_{PJ-i} = Ratio of land use case i
T = Time dependence of the stock change factors (y)

$$SOC_{historic-i} = SOC_{REF}\ x\ F_{LU,\ historic-i}\ x\ F_{MG,\ historic-i}\ x\ F_{I,\ historic-i}$$

SOC_{REF} = Reference soil carbon stock value (t ha^{-1});
$F_{LU,\ historic-i}$ = Land use factor under land-use case i before feedstock plantation;
$F_{MG,historic-i}$ = Management factor under land-use case i before feedstock plantation; and
$F_{I,\ historic-i}$ = Input factor under land-use case i before feedstock plantation.

SOC_{PJ-j} = SOC_{REF} x $F_{LU,PJ-j}$ x $F_{MG,PJ-j}$ x $F_{I,PJ-j}$
$F_{LU,PJ-j}$ = Land use factor under feedstock plantation case j;
$F_{MG,PJ-j}$ = Management factor under feedstock plantation case j; and
$F_{I,PJ-j}$ = Input factor under the feedstock plantation case j.

Indirect N_2O-N emissions: $\mathbf{E_{N2O-N,ind} = E_{N2O-N,ind,ATD} + E_{N2O-N,ind,L}}$

$E_{N2O-N,ind,ATD}$ = Indirect N_2O-N emissions due to atmospheric deposition of nitrogen volatilized (t ha^{-1});
$E_{N2O-N,ind,L}$ = Indirect N_2O-N emissions from leaching/run-off due to nitrogen application (t ha^{-1});

$$PE_{N2O-N,ind,ATD} = (F_{SN}\ x\ Frac_{GASF} + F_{ON}\ x\ Frac_{GASM})\ x\ EF_{N2O-N,ATD}$$

$$PE_{N2O\text{-}N,ind,L} = (F_{SN} + F_{ON} + F_{SOM} + F_{CR}) \text{ x } Frac_{LEACH} \text{ x } EF_{N2O\text{-}N,L}$$

$Frac_{GASF}$ = Fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_X in the N applied (t t^{-1});
$Frac_{GASM}$ = Fraction of organic N fertilizer that volatilizes as NH_3 and NO_X in the N applied (t t^{-1});
$Frac_{LEACH}$ = Fraction of all N added to/mineralized in the soil that is lost through leaching and run-off (t t^{-1});
$EF_{N2O\text{-}N,ATD}$ = Emission factor for N-atmospheric deposition on soils (t t^{-1}); and
$EF_{N2O\text{-}N,L}$ = Emission factor for N_2O emissions from N leaching and run-off (t t^{-1}).

g. Annualised emissions from carbon stock changes caused by LUC

$$E_l = 10^6 \text{x } P^{-1} x \left[\sum_{i=1-4, j=1-2} \frac{CS_{historic-i} - CS_{PJ-j}}{T} \text{ x } R_{PJ-i}\right] \text{ x } \frac{44}{12}$$

$$CS_{historic\text{-}i} = SOC_{historic\text{-}i} + C_{VEG\text{-} historic\text{-}i}$$

$$CS_{PJ\text{-}j} = SOC_{PJ\text{-}j} + C_{VEG\text{-}PJ\text{-}j}$$

$CS_{historic\text{-}i}$ = Carbon stock of land use case i before feedstock plantation (t ha^{-1});
$CS_{PJ\text{-}j}$ = Carbon stock under feedstock plantation case j (t ha^{-1});
$C_{VEG\text{-} historic\text{-}I}$ = Vegetation carbon stock of land use case i before feedstock plantation (t ha^{-1}); and
$C_{VEG\text{-}PJ\text{-}j}$ = Vegetation carbon stock under feedstock plantation case j (t ha^{-1}).

1.2 GHG emissions in ethanol conversion phase

$$E_{phase\text{-}2} = E_p = EF_{DAP} \text{ x } Amount_{DAP} + EF_{Urea} \text{ x } Amount_{Urea} + EF_{Enzyme} \text{ x } Amount_{Enzyme} + EF_{NaOH} + E_{others} - E_{ccr} \quad (3)$$

EF_{DAP} = CO_2e emission factor of DAP (g kg^{-1});
EF_{Urea} = CO_2e emission factor of urea (g kg^{-1});
EF_{Enzyme} = CO_2e emission factor of enzyme (g kg^{-1});
EF_{NaOH} = CO_2e emission factor of NaOH (g kg^{-1});
$Amount_{DAP}$ = Amount of DAP for biofuel processing (kg L^{-1});
$Amount_{Urea}$ = Amount of urea for biofuel processing (kg L^{-1});
$Amount_{Enzyme}$ = Amount of enzyme for biofuel processing (kg L^{-1});
$Amount_{NaOH}$ = Amount of NaOH for biofuel processing (kg L^{-1});
E_{others} = CO_2e emissions from other sources (g L^{-1}); and
E_{ccr} = Amount of CO_2 collected (g L^{-1}).

1.3 GHG emissions in distribution and blending phase

$$E_{phase\text{-}3} = E_{td} = EF_{electricity} \text{ x } Amount_{electricity} + EF_{diesel\text{-}2} \text{ x LHV x } Amount_{diesel\text{-}2} \quad (4)$$

$EF_{electricity}$ = CO_2e emission factor of 1 kW h of electricity (g kW h^{-1});
$Amount_{electricity}$ = Amount of electricity for blending (kW h L^{-1}); and
$Amount_{diesel\text{-}2}$ = Amount of diesel consumption for distribution and blending (L).

Indirect land use change (iLUC) refers to the use of cropland for biofuel feedstock production increasing the global food prices, leading to the conversion of forest and grasslands to cropland for food production, and eventually decreasing the carbon sequestration in the future [57,58]. The estimating iLUC involves the use of economic models linked with the biophysical models so as to simulate the change in carbon sequestration and thus the GHG emissions [58,59]. This estimation not only depends on many assumptions but also requires a comprehensive analysis at the global level [59,60].

In our analysis the iLUC effects is expected to be very small because Vietnam has been exporting cassava and its feedstock production of cassava and jatropha has almost not competed with the food production regarding soil suitability and policy planning. In addition, we assume that cassava for biofuel feedstock comes wholly from newly domestic cultivation keeping other activities unchanged. Jatropha has been developed in unused barren soil in the North and marginal degraded soil in the Coastal region. From our estimation of LUC, to meet the targeted volume of biofuels in 2025, the total newly cultivated cassava and jatropha areas of 94,086 ha and 245,859 ha are respectively equivalent to 1.5% and 3.9% of the arable land in 2009.

Appendix 2.5 Parameters in the calculation

Parameters	Value	Source
Emission factors of fertilizer and pesticide		
- EF_N	5880.60	[28]
- EF_{P2O5}	1010.70	[28]
- EF_{K2O}	576.10	[28]
- $EF_{Pesticide}$	10971.30	[28]
- $EF_{UREA\text{-}1}$	0.20	[34]
Emission factor and LHV of diesel		
LHV	35.87	[20]
EF_{diesel}	83.80	[28,35]
CO_2e emissions from burning cassava residue		
GWP_{CH4}	25	[28,34]
GWP_{N2O}	298	[28,34]
$EF_{CH4,\ Agriresidue}$	0.0027	[34]
$EF_{N2O,Agri.residue}$	0.00007	[34]

Parameters	Value	Source
N_2O emission from managed soils		
$FRAC_{GASM}$	0.20	[34]
$FRAC_{LEACH}$	0.30	[34]
$FRAC_{GASF}$	0.10	[34]
$EF_{NO2\text{-}N,dir}$	0.01	[34]
$EF_{N2O\text{-}N,L}$	0.0075	[34]
$EF_{N2O\text{-}N,ATD}$	0.01	[34]
$W_{N,\ AG}$	0.0157	[39]
$W_{N,\ OF}$	0.0032	[38]
R	15	[34]

Parameters	Value	Source
Emission factors of inputs in ethanol conversion		
- EF_{DAP}	1527.00	[28]
- $EF_{UREA\text{-}2}$	3167.00	[28]
- EF_{Enzyme}	1000.00	[42]
- EF_{NaOH}	469.30	[28]
Emission factor of electricity		
- $EF_{electricity}$	565.20	[28]

CO_2 emissions from land use change					
SOC_{REF} (t ha^{-1})	47	[34]			
	Forest land	Grassland	Annual cropland	Perennial cropland	Intercropping[a]
- F_{LU}	1.00	1.00	0.48	1.00	0.93
- F_{MG}	1.00	0.97	1.15	1.15	1.15
- F_I	1.00	1.00	1.00	1.00	1.00
SOC (t ha^{-1})	47.00	45.59	25.94	54.05	50.36
C_{VEG}	21.00	8.10	-	14.40	12.51
CS	68.00	53.69	25.94	68.45	62.87

a These figures are calculated from the parameters of annual cropland and perennial cropland.

Appendix 2.6 Estimation of land use change due to cassava expansion

a. Projection of cassava area for ethanol production

Items	Unit	2009	2010	2011	2012	2013	2014	2015	2020	2023	2024	2025
Ethanol	kt	2.0	39.4	76.8	114.1	151.5	188.9	226.3	413.1	525.3	562.6	600.0
Ethanol	10^6 L	2.5	49.8	97.2	144.5	191.8	239.1	286.4	522.9	664.9	712.2	759.5
Cassava fresh root	kt	15.2	299.1	582.9	866.8	1150.6	1434.5	1718.4	3137.7	3989.2	4273.1	4557.0
Yield	t ha^{-1}		17.2	18.4	19.7	21.2	22.7	24.3	34.4	42.4	45.5	48.7
Cultivated area	10^3 ha		17.4	31.7	43.9	54.4	63.3	70.7	91.2	94.1	94.0	93.5

b. Land use change due to cassava production expansion

Province	Average cassava area in 2005-2009 (ha)	Weight (%)	% of LUC to cassava as mono-crop from				% of LUC to cassava as intercrop from	
			Forest land	Grass land[a]	Annual crop land	Perennial crop land	Annual crop land	Perennial crop land
Tay Ninh	45600	14.17	0	5	40	35	5	15
Binh Phuoc	23300	7.24	10	10	10	5	20	45
Dong Nai	19300	6.01	5	10	30	15	5	35
Gia Lai	49600	15.40	20	35	10	30	0	5
Kom Tum	34100	10.59	25	50	15	5	0	5
Dak Lak	20800	6.45	20	45	20	10	0	5
Dak Nong	19500	6.07	15	55	20	0	0	10
Quang Ngai	19300	6.01	10	75	5	10	0	0
Binh Thuan	24400	7.57	10	20	55	15	0	0
Nghe An	16600	5.17	0	20	55	25	0	0
Binh Dinh	13200	4.11	5	30	10	55	0	0
Quang Nam	13800	4.28	5	20	75	0	0	0
Phu Yen	12900	4.02	20	25	15	40	0	0
Quang Tri	9400	2.91	5	70	25	0	0	0
Vietnam	%	100.0	11.7	31.2	26.1	18.9	2.5	9.7
	ha	94086.0	10989.0	29305.0	24545.0	17797.0	2311.0	9139.0

a The barren land and denuded hills in Vietnam are considered as grassland.

Appendix 2.7 Calculation of energy and GHG balances for 1 L and for the targeted ethanol volume

- Ethanol productivity (L ha^{-1})	5516 a	- Energy input of 1 MJ of gasoline (MJ MJ^{-1})	1.14 d
- Liters of 600 kt of ethanol	759493671 b	- LHV of gasoline (MJ L^{-1})	32.17 e
- Fuel consumptions in transport sector in 2009 (10^6 MJ)	430000 c	- Emission from gasoline production and combustion (g MJ^{-1})	83.8 f
- Emissions from fuel production and combustion in transport sector in 2009, [Ec = (c)x(f)x10^{-6}] (10^6 t of CO_2e)	36.03 (E_c)		

Energy balance or amount of gasoline saved

Scenario	km L^{-1}	For an FU	For 1 L of ethanol	For the targeted volume (600 kt of ethanol)		
		MJ km^{-1}	MJ L^{-1}	Energy input saved (10^6 MJ)	MJ of gasoline saved (10^6 MJ)	(m) as % of (c)
	(g)	(h)	(i) = (g) x (h)	(k) = (i) x (b) x 10^{-6}	(m) = (k) : (d)	(n) = ((m) : (c)) x 100
S1 (E5, +5%)	0.60	30.07	17.97	13647	11997	2.79
S2 (E5, 0%)	12.55	-1.35[a]	-16.88	-12823	-11273	-2.62
S3 (E5, -5%)	25.75	-2.15	-55.40	-42079	-36991	-8.60
S4 (E10, +5%)	6.57	0.08	0.54	411	362	0.08
S5 (E10, 0%)	12.55	-1.35	-16.88	-12823	-11273	-2.62
S6 (E10, -5%)	19.15	-1.89	-36.14	-27451	-24132	-5.61

GHG balance in terms of CO_2e emissions or emissions saving

Scenario	km L^{-1}	For an FU	For 1 L of ethanol	For 1 ha of cassava	For the targeted volume (600 kt of ethanol)	
		g km^{-1}	g L^{-1}	kg ha^{-1}	t of CO_2e	(t) as % of E_c
	(g)	(o)	(p) = (g) x (o)	(s) = (p) x (a) x 10^{-3}	(t) = (p) x (b) x 10^{-6}	(u) = ((t) : (E_c)) x 10^4
S1 (E5, +5%)	0.60	1019.60	609.18	3360	462664	1.28
S2 (E5, 0%)	12.55	-156.08[v]	-1958	-10801	-1487314	-4.13
S3 (E5, -5%)	25.75	-186.22	-4796	-26454	-3642554	-10.11
S4 (E10, +5%)	6.57	-102.64	-675	-3721	-512325	-1.42
S5 (E10, 0%)	12.55	-156.08	-1958	-10801	-1487314	-4.13
S6 (E10, -5%)	19.15	-176.35	-3377	-18628	-2564934	-7.12

a Our estimation (see Section 2.2).

b Ref. [8].

c Ref. [1].

v A minus sign means an energy (or emission) savings

d Ref. [27].

e Ref. [20].

f Ref. [28].

g These values are calculated from the column 8 of Table 2.3 and LHV of ethanol

h These values are from the column 5 of Table 2.6.

o These values are from the column 5 of Table 2.9.

Appendix 2.8 Projection of area and LUC for production of cassava and jatropha

For cassava production

- Initial production in 2009 in thousand tonnes	2	- Cassava yield in 2010	t ha^{-1}	17.17[b]
- Targeted volume in 2025 in thousand tonnes	600[a]	- Annual growth rate of cassava yield	% y^{-1}	7.20[b]
		- Projected average cassava yield in 2010-2025	t ha^{-1}	33.09[c]

	Total	Forest land	Grassland[d]	Annual cropland	Perennial cropland
- Mono-cropped cassava (%)	87.83	11.68	31.15	26.09	18.92
- Inter-cropped cassava (%)	12.17	-	-	2.46	9.71
% of total	100.00	11.68	31.15	28.55	28.63
ha in 2025	94,086.00	10,989.00	29,305.00	26,856.00	26,936.00

For jatropha production

- Initial production in 2009 in thousand tonnes	2.86	- Projected average jatropha yield 2010-2025	t ha^{-1}	4.50[f]
- Targeted volume in 2025 in thousand tonnes	237.50[e]			

	Total	Forest land	Grassland[d]	Annual cropland
% of total	100.00	15.32	78.92	5.76
ha in 2025	245,859.00	37,666.00	194,032.00	14,161.00

a Ref. [8].

b Ref. [16].

c The projected average cassava yield in the period from 2010 to 2025 is calculated from the annual growth rate of cassava yield as the technological growth and the weight of planted areas [16,55,56].

d The barren land and denuded hills in Vietnam are considered as grassland.

e Ref. [9,11].

f Ref. [61] and the survey in 2011.

Chapter 3

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

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%.

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3.1 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 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. Ref. [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 3.2 presents the methodology for establishing the cost-effectiveness analysis. Section 3.3 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 3.4. Section 3.5 contains our conclusions.

3.2 Methodology

3.2.1 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. Figure 3.1 shows the life-cycle systems of production and utilization of biofuels.

3.2.2 Functional unit and sensitivity analysis

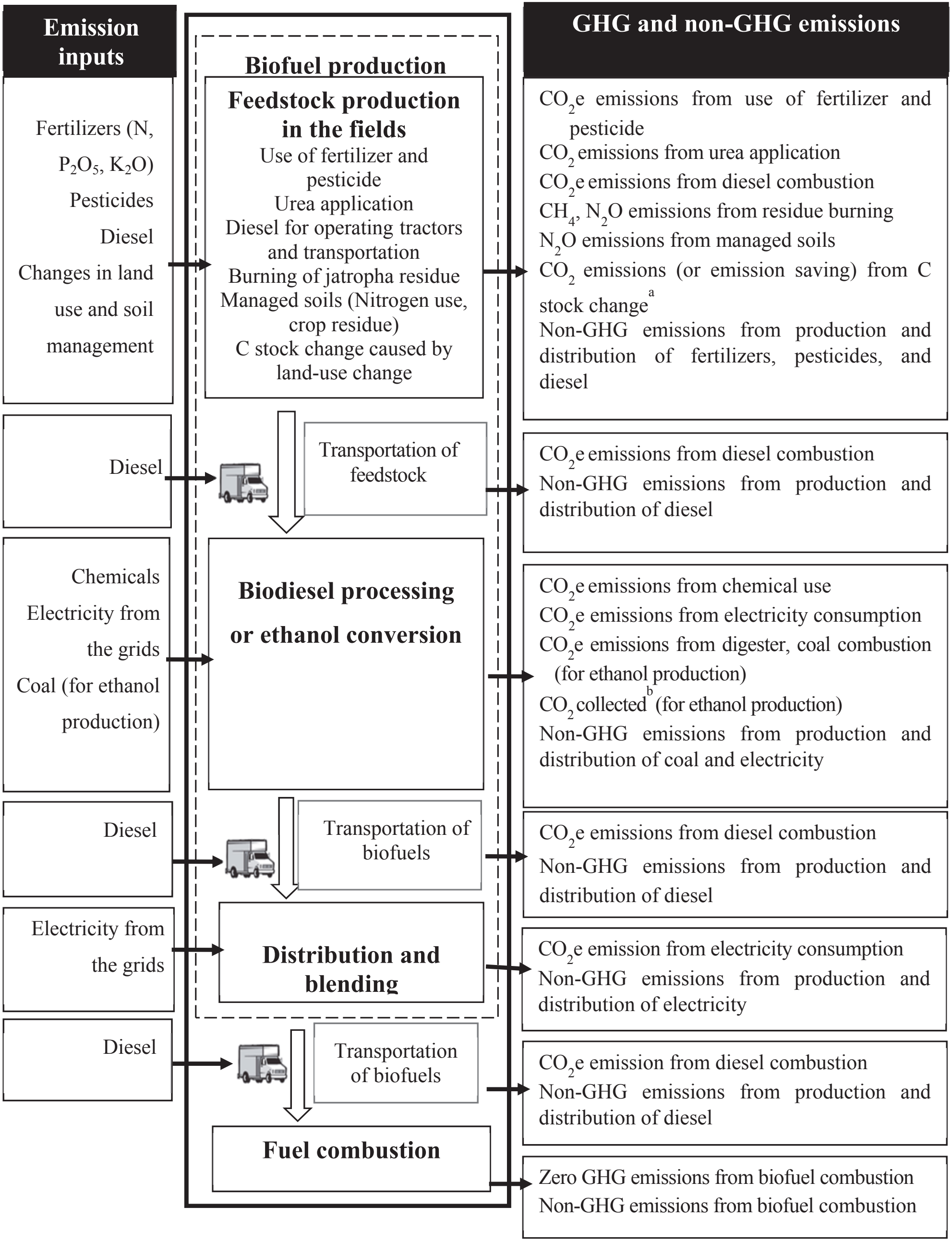
Following the suggestion by Gnansounou et al. [16], this study applies the FU of travelling 1 km using biofuels or fossil fuels as energy for road vehicles. The efficiencies in terms of MJ km^{-1} of biofuel components in blends are separated from the efficiencies of the fossil fuel components and those 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 3.1 Properties of fuels and blends.

Properties	Unit	Gasoline	Ethanol	E5[a]	E10[a]	Diesel	Biodiesel	B5[a]	B10[a]
Density	g L^{-1}	743.0	790.0	745.4	747.7	832.0	879.0	834.4	836.7
LHV	MJ L^{-1}	32.2	21.1	31.6	31.1	35.9	32.6	35.7	35.6

a The properties of blends are calculated from those of gasoline and ethanol for E5 and E10 and from diesel and biodiesel for B5 and B10 according to the volume shares [16].
Source: [1]

Table 3.1 provides properties of fuels as a base to convert from fuel consumption (L km^{-1}) to fuel efficiency (MJ km^{-1}). Table 3.2 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.



a The land use change effect could cause an increase in emissions or an emission saving depending on the change in C stock before and after feedstock plantation.

b This is a GHG emission saving.

Figure 3.1 Life-cycle system of biofuel production and utilization.

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 3.3. Accordingly, we compare the social costs of the fuels in terms of US Dollar for a functional unit of 1 kilometer (\$ km^{-1}) in Section 3.2.3.

Table 3.2 Percentage changes in fuel consumption of ethanol blends (E5 and E10) w.r.t gasoline and of biodiesel blends (B5 and B10) w.r.t diesel.

Blends	E5		E10		Source
Fuel consumption indicators	L km^{-1}	g kW h^{-1}	L km^{-1}	g kW h^{-1}	
Vehicle					
- Ford Laser Ghia 1.8		-5.2[a]		-4.2	[26]
- Honda Super Dream 100 cc		-6.4		-5.4	[26]
- 1.4i SI engine	5.2[b]	2.8-0.2[c]	5.5[b]	3.6-1.5[c]	[27],[28]
- Ford Focus	-1.2[d]				[16]
- Renault Megane	-0.6				[29]
- Various car models			-5.6[d]		[16,30]
- Toyota 1.6 L/2000			1.1		[18]
- XU7JP/L3 engine			5.1		[31]
Vehicle	B5		B10		
- 6-cylinder MAN diesel engine		2.5			[34]
- Mitsubishi-6D14		0.4			[35]
- Perkins D3.152		2.7			[36]
- Various trucks	0				[37]
- Ford Focus 1.8 Tddi 90 VC	0.3		0.6		[17]
-Renault Laguna 1.9 dCi passenger car			1.0		[38]
- Mitsubishi-6D14				0.7	[35]

a A minus sign means the lower fuel consumption of ethanol blends w.r.t gasoline.
b Ref. [27].
c Ref. [28]. These two values are measured at the vehicle speeds of 80 km h^{-1} and 100 km h^{-1} respectively.
d These are averaged from the figures in Ref. [16].

Table 3.3 Fuel efficiencies of ethanol and biodiesel components in blends.

Fuel efficiency of ethanol component in blends

Indicator	Blend			Gasoline component		Ethanol component		
	Fuel consumption	Fuel efficiency		Percentage of gasoline energy in blend (%)	Fuel efficiency	Percentage of ethanol energy in blend (%)	Fuel efficiency	
	(L km^{-1})	(MJ km^{-1})	(km MJ^{-1})		(km MJ^{-1})		(km MJ^{-1})	(MJ km^{-1})
	(1)	(2)	(3) = 1:(2)	(4)	(5) = (3) fo gasoline	(6)	(7) = ((3) x 100 - (4) x (5)):(6)	(8) = 1:(7)
Gasoline	0.080[b]	2.56[a]	0.39	100.00	0.39			
Ethanol								
- S1 (E5, +5%)	0.084[c]	2.65	0.38	96.66	0.39	3.34	0.03	35.32
- S2 (E5, 0%)	0.080[d]	2.52	0.40	96.66	0.39	3.34	0.59	1.68
- S3 (E5, -5%)	0.076[e]	2.39	0.42	96.66	0.39	3.34	1.22	0.82
- S4 (E10, +5%)	0.084[c]	2.60	0.38	93.21	0.39	6.79	0.31	3.21
- S5 (E10, 0%)	0.080[d]	2.48	0.40	93.21	0.39	6.79	0.59	1.68
- S6 (E10, -5%)	0.076[e]	2.35	0.43	93.21	0.39	6.79	0.91	1.10

Fuel efficiency of biodiesel component in blends

Indicator	Blend			Diesel component		Biodiesel component		
	Fuel consumption	Fuel efficiency		Percentage of diesel energy in blend (%)	Fuel efficiency	Percentage of biodiesel energy in blend (%)	Fuel efficiency	
	(L km^{-1})	(MJ km^{-1})	(km MJ^{-1})		(km MJ^{-1})		(km MJ^{-1})	(MJ km^{-1})
	(9)	(10)	(11) = 1:(10)	(12)	(13) = (11) for diesel	(14)	(15) = ((11) x 100 - (12) x (13)):(14)	(16) = 1:(15)
Diesel	0.054[f]	1.94[g]	0.52	100.00	0.52			
Biodiesel								
- S7 (B5, 0%)	0.054[h]	1.93	0.52	95.43	0.52	4.57	0.57	1.76
- S8 (B5, +5%)	0.057[i]	2.02	0.49	95.43	0.52	4.57	0.03[j]	37.01
- S9 (B10, 0%)	0.054[h]	1.92	0.52	90.82	0.52	9.18	0.57	1.76
- S10 (B10, +5%)	0.057[i]	2.02	0.50	90.82	0.52	9.18	0.30	3.36

a.Ref. [16]

b This figure is calculated from 2.56 MJ km^{-1} and the LHV of gasoline.

c These figures equal the consumption of gasoline multiplied by 1.05.

d These figures equal the consumption of gasoline multiplied by 1.

e These figures equal the consumption of gasoline multiplied by 0.95.

f. Ref.[17].

g. This figure is calculated from 0.054 L km^{-1} and the LHV of gasoline.

h These figures equal the consumption of diesel multiplied by 1.

i These figures equal the consumption of diesel multiplied by 1.05.

j. S8 appears a very low contribution of biodiesel to the blend B5.

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 3.3.

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.

The net present value (NPV) can be calculated as follows:

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{pF(t)}{q^t} - \left(\sum_{t=0}^{T} \frac{C(t)-B(t)}{q^t}\right), \text{ or}$$

$$\mathrm{NPV} = p\sum_{t=0}^{T} \frac{F(t)}{q^t} - \left(\sum_{t=0}^{T} \frac{C(t)-B(t)}{q^t}\right) \text{ because p is constant.}$$

By setting NPV equal to zero we obtain

$$p = \frac{\left(\sum_{t=0}^{T} \frac{C(t)-B(t)}{q^t}\right)}{\sum_{t=0}^{T} \frac{F(t)}{q^t}},$$

where p is the break-even price or the average cost for 1 GJ of fuels produced and utilised; C(t) is annual cost of biofuel production at year t; B(t) is annual benefit of by-products; F(t) is annual fuel production in terms of GJ; q^{-t} is discount factor with $q = 1+ i$, and i is the discount rate; and T is time frame of the project.

Private production costs and benefits of fuels

The gas station prices in 2010 exclusive of tariffs, taxes, and fees represent the private costs of gasoline and diesel. The private costs are calculated as the sum of the import cost (including cost, insurance and freight) and the transportation cost from the dock-warehouse to gas stations using the average national transport distance of 50 km [39,40].

For biofuels, private production costs incur in the three phases of feedstock production, biofuel processing, distribution and blending (Figure 3.1). The feedstock production phase incurs the costs of land rental, seedlings, fertilizers, pesticides, diesel for tractors and water pumping machine, maintenance, labour, and seed transportation. The inputs in this phase are collected per hectare and then converted to inputs per GJ of biofuel output using the projected average yields (t ha^{-1}), the processing ratios (kg L^{-1}), and the LHVs of biofuels (GJ L^{-1}). For the biofuel processing phase, cost items include capital, electricity, coal, labour, water, and chemicals. The revenue of glycerine and compost are considered as private benefits of biodiesel production. The private benefits of ethanol production include the revenues of by-products of cassava stillage, CO_2 from fermentation sold for further utilization and fixation as an alternative for long term storage of CO_2, and the certified emission reductions (CERs) which the ethanol plants have earned from the Clean Development Mechanism project. For the processing, distribution and blending phases, the inputs are calculated for 1 L on the basis of the production capacity of 10^8 L y^{-1} and converted to inputs per GJ of output using the LHVs of biofuels. For the distribution and blending phase, the cost of electricity equals its average price in 2010 multiplied by the quantity on the basis of the pumping capacity of 10,884 L kW h^{-1}, which is collected from the survey (see Section 3.3.1 for details on the survey).

The transportation costs are calculated from transportation distances, truck capacity, and diesel consumption. The three stages of transportation include transporting 1) feedstock to biofuel plants; 2) biofuels from processing plants to blending stations; and 3) blends from blending stations to gas stations. To calculate the diesel consumption for transportation, we need national transportation distances for feedstock, biofuels, and blends, truck capacities, and diesel consumption. Each national distance is the average of three regional distances with the weights of corresponding capacities.

External costs and benefits of fuels

Three externalities are considered in the calculation of external costs and benefits: 1) GHG emissions from fuel production, distribution, and combustion, 2) non-GHG emissions from fuel production, distribution, and combustion, and 3) security of supply of fossil fuels.

GHG emissions

The GHGs consisting of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are aggregated into the CO_2 equivalent (CO_2e) using the global warming potential (GWP) factors of 1 for CO_2, 25 for CH_4, and 298 for N_2O [41-42]. The external cost of GHG emissions is calculated by multiplying the CO_2e emissions by the global external cost of CO_2e emissions of 33.2 \$ t^{-1}, which represents the avoidance costs of climate change and was estimated for the year 2010 on the basis of cost-effectiveness analysis to determine the least-cost option to achieve the emission reduction target set under the Kyoto protocol [43]. For gasoline and diesel, the GHG emissions from the production and combustion in terms of CO_2e are 83.8 g MJ^{-1} [41,44]. For biofuels, the GHG emission from biofuel combustion is zero according to the Renewable Energy Directive (RED) [44]. The GHG emissions from biofuel production are calculated using the guidelines from the IPCC, RED, and the Biograce project (Figure 3.1) [41,42,44,45]. The GHG emissions from plant construction, production of equipment and vehicles for transportation are not taken into account under the cut-off criteria suggested in Ref. [41,44,45]. A detailed explanation for the calculation of GHG emissions from biofuel production are presented in the Appendix 2.4.

Non-GHG emissions

The four non-GHG emissions of HC, NO_x, PM, and SO_2 are considered in this study. The external costs equal the amounts of non-GHG emissions from fuel production, distribution, and combustion multiplied by the unit damage costs of non-GHG emissions, which will be detailed in section 3.3.2 (see Figure 3.1).

Security of supply

The security of supply of fossil fuels is a motivation for biofuel production in most countries [2-5,43,46]. It is defined as the supply reliability at affordable prices [3]. The external costs of security of supply were formulated in various aspects and estimated ranging from 0.03 to 0.19 $\$ L^{-1}$ at the 2010 price (Table 3.5).

3.3 Case study in Vietnam

3.3.1 Data collection

The primary data for the case study are collected through two surveys in the harvesting seasons of cassava and jatropha in Vietnam from January to June in 2011. For the ethanol survey, we selected four of the top-ten cassava producing provinces: Binh Phuoc, Tay Ninh, Dong Nai and DakNong with the presence of four among the total eight ethanol plants. For the biodiesel survey, we chose three jatropha producing provinces of Binh Thuan, Ninh Thuan, and Dong Nai with the presence of two jatropha-based biodiesel plants. We interviewed farmers, managers in biofuel plants, stakeholders including agricultural input suppliers, labourers, transporters, and key informants to obtain data on 1) farm inputs, 2) on-site conversion ratios in processing, 3) biofuel processing inputs, 4) LUC estimation, and other information.

3.3.2 Biofuel industry in Vietnam

Biofuel production has rapidly developed under the government policies. Up to 2010, eight ethanol plants had started with the total annual capacity of 680 million liters. Seven of eight plants are located in the Central Highlands, South Central Coastal, and Southeast regions, which contributed 72% of total cassava output in the period from 2006 to 2010 [47]. Jatropha has been planted mostly in unused barren land in the North and Coastal regions in compliance with the direction of the Ministry of Agriculture and Rural Development [48-50].

Private production costs and external costs for GHG emissions

We calculate the private production costs and the external costs based on the production structure for ethanol and biodiesel production in Vietnam (Appendix 3.3) and report these calculations in Section 3.4. A detailed description of the calculations for energy and GHG emissions for ethanol is given in Le et al. [20].

External costs of non-GHG emissions

Firstly, for the production and distribution phases of fossil fuels the amounts of non-GHG emissions per GJ are collected from GREET database [51]. For the production and distribution phases of biofuels, the amounts of non-GHG emissions are calculated by multiplying the emission factors from GREET database [51] and the amounts of production inputs including fertilizers, pesticide, electricity, coal, and diesel. We ignore the chemical inputs due to their expected insignificant amounts and the lack of data on their emission factors. Secondly, for the fuel combustion phase the amounts of non-GHG emissions are derived from the official emission standards in Vietnam that are based on European emission standards for vehicles [52-56]. The external costs equal the non-GHG emissions from fuel combustion multiplied by the unit damage costs of non-GHG emissions. The non-GHG emissions from fossil fuel combustion follow the “Euro 2 and Euro 3 standards” (see Refs. [52,53,56]) for motorbikes for the periods from 2010 to 2016 and from 2017 to 2025 respectively; the “Euro 2, Euro 4, and Euro 5 standards” for cars for the periods from 2010 to 2016, from 2017 to 2021, and from 2022 to 2025 respectively [52-56]. While diesel is used by cars, gasoline is used by both cars and motorbikes in Vietnam. Therefore, the shares of gasoline consumption are estimated at 80% and 20% for the period of 2017-2021 and at 65% and 35% for the period of 2022-2025, for motorbikes and cars respectively using the numbers of motorbikes and cars, the ratios of gasoline and diesel engines, ratios of diesel and gasoline consumption for transportation [1,57]. The non-GHG emissions from biofuel combustion are calculated using the non-GHG emissions from fossil fuel combustion and the relative change of non-GHG emissions from combustion of biofuels compared to fossil fuels (-15% HC, -10% NO_x, -20% PM, -80% SO_2 for ethanol compared to gasoline; and -67% HC, +10% NO_x, -47% PM, -100% SO_2 for biodiesel compared to diesel) [58,59].

Due to the lack of data on the external damage costs of non-GHG emissions in Vietnam, we need to use proxies for these costs. We therefore adjust the external damage costs for EU countries reported by the European Commission [60] for Vietnam. The scaled unit damage costs at the 2010 price are obtained from Ref. [60] for the year period period of 2010-2025 and adjusted to reflect the differences between Vietnam and the EU countries concerning the willingness-to-pay and the physical damage scale per ton of pollutants [63]. Assuming that the willingness-to-pay and the physical damage scale per ton of pollutants are proportional to the gross domestic product (GDP) per capita and the population density respectively, these two adjusting factors are measured by the ratios of GDPs (Purchasing Power Parity) per capita and population densities of EU and Vietnam [63] (Table 3.4).

Table 3.4 Converting external damage costs of non-GHG emissions for EU to scaled external damage costs for Vietnam.

Pollutants	Damage costs for EU (€ t^{-1})		Adjusting factors[a]		Damage costs for Vietnam (\$ t^{-1}) [b]	
	2010	2025	GDP per capita ratio	Population density ratio	2010	2025
HC	1148	564	0.09	2.24	314	154
NO_x	7793	7350	0.09	2.24	2135	2014
PM	29,006	23,454	0.09	2.24	7948	6427
SO_2	7501	6718	0.09	2.24	2055	1841

a Population densities are 116.0 and 260.3 persons per square kilometer; and GDPs (PPP) per capita are 33,729 $ and 3104 $ respectively for EU and Vietnam in 2010.

b The costs in Euro currency are multiplied by the average exchange rate in 2010 from the European state bank (1.33 \$ $€^{-1}$).

Source: [60-62]

External costs of security of supply

Due to the lack of data on the external costs related to the security of supply of fossil fuels for Vietnam, this study considers the external cost of security of supply from the literature and applies the lowest estimation of 0.03 \$ L^{-1} in the calculation.

It is worth noting that, in the absence of data on the external costs of non-GHG emissions and fossil fuel security of supply for Vietnam, our empirical analysis is based on the adjustment results from estimation for EU countries for the former and on the lowest estimation that we found in literature for the latter. The readers should be aware of the uncertainty about these two estimates.

Table 3.5 External costs of fossil fuel security of supply.

External cost formulation	External costs in 2010 ($ L^{-1})	Source
Incremental benefits of the import reduction to society	0.03	[64]
Costs of keeping stocks for a period needed to start up biofuel program without subsidy	0.16-0.19	[5]
Direct economic costs of the transfer of wealth from the US. to oil producing countries, GDP losses due to the oil price higher than its competitive level, and macroeconomic adjustment	0.19	[65]

3.4 Results and discussion

In this section we present the cost-effectiveness of biofuels in comparison with fossil fuels. We first show the private, external and social costs of production and utilization in terms of $ GJ^{-1}, we then focus on the costs per functional unit, i.e., the costs in US Dollar per kilometer ($ km^{-1}). Three discount rates of 4%, 8%, and 10% are used to investigate the impact of discount rates on the results. The detailed calculation is presented in the Appendix 3.3.

3.4.1 Cost-effectiveness of cassava-based ethanol and gasoline

At the discount rate of 4%, the private cost of ethanol is 18.6 $ GJ^{-1} (Table 3.6), of which the cassava production cost amounts to 57.9%, the conversion cost accounts for 39.5%, and the cost of distribution and blending contributes to 2.6%. The private cost of ethanol is 17.7% higher than that of gasoline, but its external cost is 60.3% lower than that of gasoline. The social cost of ethanol is 20.2 $ GJ^{-1}, which is 1.6% higher than that of gasoline at the discount rate of 4%.

Table 3.6 shows that the social cost per GJ of ethanol is higher than that of gasoline due to its higher private cost component. The higher external costs related to emissions and the security of supply lead to the higher external cost for gasoline; however, the social cost of ethanol is eventually higher than that of gasoline. These findings hold for the three discount rates and the differences are even larger at the higher discount rate. For instance, the social cost of ethanol is 13.9% higher than that of gasoline at the discount rate of 10%.

Table 3.6 Costs of production and utilization of ethanol and gasoline ($ GJ^{-1}).

Cost items	Ethanol			Gasoline		
	Discount rate			Discount rate		
	4%	8%	10%	4%	8%	10%
Private cost	18.57	20.13	20.93	15.78	15.78	15.79
- Cassava production	10.76	11.24	11.48			
- Ethanol conversion	7.33	8.37	8.91			
- Distribution and blending	0.48	0.52	0.53			
External cost	1.63	1.70	1.74	4.11	4.12	4.13
- GHG emissions	1.22	1.29	1.33	2.76	2.76	2.76
- Non-GHG emissions	0.40	0.41	0.41	0.25	0.26	0.26
- Security of supply	NA[a]	NA[a]	NA[a]	1.10	1.10	1.10
Social cost	20.20	21.83	22.67	19.89	19.90	19.91

a Not applied.

Regarding the external costs of ethanol production, the non-GHG emissions are mostly caused by the ethanol conversion, particularly coal combustion and electricity use (Appendix 3.2) [20]. This finding encourages the ethanol plants to make the best use of by-product biogas or use the environmental friendly substitutes for coal and electricity together with the agricultural practices suggested in Ref. [20] so as to reduce the external cost. The contributions of the external costs of non-GHG emissions to the social costs are less than 3.0% for all fuels. These small contributions result in a relatively insignificant effect on the overall results.

If we take into account the fuel efficiency in transportation, we obtain the costs per functional unit, i.e., in terms of $ km^{-1}. The social costs in terms of $ GJ^{-1} are multiplied by the fuel efficiency (GJ km^{-1}) to obtain the cost-effectiveness ($ km^{-1}).

In terms of a functional unit, the ethanol substitution for gasoline is cost–effective for scenarios S2, S3, S5, and S6, but not for the scenarios S1 and S4 (Table 3.7). At the discount rate of 4%, the ethanol substitution for gasoline in form of E5 would save 0.02 $ km^{-1} or 33.4% of the social cost per functional unit compared to gasoline (see columns 5 and 6 in Table 3.7) for scenario S2. The saving performance also holds for scenarios S3, S5, and S6. For scenarios S1 and S4 the cost differences are positive, meaning that the ethanol substitution for gasoline is not cost-effective. Seeking for break-even points, the zero cost difference is found at 1.7% and 3.5% higher fuel consumption of E5 and E10 compared to gasoline respectively at the discount rate of 4%, provided that other factors are constant. This means that the ethanol substitution for gasoline in form of E5 or E10 will be cost effective if the fuel consumption of E5 and E10 in 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 at the discount rate of 4%.

Table 3.7 Cost-effectiveness of ethanol and gasoline.

Scenarios	Social cost	Fuel efficiency	Social cost ($ km^{-1})		Cost difference	
	($ GJ^{-1})	(GJ km^{-1})	Ethanol	Gasoline	($ km^{-1})	(%)
	(1)	(2)[a]	(3) = (1) x (2) for ethanol	(4) = (1) x (2) for gasoline	(5) = (3) - (4)	(6) = (5) x 100:(4)
At the discount rate of 4%						
Gasoline	19.89	0.0026		0.05		
Ethanol						
- S1 (E5, 5%)	20.20	0.0353	0.71	0.05	0.66	1298.53
- S2 (E5, 0%)	20.20	0.0017	0.03	0.05	-0.02[b]	-33.40
- S3 (E5, -5%)	20.20	0.0008	0.02	0.05	-0.03	-67.56
- S4 (E10, 5%)	20.20	0.0032	0.06	0.05	0.01	27.14
- S5 (E10, 0%)	20.20	0.0017	0.03	0.05	-0.02	-33.40
- S6 (E10, -5%)	20.20	0.0011	0.02	0.05	-0.03	-56.37
At the discount rate of 8%						
Gasoline	19.90	0.0026		0.05		
Ethanol						
- S1 (E5, 5%)	21.83	0.0353	0.77	0.05	0.72	1410.55
- S2 (E5, 0%)	21.83	0.0017	0.04	0.05	-0.01	-28.07
- S3 (E5, -5%)	21.83	0.0008	0.02	0.05	-0.03	-64.96
- S4 (E10, 5%)	21.83	0.0032	0.07	0.05	0.02	37.32
- S5 (E10, 0%)	21.83	0.0017	0.04	0.05	-0.01	-28.07
- S6 (E10, -5%)	21.83	0.0011	0.02	0.05	-0.03	-52.87
At the discount rate of 10%						
Gasoline	19.91	0.0026		0.05		
Ethanol						
- S1 (E5, 5%)	22.67	0.0353	0.80	0.05	0.75	1468.30
- S2 (E5, 0%)	22.67	0.0017	0.04	0.05	-0.01	-25.32
- S3 (E5, -5%)	22.67	0.0008	0.02	0.05	-0.03	-63.62
- S4 (E10, 5%)	22.67	0.0032	0.07	0.05	0.02	42.57
- S5 (E10, 0%)	22.67	0.0017	0.04	0.05	-0.01	-25.32
- S6 (E10, -5%)	22.67	0.0011	0.02	0.05	-0.03	-51.07

a These are the figures in the column 8 in Table 3.3 divided by 1000.
b A minus sign means cost-effectiveness.

The similar results are found at the discount rates of 8% and 10%. The ethanol substitution for gasoline is also cost-effective for scenarios S2, S3, S5, and S6, but not for S1 and S4. In view of the break-even points, the higher discount rate requires the lower fuel consumption of ethanol blends in terms of L km^{-1} to achieve the cost-effectiveness of the ethanol substitution for gasoline. For instance, the fuel consumption of E5 and E10 compared to gasoline is allowed to increase up to 1.7% and 3.5% respectively at the discount rate of 4%; these figures are respectively 1.3% and 2.6% at discount rate of 10%.

3.4.2 Cost-effectiveness of jatropha-based biodiesel and diesel

At the discount rate of 4%, the private cost of biodiesel is 29.2 \$ GJ^{-1} (Table 3.8), of which the jatropha production cost amounts to 97.3%, the processing cost accounts for 1.7%, and the cost of distribution and blending contributes to 1.0%. The private cost of biodiesel is 95.8% higher than that of diesel. Biodiesel could produce an external benefit of 2.19 \$ GJ^{-1}, while diesel incurs an external cost of 4.2 \$ GJ^{-1}. The social cost of biodiesel is 27.0 \$ GJ^{-1}, which is 41.3% higher than that of diesel at the discount rate of 4%.

Table 3.8 Costs of production and utilization of biodiesel and diesel (\$ GJ^{-1}).

Cost items	Biodiesel			Diesel		
	Discount rate			Discount rate		
	4%	8%	10%	4%	8%	10%
Private cost	29.20	30.64	31.40	14.91	14.91	14.91
- Jatropha production	28.41	28.86	29.11			
- Biodiesel processing	0.50	1.47	1.96			
-Distribution and blending	0.29	0.31	0.32			
External cost	-2.19	-2.24	-2.26	4.21	4.24	4.26
- GHG emissions	-2.58	-2.65	-2.69	2.76	2.76	2.76
- Non-GHG emissions	0.40	0.42	0.43	0.46	0.49	0.50
- Security of supply	NA[a]	NA[a]	NA[a]	0.99	0.99	0.99
Social cost	27.02	28.41	29.14	19.12	19.15	19.17

a Not applied.

Table 3.8 shows that the social cost per GJ of biodiesel is much higher than that of diesel due to its higher private cost component. The higher external costs related to emissions and the security of supply lead to the higher external cost for diesel, while the positive effect of land use change due to jatropha plantation achieves an emission saving or an external benefit for biodiesel. Even with this external benefit, the social cost of biodiesel is much higher than that of diesel. These findings hold for the three discount rates and the differences are larger at the higher discount rates. For instance, the social cost of biodiesel per GJ is 52.0% higher than that of diesel at the discount rate of 10%.

Regarding the external costs of biodiesel production, the non-GHG emissions are mostly caused by the use of chemical fertilizers and diesel for seed transportation (Appendix 3.2). For the external cost reduction, this finding encourages farmers to minimize their use of chemical fertilizers and the biodiesel plants to better locate surrounding the feedstock areas so as to shorten the transport distance and thus the amount of diesel use for transporting dried seed.

Table 3.9 Cost-effectiveness of biodiesel and diesel.

Scenarios	Social cost	Fuel efficiency	Social cost ($ km^{-1})		Cost difference	
	($ GJ^{-1})	(GJ km^{-1})	Biodiesel	Diesel	($ km^{-1})	(%)
	(1)	(2)[a]	(3) = (1) x (2)	(4) = (1) x (2)	(5) = (3) - (4)	(6) = (5) x 100:(4)
At the discount rate of 4%						
Diesel	19.12	0.0019		0.04		
Biodiesel						
- S7 (B5, 0%)	27.02	0.0018	0.05	0.04	0.01[b]	28.58
- S8 (B5, +5%)	27.02	0.0370	1.00	0.04	0.96[c]	2600.22
- S9 (B10, 0%)	27.02	0.0018	0.05	0.04	0.01	28.58
- S10 (B10, +5%)	27.02	0.0034	0.09	0.04	0.05	145.47
At the discount rate of 8%						
Diesel	19.15	0.0019		0.04		
Biodiesel						
- S7 (B5, 0%)	28.41	0.0018	0.05	0.04	0.01	34.98
- S8 (B5, +5%)	28.41	0.0370	1.05	0.04	1.01	2734.64
- S9 (B10, 0%)	28.41	0.0018	0.05	0.04	0.01	34.98
- S10 (B10, +5%)	28.41	0.0034	0.10	0.04	0.06	157.69
At the discount rate of 10%						
Diesel	19.17	0.0019		0.04		
Biodiesel						
- S7 (B5, 0%)	29.14	0.0018	0.05	0.04	0.01	38.31
- S8 (B5, +5%)	29.14	0.0370	1.08	0.04	1.04	2804.43
- S9 (B10, 0%)	29.14	0.0018	0.05	0.04	0.01	38.31
- S10 (B10, +5%)	29.14	0.0034	0.10	0.04	0.06	164.04

a These are the figures in the column 8 in Table 3.3 divided by 1000.
b A plus sign means cost-ineffectiveness.
c The high cost-ineffectiveness in S8 due to low contribution of biodiesel to the blend B5.

In terms of a functional unit, the biodiesel substitution for diesel is not cost–effective for all scenarios (Table 3.9). At the discount rate of 4%, the biodiesel substitution for diesel in form of B5 would increase social cost of 0.01 $ km^{-1} or 28.6% of the social cost per functional unit compared to diesel (see columns 5 and 6 in Table 3.9) for scenario S7. Seeking for break-even points, the zero cost difference is found at 1.4% and 2.8% lower fuel consumption of B5 and B10 compared to diesel respectively at the discount rate of 4%, provided that other factors are constant. This means that the biodiesel substitution for diesel in form of B5 or B10 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%.

Similar results are found at the discount rates of 8% and 10%. The biodiesel substitution for diesel is not cost-effective for all scenarios. In view of the break-even points, the higher discount rate requires lower fuel consumption of biodiesel blends in terms of L km^{-1} to achieve the cost-effectiveness of the biodiesel substitution for diesel. For instance, the fuel consumption of B5 and B10 compared to diesel would decrease more than 1.4% and 2.8% compared to diesel respectively at the discount rate of 4%; these figures are respectively 1.9% and 3.7% at discount rate of 10%. However, these fuel consumption levels of biodiesel blends have not been achieved in reality.

3.5 Conclusions

In this paper we have compared the social costs of biofuels and fossil fuels: ethanol and gasoline, and biodiesel and diesel for an FU of 1 km of vehicle transportation with a focus on the blends of E5 and E10 for ethanol and B5 and B10 for biodiesel in Vietnam. In terms of per MJ, the social costs of biofuels are higher than those of their alternative fossil fuels due to higher private cost components. With the consideration of fuel efficiency in transportation, different results are obtained. The ethanol substitution for gasoline in form of E5 and E10 saves 0.02 $ km^{-1} or 33.4% of social cost per km of vehicle transportation compared to gasoline if the fuel consumption of E5 and E10, in terms of L km^{-1} is equal to the fuel consumption of gasoline at the discount rate of 4%. The lower fuel consumption of E5 and E10 compared to gasoline, the higher achievement of this saving. The biodiesel substitution for diesel in form of B5 or B10 remains not cost–effective if the fuel consumption of B5 and B10 remains the same or 5% higher compared to diesel.

Examining the cost-effectiveness of biofuels under efficiency levels of blends, we identify the required fuel consumption of blends to make biofuel cost-effective compared to fossil fuels. For the ethanol to be cost-effective, the fuel consumption of E5 and E10, in terms of L km^{-1} compared to gasoline, is not exceeding by more than 1.7% and 3.5% for E5 and E10 respectively at the discount rate of 4%. For the cost-effectiveness of biodiesel, the fuel consumption of B5 and B10 compared to diesel would decrease by more than 1.4% and 2.8% for B5 and B10 respectively at the discount rate of 4%. We can conclude that the cost-effectiveness of using biofuel in comparison to fossil fuel depends on the efficiency of biofuel production and blended fuel combustion. For a sustainable biofuel market in Vietnam, further investments will be needed for both, improving the efficiency of biofuel production and blended fuel combustion.

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Appendices

Appendix 3.1 List of parameters of non-GHG emission factors List of parameters of non-GHG emission factors.

Items	Unit	MNHC	NOx	PM	SOx
Pesticide	g kg^{-1}	2.6263	34.8871	7.8847	32.2446
Fertilizer					
- N	g kg^{-1}	0.4975	4.6648	0.6536	3.0276
- P_2O_5	g kg^{-1}	0.1406	2.3152	0.8523	7.3793
- K_2O	g kg^{-1}	0.1006	1.4820	0.2203	1.1562
Electricity	g kW h^{-1}	0.0154	0.3730	0.0149	0.7074
Gasoline	g MJ^{-1}	0.0222	0.0218	0.0022	0.0136
Diesel	g MJ^{-1}	0.0045	0.0214	0.0021	0.0131
Coal	g kg^{-1}	0.1767	0.2931	1.0036	0.1662

Source: [51]

Appendix 3.2 Contribution of emission inputs to non-GHG emissions from biofuel production (%)

Contribution of emission inputs to non-GHG emissions from ethanol production (%)

Pollutants	NMHC	NO_x	PM	SO_2
All emission inputs	100.00	100.00	100.00	100.00
in which:				
- Pesticide	0.10	0.49	0.06	0.39
- Fertilizer	7.58	13.63	2.44	22.12
- Electricity	3.54	30.31	0.68	49.90
- Diesel	3.17	5.37	0.30	2.86
- Coal	85.61	50.20	96.51	24.72

Contribution of emission inputs to non-GHG emissions from biodiesel production (%)

Pollutants	NMHC	NO_x	PM	SO_2
All emission inputs	100.00	100.00	100.00	100.00
in which:				
- Pesticide	0.54	0.71	0.83	0.35
- Fertilizer	47.41	53.22	83.72	66.45
- Electricity	11.92	27.34	5.71	27.16
- Diesel	40.13	18.73	9.75	6.04

Appendix 3.3 Detailed calculation of social costs of fuels[a]

	1. Cassava-based ethanol	2009	2010	2011	2012	2013	…	2023	2024	2025
		0	1	2	3	4		14	15	16
	Fuel production (GJ)		1,051,661	2,049,905	3,048,149	4,046,392		14,028,829	15,027,073	16,025,316
	Total production cost ($ 10^9)									
Private costs	Land opportunity cost		3654	6644	9216	11,412		19,743	19,727	19,625
	Farm operation cost (seed, fertilizer, pesticide, diesel, labour, maintenance)		16,366	29,759	41,279	51,117		88,429	88,360	87,902
	Transportation of dried chip		450	877	1304	1731		6002	6429	6856
	Operation costs, overhead, and maintenance costs		5901	11,502	17,103	22,704		78,714	84,315	89,916
	Revenue of by-products		-1507	-2937	-4367	-5797		-20,097	-21,527	-22,957
	Capital costs in ethanol conversion	36,792	34,775	34,775	34,775	34,775		34,008	34,008	
	Residual value of capital in ethanol conversion									-266,658
	Capital costs in fuel distribution and blending	1174	1115	1115	1115	1115		1115	1115	
	Residual value of capital in fuel distribution and blending									-7026
	Fuel distribution and blending		394	767	1141	1515		5252	5626	6000
Non-private	Net GHG (CO_2e) emissions in ethanol production		2586	4652	6379	7802		10,969	10,598	10,156
	Net GHG (CO_2e) emissions in distribution and blending		51	99	148	196		680	729	1655
	Non-GHG emissions		555	1070	1511	1955		4989	5264	5531
	q^t	1.00	1.08	1.17	1.26	1.36		2.94	3.17	3.43
	$\sum F(t) X q^{-t}$		973,761	2,731,224	5,150,942	8,125,162		52,066,074	56,803,234	61,480,871
	Cash-flow [C(t) - B(t)] ($ 10^9									
	- Social cost	37,967	64,345	88,334	109,618	128,543		230,875	235,721	204,765
	- Private cost	37,967	61,154	82,512	101,579	118,590		214,237	219,130	187,423
	- External cost		3192	5822	8038	9953		16,639	16,591	17,342
	- Cassava production cost		20,470	37,280	51,799	64,261		114,174	114,517	114,383
	- Ethanol conversion cost	36,792	39,175	43,349	47,524	51,698		93,693	97,870	67,038
	- Distribution and blending cost	1174	1508	1882	2256	2629		6367	6741	6000
	- GHG emission cost		2637	4752	6527	7998		11,650	11,327	11,810
	- Non-GHG emission cost		555	1070	1511	1955		4989	5264	5531
	Average cost {$\sum$([C(t) - B(t)] X q^{-t})} / ($\sum$ F(t) X q^{-t}) ($ GJ^{-1})									
	- Social cost		66.33	42.45	35.75	32.57		22.98	22.47	21.83
	- Private cost		63.30	39.55	32.97	29.90		21.16	20.72	20.13
	- External cost		3.03	2.91	2.78	2.66		1.81	1.75	1.70
	- Cassava production cost		19.46	18.64	17.87	17.14		11.94	11.58	11.24
	- Ethanol conversion cost		42.22	20.01	14.39	12.12		8.70	8.62	8.37
	- Distribution and blending cost		1.61	0.90	0.72	0.64		0.53	0.52	0.52
	- Cost of GHG emission		2.51	2.39	2.27	2.16		1.39	1.34	1.29
	- Cost of non-GHG emission		0.53	0.52	0.51	0.50		0.42	0.41	0.41

2. Gasoline		2009	2010	2011	2012	2013	…	2023	2024	2025
		0	1	2	3	4		14	15	16
Fuel production Gasoline (GJ)			1051,661	2,049,905	3,048,149	4,046,392		1,4028,829	15,027,073	16,025,316
Total production cost ($ 10^9)										
private	CIF price and diesel for transportation		16,569	32,297	48,024	63,752		221,027	236,754	252,482
	Capital for truck	214	203	203	203	203		203	203	
	Residual value at this year									-916
Non private	GHG (CO_2e) emissions		2903	5658	8414	11,169		38,724	41,479	44,235
	Non-GHG emissions		365	702	1030	1349		2888	3052	3212
	Security of supply		1161	2264	3366	4469		15,494	16,596	17,699
q^t		1.00	1.08	1.17	1.26	1.36		2.94	3.17	3.43
$\sum F(t) X q^{-t}$			973,761	2,731,224	5,150,942	8,125,162		52,066,074	56,803,234	61,480,871
Cash-flow [C(t) - B(t)] ($ 10^9)										
	- Social cost	214	21,203	41,126	61,039	80,944		278,341	298,092	317,634
	- Private cost	214	16,773	32,500	48,228	63,955		221,230	236,958	252,482
	- External cost		4430	8625	12,811	16,988		57,107	61,129	65,147
	- Cost of GHG (CO_2e) emissions		2903	5658	8414	11,169		38,724	41,479	44,235
	- Cost of non-GHG emissions		365	702	1030	1349		2888	3052	3212
	- Cost of security of supply		1161	2264	3366	4469		15,494	16,596	17,699
Average cost $\{\sum([C(t) - B(t)] X q^{-t})\} / (\sum F(t) X q^{-t})$ ($ GJ^{-1})										
	- Social cost		20.20	20.06	20.03	20.01		19.92	19.91	19.90
	- Private cost		15.99	15.86	15.82	15.81		15.79	15.78	15.78
	- External cost		4.21	4.21	4.21	4.20		4.13	4.13	4.12
	- Cost of GHG (CO_2e) emissions		2.76	2.76	2.76	2.76		2.76	2.76	2.76
	- Cost of non-GHG emissions		0.35	0.34	0.34	0.34		0.27	0.26	0.26
	- Cost of security of supply		1.10	1.10	1.10	1.10		1.10	1.10	1.10

	3. Jatropha-based biodiesel	2009 0	2010 1	2011 2	2012 3	2013 4	…	2023 14	2024 15	2025 16
Fuel production B100 (GJ)			131,187	151,036	190,669	461,063		7,880,229	8,646,963	9,413,696
Total production cost ($ 10^9)										
Private costs	Land opportunity cost		101	114	567	1019		5544	5996	6449
	Farm operation cost (seed, fertilizer, pesticide, diesel, labour, maintenance)		3498	3973	16,143	25,422		199,318	217,121	234,924
	Transportation of jatropha seed		64	73	92	223		3817	4188	4560
	Operation costs, overhead and maintenance		1065	1226	1548	3743		63,980	70,205	76,430
	Compost and glycerin		-1359	-1565	-1975	-4777		-81638	-89,582	-97,525
	Capital costs in biodiesel processing	3953	598	1194	8148	15,627		23,106	23,106	
	Residual value of capital in processing at this year									-169,399
	Capital costs in distribution and blending	95	14	29	195	374		553	553	
	Residual value of capital in distribution at this year									-3403
	Fuel distribution and dispensing		28	33	41	100		1,703	1,869	2035
Non-private	Net GHG (CO_2e) emissions in B100 production		-331	-374	-1777	-3329		-18,145	-19,623	-21,101
	Net GHG (CO_2e) emissions in distribution and blending		4	4	6	13		228	251	273
	Non-GHG missions		120	137	199	432		2016	2179	2337
q^t		1.00	1.08	1.17	1.26	1.36		2.94	3.17	3.43
$\sum F(t) X q^{-t}$			121,469	250,958	402,317	741,211		20,212,654	22,938,538	25,686,306
Cash-flow [C(t) - B(t)] ($ 10^9)										
	- Social cost	4048	3802	4845	23,189	38,850		200,486	216,267	208,385
	- Private cost	4048	4009	5078	24,760	41,733		216,383	233,457	226,872
	- External cost		-207	-233	-1572	-2884		-15,902	-17,195	-18,492
	- Jatropha production		3662	4160	16,802	26,665		208,679	227,306	245,932
	- Biodiesel processing	3953	304	856	7721	14,594		5447	3729	21,095
	- Distribution and blending cost	95	43	61	236	474		2257	2,423	2035
	- Cost of GHG emission		-327	-370	-1771	-3315		-17,917	-19,373	-20,828
	- Cost of non-GHG emission		120	137	199	432		2016	2179	2337
Average cost $\{\sum([C(t) - B(t)] X q^{-t})\} / (\sum F(t) X q^{-t})$ ($ GJ^{-1})										
	- Social cost		33.31	32.58	65.02	66.79		29.54	29.07	28.41
	- Private cost		34.89	34.14	69.09	71.86		31.85	31.34	30.64
	- External cost		-1.58	-1.56	-4.07	-5.07		-2.31	-2.27	-2.24
	- Jatropha production cost		27.92	27.73	50.45	53.83		29.58	29.19	28.86
	- Biodiesel processing cost		6.54	5.99	17.94	17.34		1.94	1.83	1.47
	- Distribution and blending cost		0.44	0.42	0.71	0.70		0.32	0.32	0.31
	- Cost of GHG emission		-2.50	-2.47	-5.02	-6.02		-2.77	-2.71	-2.65
	- Cost of non-GHG emission		0.92	0.91	0.96	0.95		0.47	0.44	0.42

	4. Diesel	2009 0	2010 1	2011 2	2012 3	2013 4	…	2023 14	2024 15	2025 16
	Fuel production pathway 2010-2025 (GJ)		131,187	151,036	190,669	461,063		7,880,229	8,646,963	9,413,696
	Total production cost ($ 10^9)									
private	CIF price and diesel for transportation		1953	2248	2838	6862		117,289	128,701	140,113
	Capital for truck	24	4	7	49	95		140	140	
	Residual value at this year									-631
Non private	GHG (CO_2e) emissions		362	417	526	1273		21,752	23,868	25,985
	Non-GHG emissions		144	164	204	487		2334	2527	2715
	Security of supply		130	150	189	457		7805	8565	9324
	∑ F(t) X q^{-t}		121,469	250,958	402,317	741,211		20,212,654	22,938,538	25,686,306
	q^t	1.00	1.08	1.17	1.26	1.36		2.94	3.17	3.43
	Cash-flow [C(t) - B(t)] ($ 10^9)									
	- Social cost	24	2593	2986	3807	9174		149,323	163,804	178,140
	- Private cost	24	1956	2255	2887	6957		117,429	128,841	140,113
	- External cost		636	730	919	2217		31,892	34,961	38,024
	- Cost of GHG (CO_2e) emissions		362	417	526	1,273		21,752	23,868	25,985
	- Cost of non-GHG emissions		144	164	204	487		2334	2527	2715
	- Cost of security of supply		130	150	189	457		7805	8565	9324
	Average cost {∑([C(t) - B(t)] X q^{-t})} / (∑ F(t) X q^{-t}) ($ GJ^{-1})									
	- Social cost		19.80	19.78	19.85	19.83		19.21	19.18	19.15
	- Private cost		14.94	14.94	15.01	15.01		14.91	14.91	14.91
	- External cost		4.85	4.84	4.83	4.82		4.29	4.26	4.24
	- Cost of GHG (CO_2e) emissions		2.76	2.76	2.76	2.76		2.76	2.76	2.76
	- Cost of non-GHG emissions		1.10	1.09	1.08	1.07		0.54	0.51	0.49
	- Cost of security of supply		0.99	0.99	0.99	0.99		0.99	0.99	0.99

a Costs and benefits in Vietnamese currency (VND) are converted to those in US Dollar ($) using the central bank rate in 2010 of 19,062 VND $\$^{-1}$.


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Chapter 4

An applied general equilibrium analysis for biofuel production policy in Vietnam: welfare, food production, and emissions

Biofuel production has been considered as an opportunity to enhance domestic energy security, foster rural development, and provide a solution for green energy. In Vietnam, the government supports biofuel production with a focus on ethanol and biodiesel for domestic transportation to reduce the imports of fossil fuel. However, there have been concerns about the impacts on welfare and on food production due to land competition for biofuel feedstock. This paper aims to investigate the impacts of the biofuel production policy in Vietnam by 2025 on food production, greenhouse gas emissions and welfare by simulating the biofuel production targets in an applied general equilibrium model for Vietnam and its main trading partners. Under the biofuel production policy there is a decline in food production by 0.5% for agricultural food, 1% for processed foods, and 0.1% decline for food consumption in Vietnam. The biofuel production policy results in an enhancement of energy security by increasing domestic production of biofuel in Vietnam, which leads to a reduction in the import of fossil fuel. The biofuel production policy has positive environmental impact in terms of greenhouse gas emission savings from biofuel production and utilization with an increase in the annual greenhouse gases emission saving in Vietnam from 6% under business as usual to 25% percent in the period from 2010 to 2025. Welfare of Vietnam in 2025 increases by 0.4% under the implementation of the biofuel policy in Vietnam because of better allocation of resources, more local production of energy and a reduction of energy imports. For its main trading partners (MTP), the biofuel implementation in Vietnam induces changes in international trade with Vietnam, particularly reducing the export of fossil fuel and increasing in import of certified emission reductions from Vietnam. Overall, there is a negligible change in the welfare in MTP.

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4.1 Introduction

Biofuel production has been considered as an opportunity to enhance domestic energy security, foster rural development, and provide a solution for green energy [1-3]. Vietnam has been a net energy exporter in the past, and it is projected to be a net energy importer after 2015 [4,5]. Petroleum products accounted for more than 97% of the energy import in the period from 2000 to 2010 [4]. Their imports grew at an average annual rate of 4% while the export of crude oil decreased at an average annual rate of 6% in the same period [4]. The first refinery in Vietnam started its operation in 2009 with a capacity of 5.2 million tonnes of petroleum products, supplying 30% of the domestic demand [6]. Biofuel production has been supported by the Government of Vietnam with a focus on ethanol and biodiesel for domestic transportation to reduce the imports of fossil fuel [2,3]. Blends of E5 and B5 are utilized in domestic transport in the period from 2010 to 2015, and E10 and B10 are proposed after 2015. Since the most applicable feedstocks of cassava and jatropha are cultivated in less developed provinces and biofuel plants are located in the surroundings of these production areas, the biofuel production is expected to benefit the rural areas by fostering economic growth, creating jobs, diversifying agricultural markets, and boosting farm income [2,3].

Despite these benefits, the literature showed adverse impacts of biofuel production on food security, natural resource sustainability, and economic growth [1,7-9]. Several studies considered the effects of biofuel production policy on specific aspects of land use change [10-13], food supply or the agricultural market [9,14-16], or prices of fossil fuel [17,18]. Few studies examined the effects of biofuel production on welfare or economic growth (e.g. in Europe [19,20], and in Mozambique and Tanzania [21,22]). However, the biofuel impacts are different between developed and developing countries due to differences in consumption and production structures, technology, trade patterns and fuel substitutability [1,8,9,21-24]. In studies for Mozambique and Tanzania authors assumed land abundance, biofuel production driven by foreign direct investment for export, and profit repatriation in their models [21,22].

The setting in Vietnam is different because there is no land abundance and its biofuel production is aimed at the local transport sector. As the cassava sector in Vietnam contributed 11% of its output to final human food consumption and 37% to intermediate use for starch and animal feed production in 2010, the impacts of the cassava-based ethanol production in Vietnam on food production and food security have been questioned [25-27]. An important issue is the impact of the biofuel production policy on welfare in Vietnam as the country's poverty rate in 2012 was 11% [28]. This paper aims to investigate the impacts of biofuel production policy in Vietnam on welfare in Vietnam and its main trading partners, and on food production and emissions of greenhouse gases. For this purpose we use applied general equilibrium (AGE) modeling because AGE models are suitable for studying economy-wide impacts [29,30]. The paper contributes to the existing literature by considering the impacts on welfare with explicit welfare function under the Negishi theorem and incorporating emissions of greenhouse gases, not only from feedstock production but also from the production and utilization of biofuel as a substitute for fossil fuel in transportation. The study also provides an applied equilibrium model for the case of biodiesel from non-edible feedstock of jatropha and with the consideration of the co-products of biofuels.

The paper is organized as follows. Section 4.2 presents the specification of the applied general equilibrium model for Vietnam and its main trading partners. Section 4.3 describes data and model calibration. The results are discussed in Section 4.4, and Section 4.5 concludes the study.

4.2 Model specification

An AGE model represents the interaction between policies and economic activities by taking into account the behaviours of all economic agents, and their implications for consumption, production, trade flows and welfare [29]. Its nature permits the assessment of new phenomena, such as the biofuel production policy in Vietnam, which is the focus of our study.

Our AGE model is an open-economy model with two regions: Vietnam and its main trading partners (MTP), which include ten countries (Australia, China, Germany, Japan, Korea, Malaysia, Singapore, Taiwan, Thailand, and the United State) with a contribution of 70% of the total trade volume of Vietnam in 2010 [30-32]. The model distinguishes two representative consumers: respectively in Vietnam and MTP, and considers production, consumption and international trade of different commodities. Regarding feedstocks for the biofuel production in Vietnam, cassava has been a commodity for exports, whereas jatropha is used for local production of biodiesel [3,33-35]. Therefore, cassava is considered as a tradable good and jatropha is non-tradable. In the model, there are six tradable goods: agricultural goods, processed food, other industrial goods, fossil fuels, services, cassava, and three non-tradable goods: jatropha, cassava-based ethanol, and jatropha-based biodiesel for Vietnam. As we focus on the biofuel production policy, we additionally consider two co-products of biofuel production. The first co-product is related to ethanol production and refers to the certified emission reductions (CERS) for carbon. These CERS can be sold to other countries as an ancillary benefit of ethanol production. The second is a co-product in terms of the seedcake that is co-produced in biodiesel production as a compost fertilizer for domestic intermediate use in agriculture (CAKE). As such eleven production goods are included in the model (see Table 4.1). The production factors are labour, capital, and agricultural land.

Our model covers the period from 2010 to 2025 with the year 2010 as the base year. The baseline includes the exogenous trends of labour, capital, land use change, and technical progress till the year 2025 (Section 4.3.3). The biofuel production in 2025 is based on the government's targets. The model maximizes welfare, subject to production technologies and commodity balances.

4.2.1 Objective function and utility function

Table 4.1 Notations used in the model.

Name	Notation	Set
Goods and composites		j
Agricultural goods	AGRI	1
Processed food	PFOO	2
Other industrial goods	INDU	3
Fossil fuel	FFUE	4
Service	SERV	5
Cassava	CASA	6
Jatropha	JATR	7
Ethanol	ETHA	8
Biodiesel	BDIE	9
Co-product of ethanol	CERS	10
Co-product of biodiesel	CAKE	11
Food composite of AGRI, PFOO, CASA	FOOD	12
Biofuel composite of ETHA and BDIE	BFUE	13
Fuel composite of FFUE and BFUE	FUEL	14
Composite of INDU and CAKE	INCA	15
Goods and composites for consumption		
Good j used as final consumption in the region i	$C_{i,j}$	j=1-6, 8-10, 12-14
Goods and composites for production		
Good j is used as an intermediate input for production of good m (m being 1 for AGRI, 2 for PFOO, 3 for INDU, 4 for FFUE, 5 for SERV, 6 for CASA, 7 for JATR, 8 for ETHA, 9 for BDIE, and 10 for CERS, and 11 for CAKE) in region i	$INT_{i,j,m}$	j=1-9, 11, 13-15
Intermediate composite for production of good m in region i	$QINT_{i,m}$	
Production factor inputs		
Agricultural land in the region i for production of good m	$LD_{i,m}$	
Labor in the region i for production of good m	$LB_{i,m}$	
Capital in the region i for production of good m	$KL_{i,m}$	
Others		
Utility of the region i	U_i	
Production output of good m in region i	$Q_{i,m}$	
Net export of good j in region i	$XNET_{i,j}$	
Reduction in GHG emission from biofuel production and utilization in Vietnam (for i=1 for Vietnam; j=8 for ethanol and j=9 for biodiesel)	$EMSA_{i,j}$	

The general competitive equilibrium in the Negishi format is represented through a welfare optimum subject to production technologies and commodity balances with nonzero welfare weights (α_i) for the two regions such that the consumer's budget constraint holds. In the model, the two regions are indexed by i (i=1 for Vietnam and i=2 for MTP). Goods and composites are indexed by j (j=1-15, see Table 4.1); they are used for final consumption (j=1-6, 8-10, 12-14) and for production (j=1-9, 11, 13-15). Eleven producers are indexed by m (m=1-11) respectively for agricultural goods, processed food, other industrial goods, fossil fuel, services, cassava, jatropha, ethanol, biodiesel, co-products of ethanol (CERS) and biodiesel (CAKE).

The model structure is as follows:

$$\mathrm{W} = \max \textstyle\sum_{\mathrm{i}} \alpha_{\mathrm{i}} \log \mathrm{U}_{\mathrm{i}} \tag{4.1}$$

where W is the total welfare, U_i is the utility of the region i, α_i represents the welfare weight of region i and is chosen as such that the budget constraints are satisfied.

The utility function in Vietnam is a nested function combining a Cobb-Douglas (CD) function and a Constant Elasticity of Substitution (CES) function with three levels (see Figure 4.1). In this study, the CD function is used because it allows for substitution with elasticity 1, and its calibration is straightforward [36]. For the key sectors of biofuel and fuel composite, the CES function is applied to allow for differentiated elasticity of substitution. At level 1, the CD utility function has four consumption goods: (i) other industrial goods, (ii) services, (iii) food composite, and (iv) fuel composite. At level 2, a CD function is applied for the food composite of agricultural goods, processed food, and cassava; a CES function is applied for the fuel composite of fossil fuel and biofuel. At level 3, a CES function is used for the biofuel composite of ethanol and biodiesel.

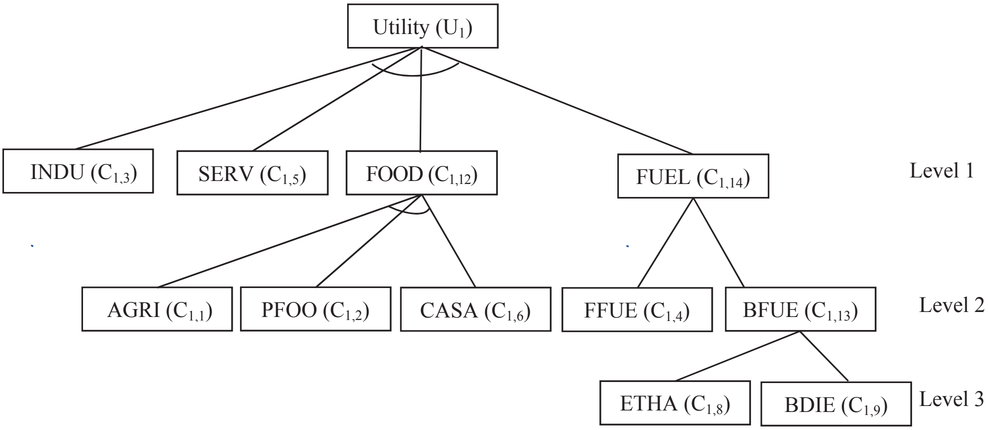

Figure 4.1 Structure of utility function for Vietnam.

For MTP, a similar utility structure is applied; however, MTP purchases and consumes CERS from Vietnam. We have assumed that fuel consumption is only from fossil fuel in MTP (see Appendix 4.1.1).

The utility functions for Vietnam and MTP are as follows:

$$\mathrm{U_i} = \prod\nolimits_{\mathrm{k}} \mathrm{C}_{\mathrm{i,k}}^{\beta_{\mathrm{i,k}}} \tag{4.2}$$

where $C_{i,k}$ is the consumption of good k in region i; for Vietnam, k=3,5,12, and 14; for MTP, k=3-5,10, and 12. $\beta_{i,k}$ is the share of consumption good k in expenditure of region i. Composites of food and fuel are defined in a CD function of agricultural goods, processed food and cassava and a CES function of biofuel and fossil fuel respectively. A composite of biofuel is defined in a CES function of ethanol and biodiesel.

$$\mathrm{C_{i,12}} = \mathrm{C}_{\mathrm{i,1}}^{\beta_{\mathrm{i,1}}} \mathrm{C}_{\mathrm{i,2}}^{\beta_{\mathrm{i,2}}} \mathrm{C}_{\mathrm{i,6}}^{\beta_{\mathrm{i,6}}} \tag{4.3}$$

$$\mathrm{C_{1,13}} = \left[\beta_{13}^{\frac{1}{\sigma_{13}}} \mathrm{C}_{1,8}^{\frac{\sigma_{13}-1}{\sigma_{13}}} + (1-\beta_{13})^{\frac{1}{\sigma_{13}}} \mathrm{C}_{1,9}^{\frac{\sigma_{13}-1}{\sigma_{13}}}\right]^{\frac{\sigma_{13}}{\sigma_{13}-1}} \tag{4.4}$$

$$\mathrm{C_{1,14}} = \left[\beta_{14}^{\frac{1}{\sigma_{14}}} \mathrm{C}_{1,4}^{\frac{\sigma_{14}-1}{\sigma_{14}}} + (1-\beta_{14})^{\frac{1}{\sigma_{14}}} \mathrm{C}_{1,13}^{\frac{\sigma_{14}-1}{\sigma_{14}}}\right]^{\frac{\sigma_{14}}{\sigma_{14}-1}} \tag{4.5}$$

$$\beta_{13} = \frac{C_{1,8}}{C_{1,8}+C_{1,9}} \tag{4.6}$$

$$\beta_{14} = \frac{C_{1,4}}{C_{1,4}+C_{1,8}+C_{1,9}} \tag{4.7}$$

where β_{13} and β_{14} are the expenditure shares of ethanol in total biofuel expenditure and of fossil fuel in total fuel expenditure for Vietnam, σ_{13} is the elasticity of substitution between ethanol and biodiesel, σ_{14} is the elasticity of substitution between biofuel and fossil fuel. Appendix 4.3 gives the values of the parameters in utility functions.

4.2.2 Production function

To describe the detailed production functions of eleven goods, we grouped them into 5 categories according to their production technologies: agricultural goods (m=1), good m (m=2-4 for Vietnam and m=2-5 for MTP), service, cassava and jatropha, biofuels and their co-products.

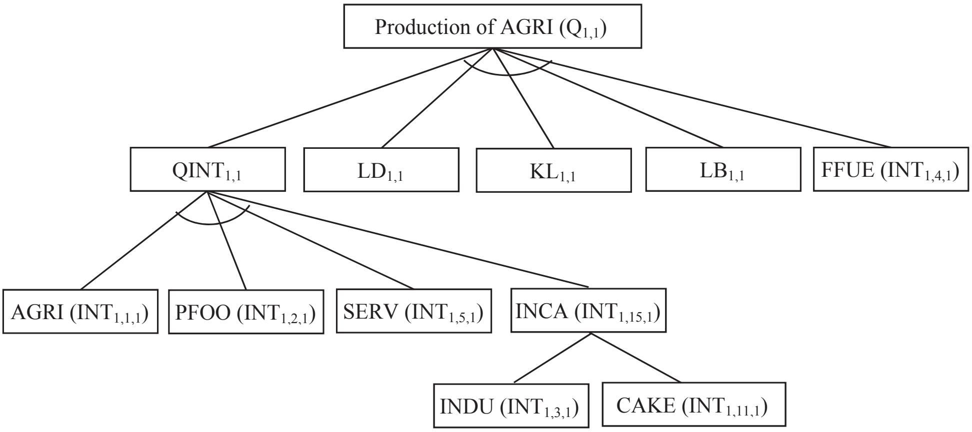

Figure 4.2 Structure of production functions of agricultural goods for Vietnam.

First, the function of agricultural goods (m=1) for Vietnam is specified using the Cobb-Douglas production technology (see Figure 4. 2). The CD production function of agricultural goods in Vietnam is as follows:

$$Q_{1,1} = A_{1,1} QINT_{1,1}^{\delta_{1,QINT,1}} LD_{1,1}^{\delta_{1,LD,1}} KL_{1,1}^{\delta_{1,KL,1}} LB_{1,1}^{\delta_{1,LB,1}} INT_{1,4,1}^{\delta_{1,4,1}} \tag{4.8}$$

$$\text{with} \quad \delta_{1,QINT,1} + \delta_{1,LD,1} + \delta_{1,KL,1} + \delta_{1,LB,1} + \delta_{1,4,1} = 1 \tag{4.9}$$

$$QINT_{1,1} = INT_{1,1,1}^{\delta_{1,1,1}} INT_{1,2,1}^{\delta_{1,2,1}} INT_{1,5,1}^{\delta_{1,5,1}} INT_{1,15,1}^{\delta_{1,15,1}} \tag{4.10}$$

$$\text{with } \delta_{1,1,1} + \delta_{1,2,1} + \delta_{1,5,1} + \delta_{1,15,1} = 1 \tag{4.11}$$

$$\text{and } INT_{1,15,1} = INT_{1,3,1} + INT_{1,11,1} \tag{4.12}$$

where $Q_{1,1}$ is the production output of agricultural goods in Vietnam; $A_{1,1}$ is the productivity parameter; $LD_{1,1}$, $KL_{1,1}$ and $LB_{1,1}$ are land, capital, and labor. $QINT_{1,1}$ is intermediate composite for production of agricultural goods in Vietnam, which is formulated as a CD function of the intermediate inputs of agricultural goods ($INT_{1,1,1}$), processed food ($INT_{1,2,1}$), service ($INT_{1,5,1}$), and the composite of $INT_{1,15,1}$ being the sum of other industrial goods ($INT_{1,3,1}$) and seedcake ($INT_{1,11,1}$). $\delta_{1,QINT,1}$, $\delta_{1,LD,1}$, $\delta_{1,KL,1}$, $\delta_{1,LB,1}$, $\delta_{1,j,1}$ are the cost share of intermediate composite, land, capital, labor, and intermediate input j for production of agricultural goods.

For MTP, the production function of agricultural goods includes the same variables of MTP except for seedcake because it is a non-tradable co-product only available in Vietnam.

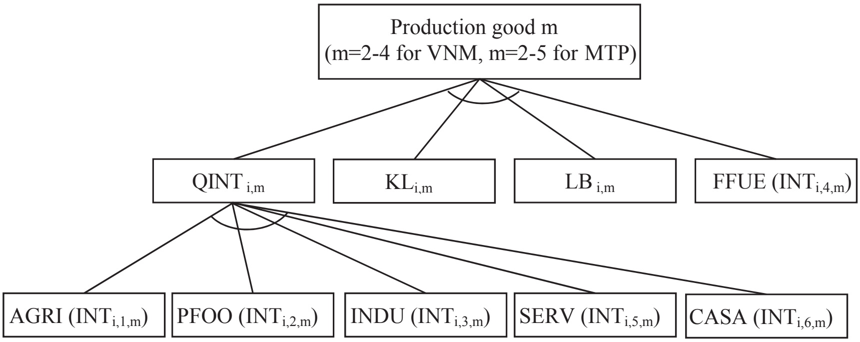

Figure 4.3 Structure of production function of good m.

Second, the production function of production good m (particularly m=2-4 for Vietnam and m=2-5 for MTP) is specified using the Cobb-Douglas production technology (see Figure 4.3). The CD production function for producer m in region i is as follows:

$$\mathrm{Q_{i,m} = A_{i,m} QINT_{i,m}^{\delta_{i,QINT,m}} KL_{i,m}^{\delta_{i,KL,m}} LB_{i,m}^{\delta_{i,LB,m}} INT_{i,4,m}^{\delta_{i,4,m}}}$$

for m = 2-4 for VNM and m =2-5 for MTP (4.13)

$$\text{with } \mathrm{\delta_{i,QINT,m} + \delta_{i,KL,m} + \delta_{i,LB,m} + \delta_{i,4,m} = 1} \qquad (4.14)$$

where $Q_{i,m}$ is the production output of good m (m=2-4 for Vietnam and m=2-5 for MTP) in region i; $A_{i,m}$ is the productivity parameter of production good m in region i; $LB_{i,m}$ and $KL_{i,m}$ are labor and capital used for producing good m in region i. $\delta_{i,QINT,m}$, $\delta_{i,KL,m}$, $\delta_{i,LB,m}$, $\delta_{i,j,m}$ are cost share of the intermediate composite, capital, labor, and intermediate input of good j in the production function of good m in region i (see Appendix 4.3). $QINT_{i,m}$ is intermediate composite for production of good m in region i, which is formulated as a CD function of the intermediate inputs of agricultural goods, processed food, other industrial goods, cassava and services (see Figure 4.3).

Third, the service sector of Vietnam utilizes the intermediate input of fuel ($INT_{1,14,5}$) which is composed of biofuels ($INT_{1,13,5}$) and fossil fuel ($INT_{1,4,5}$) in addition to capital, labor and other intermediate inputs (Figure 4.4).

$$\mathrm{Q_{1,5} = A_{1,5} QINT_{1,5}^{\delta_{1,QINT,5}} KL_{1,5}^{\delta_{1,KL,5}} LB_{1,5}^{\delta_{1,LB,5}} INT_{1,14,5}^{\delta_{1,14,5}}} \qquad (4.15)$$

$$\text{with } \mathrm{\delta_{1,QINT,5} + \delta_{1,KL,5} + \delta_{1,LB,5} + \delta_{1,14,5} = 1} \qquad (4.16)$$

$$\mathrm{QINT_{1,5} = INT_{1,2,5}^{\delta_{1,2,5}} INT_{1,3,5}^{\delta_{1,3,5}} INT_{1,5,5}^{\delta_{1,5,5}}} \qquad (4.17)$$

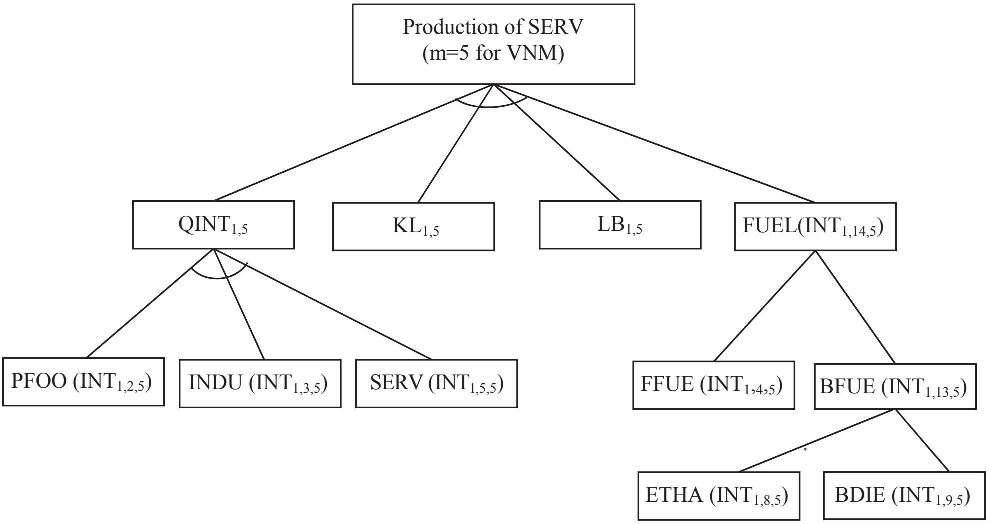

Figure 4.4 Structure of production function of services for Vietnam.

The CES function of the fuel composite in the production function of the service sector for Vietnam is as follows (see Appendix 4.1.2):

$$\mathrm{INT}_{1,13,5} = \left[\delta_{13}^{\frac{1}{\sigma_{13}}}\mathrm{INT}_{1,8,5}^{\frac{\sigma_{13}-1}{\sigma_{13}}} + (1-\delta_{13})^{\frac{1}{\sigma_{13}}}\mathrm{INT}_{1,9,5}^{\frac{\sigma_{13}-1}{\sigma_{13}}}\right]^{\frac{\sigma_{13}}{\sigma_{13}-1}} \tag{4.18}$$

$$\mathrm{INT}_{1,14,5} = \left[\delta_{14}^{\frac{1}{\sigma_{14}}}\mathrm{INT}_{1,4,5}^{\frac{\sigma_{14}-1}{\sigma_{14}}} + (1-\delta_{14})^{\frac{1}{\sigma_{14}}}\mathrm{INT}_{1,13,5}^{\frac{\sigma_{14}-1}{\sigma_{14}}}\right]^{\frac{\sigma_{14}}{\sigma_{14}-1}} \tag{4.19}$$

where δ_{13} is the cost share of ethanol in total biofuel cost; δ_{14} is the cost share of fossil fuel in total fuel cost for the service production of Vietnam:

$$\delta_{13} = \frac{\mathrm{INT}_{1,8,5}}{\mathrm{INT}_{1,8,5}+\mathrm{INT}_{1,9,5}} \tag{4.20}$$

$$\delta_{14} = \frac{\mathrm{INT}_{1,4,5}}{\mathrm{INT}_{1,4,5}+\mathrm{INT}_{1,8,5}+\mathrm{INT}_{1,9,5}} \tag{4.21}$$

Fourth, the production functions of cassava and jatropha follow a Leontief production function with the production factors of land, labor, capital, and intermediate inputs of other industrial goods, services and cassava or jatropha as seeds. The Leontief production functions are specified as follows:

$$Q_{i,6} = \min\{\gamma_{i,LD,6}\mathrm{LD}_{i,6}, \gamma_{i,KL,6}\mathrm{KL}_{i,6}, \gamma_{i,LB,6}\mathrm{LB}_{i,6}, \gamma_{i,3,6}\mathrm{INT}_{i,3,6}, \gamma_{i4,6}\mathrm{INT}_{i,4,6}, \gamma_{i,6,6}\mathrm{INT}_{i,6,6}\},$$

i=1 for VNM and i=2 for MTP (4.22)

$$Q_{1,7} = \min\{\gamma_{1,LD,7}\mathrm{LD}_{1,7}, \gamma_{1,KL,7}\mathrm{KL}_{1,7}, \gamma_{1,LB,7}\mathrm{LB}_{1,7}, \gamma_{1,3,7}\mathrm{INT}_{1,3,7}, \gamma_{1,4,7}\mathrm{INT}_{1,4,7}, \gamma_{1,7,7}\mathrm{INT}_{1,7,7}\} \tag{4.23}$$

where $\gamma_{i,LD,6}, \gamma_{i,KL,6}, \gamma_{i,LB,6}, \gamma_{i,j,6}$ are the parameters of land, capital, labor, and intermediate input j (j=3,4,6) in the Leontief function of cassava; $\gamma_{1,LD,7}, \gamma_{1,KL,7}, \gamma_{1,LB,7}, \gamma_{1,j,7}$ are the parameters of land, capital, labor, and intermediate input j (j=3,4,7) in the Leontief function of jatropha for Vietnam. There is no production of jatropha in MTP.

Fifth, the production functions of biofuels and their co-products (m=8-11) are specified using the CD function of capital, labor, other industrial good, fossil fuel, and feedstocks of cassava and jatropha respectively for ethanol and biodiesel production.

$$Q_{1,8} = A_{1,8} KL_{1,8}^{\delta_{1,KL,8}} LB_{1,8}^{\delta_{1,LB,8}} INT_{1,3,8}^{\delta_{1,3,8}} INT_{1,4,8}^{\delta_{1,4,8}} INT_{1,6,8}^{\delta_{1,6,8}} \text{ for ethanol production, m=8} \quad (4.24)$$

$$Q_{1,9} = A_{1,9} KL_{1,9}^{\delta_{1,KL,9}} LB_{1,9}^{\delta_{1,LB,9}} INT_{1,3,9}^{\delta_{1,3,9}} INT_{1,4,9}^{\delta_{1,4,9}} INT_{1,7,9}^{\delta_{1,7,9}} \text{ for biodiesel production, m=9} \quad (4.25)$$

The production functions of biofuel co-products have the same structure as those of biofuels. We also add two constraints on the outputs of co-products based on the information from the social accounting matrix of Vietnam for the year 2010.

$$Q_{1,10} = A_{1,10} KL_{1,j}^{\delta_{1,KL,10}} LB_{1,j}^{\delta_{1,LB,10}} INT_{1,3,10}^{\delta_{1,3,10}} INT_{1,4,10}^{\delta_{1,4,10}} INT_{1,6,10}^{\delta_{1,6,10}} \quad (4.26)$$

$$Q_{1,11} = A_{1,11} KL_{1,11}^{\delta_{1,KL,11}} LB_{1,11}^{\delta_{1,LB,11}} INT_{1,3,11}^{\delta_{1,3,11}} INT_{1,4,11}^{\delta_{1,4,11}} INT_{1,7,11}^{\delta_{1,7,11}} \quad (4.27)$$

$$Q_{1,10} = k_8 \, Q_{1,8} \qquad \text{with } k_8 = 0.0518 \quad (4.28)$$

$$Q_{1,11} = k_9 Q_{1,9} \qquad \text{with } k_9 = 0.2122 \quad (4.29)$$

where k_8 and k_9 are the coefficients of by-products from ethanol and biodiesel production.

4.2.3 Balance equations

We consider the production factors land, capital, and labor to be mobile between sectors within each region, but immobile between the two regions in our model. The balance equations for all commodities are as follows:

- Balance of good j in region i: $C_{i,j} + \sum_m INT_{i,j,m} + XNET_{i,j} \leq Q_{i,j} \quad (p_{i,j})$ (4.30)
- Trade balance: $\sum_i XNET_{i,j} = 0 \quad (p_j)$ for tradable good j (4.31)

  $XNET_{1,j} = 0 \quad (p_{1,j})$ for non-tradable good j in Vietnam (3.32)
- Balance of production factors:

  $\sum_m LD_{i,m} \leq \overline{LD}_i \quad (k_i)$ for land (4.33)

  $\sum_m KL_{i,m} \leq \overline{KL}_i \quad (r_i)$ for capital (4.34)

  $\sum_m LB_{i,m} \leq \overline{LB}_i \quad (w_i)$ for labor (4.35)

The four variables in brackets (p_j or $p_{1,j}$, k_i, r_i, w_i) are the Lagrange multipliers of the corresponding equations; they are the shadow prices of good j, land, capital, and labor, respectively. $C_{i,j}$, $Q_{i,j}$, $XNET_{i,j}$ are consumption, production, and net export (exports minus imports) of good j in region i (see Appendix 4.1.3 for detailed balance equations).

4.2.4 Analysis of the impact on emissions from biofuel production and utilization

The environmental aspect is considered through the impacts on emission of greenhouse gases (GHGs) in terms of CO_2 equivalent. The three GHGs consisting of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are aggregated to the CO_2 equivalent (CO_2e) using the global warning potential (GWP) factors [37].

In this study we focus on the direct impact of the production and utilization of biofuels as substitutes for fossil fuel in transportation. We do not explicitly model the emissions in other sectors, and in this respect the analysis is restricted to a partial analysis. The impact on emission is calculated based on the GHG balance, which is the difference between the GHG emissions from production and utilization of ethanol and that of gasoline for the same functional unit. We used the GHG balance of each biofuel calculated for 1 kilometer of transportation by road vehicles for each substitution (ethanol for gasoline and biodiesel for diesel) and converted them into the balance per liter of substitution in our previous studies [38,39].

The reduction in the emissions of greenhouse gases in terms of thousand tonnes of CO_2e (EMSA) from ethanol and biodiesel production and consumption in Vietnam are calculated as follows[1]:

$$\mathrm{EMSA}_{1,8} = \mathrm{c}_8\mathrm{Q}_{1,8} \text{ with } \mathrm{c}_8 = 0.11582 \tag{4.36}$$

$$\mathrm{EMSA}_{1,9} = \mathrm{c}_9\mathrm{Q}_{1,9} \text{ with } \mathrm{c}_9 = 0.18376 \tag{4.37}$$

where c_8 and c_9 are coefficients of emission savings from ethanol and biodiesel produced and consumed, respectively.

---

[1] The biofuel outputs in the base year 2010 are 49.844 million liters (equivalent to 29.050 million US dollars) for ethanol and 4.020 million liters (equivalent to 5.001 million US dollars) for biodiesel. In SAM of Vietnam, we use the data on biofuel outputs in monetary terms and follow the Harberger convention to assume that all prices of goods and factors are set equal to 1, and that the quantities of consumption and production goods are equal to the monetary values of the SAMs in the base year. The sectors of ethanol and biodiesel are scaled with a factor of 10 in the model. For this reason, one unit of biofuels in the model is equivalent to 0.1716 (49.844 divided by 290.50) in physical unit of million liter for ethanol and 0.0804 (4.020 divided by 50.01) in physical unit of million liter for biodiesel. From our previous studies [38,39], we estimated the emission saving factors of biofuels produced and consumed in Vietnam are 0.675 thousand tonne of CO_2e per million liters of ethanol and 2.286 thousand tonnes of CO_2e per million liters of biodiesel. Therefore, the coefficients of emission savings from biofuels produced and consumed in Vietnam are 0.11582 (0.675 multiplied by 0.1716) for ethanol and 0.18376 (2.286 multiplied by 0.0804) for biodiesel.

4.3 Data and calibration

4.3.1 Data

For the model calibration, we use the GTAP 8 database [30] for the Social Accounting Matrices (SAMs) of the ten trading partners of Vietnam. For Vietnam, we use the most recent Social Accounting Matrix in Vietnam in 2007 [27]. All data are converted to the base year of 2010 based on GDP growth rates [40].

To construct the SAMs for Vietnam and MTP for the calibration of the model, we firstly aggregate it into five sectors: agricultural goods, processed food, other industrial goods, fossil fuel, and services (see Appendix 4.2). Secondly, for Vietnam, we separate cassava from the agricultural sector based on the total output, trade volume, intermediate and final use of cassava, and the cost structure in Vietnam in 2010 from previous studies in Refs. [25,26,33,38,39,41]. For MTP, we separate cassava from the vegetable-fruit-nut sector in the GTAP database for the three cassava producing countries of MTP (Thailand, Malaysia, and China) on the basis of the total output, trade volume, and intermediate and final use of cassava from [41] and cost structure of the vegetable-fruit-nut sector in GTAP 8 [30]. Thirdly, we add three sectors for jatropha, ethanol and biodiesel in the SAM of Vietnam using the 2010 production quantities under the government's policies [2,3] and the cost structures from our previous studies in Refs. [38,39]. Jatropha is fully used for biodiesel production in Vietnam; biofuels are for domestic consumption and for intermediate use in the service sector following the government's policy [2,3].

4.3.2 Calibration

The SAM data contain monetary values. As in the literature of applied general equilibrium analysis, we follow the Harberger convention to calibrate the model using the base year SAMs. As a result, all prices of goods and factors are set equal to one, and the quantities of consumption and production goods are equal to the monetary values of the SAMs in the base year. This is the baseline 2010. We then project the economy to the year 2025 using the exogenous growth rates of endowments and total factor productivity (TFP), and this is the reference. Following this convention, we can analyze the effects of simulated policies using the relative changes with respect to the reference. We calibrate the parameters in production functions and utility functions based on the cost shares of inputs in total production output and expenditure shares of consumption goods in total expenditure (see Appendix 4.3 for the parameter values).

4.3.3 Definition of scenarios

The aim of our paper is to investigate the impacts of the biofuel policies in Vietnam. To identify the impacts we examine four scenarios: i) S1: the reference scenario in 2025 without any biofuel production policy; ii) S2: the scenario for the ethanol production policy target in 2025, iii) S3: the scenario for the biodiesel production policy target in 2025, iv) S4: the scenario for the combined ethanol and biodiesel production targets in 2025. We establish the impacts of the biofuel policies by comparing scenarios 2-4 with the reference scenario 1 (see Table 4.2). In a sensitivity analysis, we also consider changes in the elasticity of substitution between ethanol and biodiesel, and the elasticity of substitution between biofuel and fossil fuel.

Table 4.2 Description of scenarios and sensitivity analysis.

Scenario	Description
Baseline 2010	Baseline in 2010 Biofuel production in 2010: 49.84 million liters of ethanol, 4.02 million liters of biodiesel
Scenario 1 (S1)	Projection for 2025 without a specific biofuel policy
Scenario 2 (S2)	Targeted ethanol production in 2025
Scenario 3 (S3)	Targeted biodiesel production in 2025
Scenario 4 (S4)	Targeted ethanol and biodiesel production in 2025
Sensitivity analysis	Based on Scenario 1 we calculate the results for σ_{14} in the range from 0.6 to 1.9 and for σ_{13} equal to 0.6. We also calculate the results for σ_{13} in the range from 0.2 to 1.6 and for σ_{14} equal to 1.6.

After calibrating the model for the year 2010 (Baseline in 2010), we project the economy to the year 2025 using the exogenous growth of endowments and total factor productivity (TFP) from 2010 to 2025 as indicated in Tables 4.3 and 4.4. On the basis of Scenario 1, we analyze Scenario 2 by setting an exogenous biofuel production target for ethanol. Scenario 3 contains an exogenous biofuel production target for biodiesel, and Scenario 4 includes exogenous targets for both ethanol and biodiesel in 2025. The targeted amounts of ethanol and biodiesel production are 748.7 and 273.0 million liters following the government's policies [2,3].

To limit the specialization effects in the model with free trade, we added two constraints in the model. The first is on the service sector of Vietnam to make sure that services, such as public administration, defense and compulsory social security, ownership of dwellings, communication, and personal services are provided from domestic production. As the consumption of these services contributes 32.6% in the total consumption, we set a constraint to assure this portion will be domestically produced in Vietnam. The second constraint is on the cassava sector of MTP to limit the specialization effect of possibly shifting all cassava production to Vietnam. We set a constraint on land use for cassava production in MTP countries, assuming that the cassava sector of MTP will grow at least at the average annual rate of growth of the area of agricultural land in cassava-producing MTP countries (0.058%).

Table 4.3 Average annual growth rates of endowments for Vietnam and MTP for the period 2010-2025.

Region	Vietnam			MTP		
Factors	Labour	Capital	Land	Labour	Capital	Land
Average annual growth rate (% per annum)	1.14	5.50	0.29	0.28	3.00	-0.63

Source: [42-49]

The scenarios for the year 2025 are projected on the basis of the annual growth rates of labor, capital, agricultural land, and the total factor productivity (TFP) in each sector (Tables 4.3 and 4.4). We use the average annual growth rate of labor force based on the projection of the International Labour Organization [42]. For land, the projected average annual growth rates of agricultural land are derived from [43] for Vietnam and from [44-46] for MTP. For capital, we use the projected capital growth rate from [47] for each MTP country and then take the weighted average of 10 MTP countries based on the weights of their capital stock in the SAMs.

Table 4.4 Percentage average annual growth rate of total factor productivity per sector.

Region	AGRI	PFOO	INDU	FFUE	SERV	CASA	JATR	ETHA	BIOD	CERS	CAKE
-VNM	1.70	1.20	2.00	0.03	0.83	2.50	1.70	1.80	1.80	1.80	1.80
- MTP	1.55	1.20	1.90	-0.02	0.56	1.70					

Source: [46-67]

The projection of TFP growth rates is based on the historical data of Vietnam and each MTP. The average of TFP of MTP is calculated based on the projected TFP of each MTP and the weights of corresponding output in each sector. We use the EU KLEMS Database for USA, Japan, Australia, Germany, Korea, and Taiwan [48,49]. We also refer to the KIP database from [50] for Korea, and the JIP database from [51] for Japan. For Singapore, Thailand, Malaysia, and China, we use the FAO reports [44,52] for agricultural sectors; other studies [53-59] for remaining sectors. For Vietnam, we refer to the FAO reports [44,52] for the agricultural sector and other studies [60-67] for the remaining sectors.

4.4 Results and discussion

4.4.1 Baseline and Scenario 1

The model parameters are calibrated by using the information for the base year 2010 (Appendix 4.3). The results of production, consumption and international trade for the baseline 2010 and Scenario 1 are presented in Table 4.5. The results of Scenario 1 are the results for the reference scenario for the year 2025.

Compared to the baseline scenario, the results under S1 show the growth rate of production, consumption, and trade in the period from 2010 to 2025 (Table 4.5). The production pattern in Vietnam in 2025 is attributed to its comparative advantages and impacts on international trade. The sectors of agriculture, processed food, and other industry achieve relatively high annual growth rates of 6.9%, 8.6%, and 7.4% followed by the fossil fuel sector at 6.6% and the service sector at 4.0%. The cassava sector in Vietnam has an annual growth rate of 3.9% compared to that of 3.3% in the MTP. Overall, Vietnam attains a higher production growth in comparison with its MTP due to the effect of higher growth rates of productivity and endowments. The endogenous annual growth rates of the biofuel sectors are 6.2% for ethanol and 5.4% for biodiesel in the absence of explicit biofuel production policies in Vietnam. These are relatively low rates compared to other sectors especially the other industrial sector.

On the consumption side, the results indicate a relatively higher increase in the demand for other industrial goods and processed food at average annual rates of 6.1% and 4.8% respectively. The demand for goods and services from other sectors increases at an average annual rate of growth of 3.8% for agricultural goods, 3.5% for fossil fuel, and 3.1% for services. The average annual rate of increase in final consumption of ethanol is 5.6%, which is higher than that of biodiesel at 4.5%. The average annual growth rate of demand for food (4.5%) is greater than for fuel (3.5%) in Vietnam.

For international trade, the main characteristics of trade pattern in Vietnam remain the same: exporting agricultural goods, processed food, and cassava and importing other industrial goods, fossil fuel, and services. Vietnam increases its net exports of agricultural goods and processed food at high average annual growth rates of 10.3% and 14.8%. The net imports annually grow at 4.3% for the industry sector, 3.7% for services, and 2.9% for fossil fuel. Cassava exported to MTP increases on average by 2.5%. The changes in utility between the baseline 2010 and Scenario 1 in the model reflects the improvement of welfare with an annual growth rate of 4.4% for Vietnam and 3.9% for MTP for the period from 2010 to 2025.

Table 4.5 Production, consumption and international trade under the baseline 2010 and under Scenario 1 for the year 2025 and the average annual rates of change in the period 2010-2025.

Items	Baseline (unit) 2010		Scenario S1 (unit) 2025		Average annual rate of change in 2010-2025 (%)	
	VNM	MTP	VNM	MTP	VNM	MTP
Production						
AGRI	34,004	1,832,214	92,112	3,167,507	6.87	3.72
PFOO	43,960	2,541,122	151,084	5,059,292	8.58	4.70
INDU	77,696	20,989,178	225,546	51,259,809	7.36	6.13
FFUE	9,692	4,215,243	25,402	7,009,537	6.63	3.45
SERV	57,153	31,136,906	102,691	48,829,850	3.98	3.05
CASA	5901	19,247	10,417	31,164	3.86	3.26
JATR	41		70		3.63	
ETHA	274		677		6.22	
BIOD	47		103		5.40	
CERS	14		35		6.22	
CAKE	10		22		5.40	
Consumption						
AGRI	8,271	635,562	14,412	1,107,437	3.77	3.77
PFOO	20,638	1,420,047	41,546	2,858,592	4.77	4.77
INDU	30,977	5,990,901	75,736	14,647,421	6.14	6.14
FFUE	4,471	358,190	7,435	596,480	3.45	3.46
SERV	35,282	18,102,583	55,354	28,401,431	3.05	3.05
CASA	663	1,768	1,078	2,878	3.30	3.30
ETHA	125		282		5.59	
BDIE	15		30		4.49	
CERS		14		35		6.22
FOOD composite	14,796	1,101,402	28,470	2,120,067	4.46	4.46
FUEL composite	3,803		6,380		3.51	
Trade						
AGRI	2,669	-2,669[a]	11,635	-11,635	10.31	10.31
PFOO	7,361	-7,361	58,234	-58,234	14.78	14.78
INDU	-11,512	11,512	-21,530	21,530	4.26	4.26
FFUE	-8,227	8,227	-12,712	12,712	2.94	2.94
SERV	-4,932	4,932	-8,551	8,551	3.74	3.74
CASA	2,703	-2,703	3,888	-3,888	2.45	2.45
CERS	14	-14	35	-35	6.22	6.22
Utility	23,693	10,760,266	45,402	18,976,102	4.43	3.85
Welfare[b]		16.17		16.74		0.23

a The minus sign means imports for trade results.

b Welfare is calculated as a weighted sum of the log of utilities as specified in Equation 1.1.

4.4.2 Impacts of biofuel production policies in Vietnam

In interpreting the results it is important to bear in mind that in this AGE model we have assumed that all biofuels produced in Vietnam are for domestic use, and we did not explicitly model biofuels in MTP countries due to insufficient data on production, consumption, and trade flows of biofuels in these countries. These assumptions were made because our study focuses on the direct impact of the production and utilization of biofuels as substitutes for fossil fuel in transportation in Vietnam and the biofuels are not meant to be used for export purposes.

As compared to S1, the results of the policy scenarios S2, S3 and S4 demonstrate the economy-wide impacts of the biofuel production policy in Vietnam (Table 4.6). With the biofuel production targets, we observe changes in production, consumption, trade and welfare of Vietnam. In view of the biofuel sectors, the policy needs to increase ethanol production from 676.6 to 4363.3 units, which is equivalent to a change by 544.9%. The production of ethanol co-product (CERS) increases from 35.0 to 226.0 units with the same change of 544.9%. Surprisingly, the ethanol simulation under S2 simultaneously induces an increase in biodiesel production and its co-product of seedcake, reporting a change of 69.8% compared to the level under S1. The implementation of the biodiesel policy under S3 and S4 causes an increase in production of biodiesel and its co-product from 102.5 and 22.4 to respectively 3400.9 and 741.4 units, which is equivalent to a change by 3216.4%. The biodiesel simulation also induces an increase in ethanol production and its co-product of CERS by 8.9% under S3 compared to S1. For biofuel consumption, the results demonstrate significant increases in final consumption of 1289.6% for ethanol under S2 and S4 compared to S1, and of 11,067.9% for biodiesel under S3 and S4.

Compared to S1, the cassava production is almost unchanged under S2 and decreases by 4.0% under S4. Cassava export substantially decreases by 32.3% and 39.5% under S2 and S4 respectively to meet about 85% of the increase in intermediate use for ethanol production. The remaining demand for the intermediate use of ethanol production comes from a slight decrease in the final use of cassava reported at 3.8% and 4.6% under S2 and S4 respectively compared to S1. Jatropha production increases from 70.3 to 2312.3 units, which is equivalent to a change by 3191.0% under S3, and from 70.3 to 2308.6 units, equivalent to a change by 3185.7% under S4 to meet the demand for feedstock in biodiesel production. The biofuel simulation slightly decreases the production of the industrial sector in Vietnam by 3.7% under S2, by 5.6% under S3, and by 6.0% under S4, revealing a higher impact of the biodiesel simulation compared to that of ethanol. Consumption of industrial goods remains unchanged whereas its import increases by 22.4%, 26.8% and 33.0% under S2, S3, and S4, respectively. A small increase in production of the services sector is for intermediate use, since consumption of services remained almost stable and its import decreases. The production of the fossil fuel sector slightly increases by 0.07%, 1.4%, and 0.9% under S2, S3, and S4; this increase is mainly for intermediate use as there is a decrease both in final consumption and net imports. The biofuel production policy achieves its target of enhancing the energy security in Vietnam by increasing domestic production of fossil fuel by 0.9% and decreasing its import by 3.2% and its domestic use by 0.5% in Vietnam as a result of biofuels produced and used in Vietnam.

Regarding food sectors, in this study food includes the agricultural food and processed food. In comparison with S1, the production of agricultural food increases by 0.5% under S2, but then decreases by 0.4% and 0.5% under S3 and S4. These insignificant changes in agricultural production reveal that the land competition for food production and biofuel feedstock production seems not to be very strong under the biofuel production policy in Vietnam. The biofuel target does not require a large area of additional agricultural land because the decrease in cassava export can meet the demand for feedstock in ethanol production and some land is released for the production of jatropha. The increase in production of agricultural food under S2 goes with the increase in price and export in the international market. The production of processed food also decreases in three biofuel scenarios, especially under S2 an S4 with the decline in intermediate use of cassava for processed food of 4% and 6% respectively. Consumption of food slightly decreases by 0.11%, 0.03% and 0.14% in terms of the composite food under S2, S3 and S4, respectively.

In terms of welfare, the biofuel production policy increases the welfare in Vietnam. Compared to Scenario 1 the attainment of single ethanol and biodiesel production targets contributes to an increase in welfare of 0.3% and 0.03% respectively under S2 and S3. The effect seems to be added up with the implementation of both biofuel targets, enhancing the welfare by 0.4% under S4. When the biofuel production policy is implemented, Vietnam improves the allocation of resources and explores its comparative advantages by increasing export of agricultural products. At the same time it increases the import of industrial goods and reduces the domestic production of industrial goods as compared to the reference scenario S1. This change results in a decrease in the shadow price of capital and an increase in the shadow price of land, relative to the numeraire of the wage in Vietnam. Changes in relative prices of factor endowments together and international trade, especially exporting CERS, increases income in Vietnam, which is reflected in an increase of consumption and utility

Table 4.6 Impacts of biofuel production policies for Vietnam in 2025; levels for Scenario S1 and in percentage change for scenarios S2-S4 compared to the levels under scenario S1.

Items	Scenario S1 (unit) 2025	Rate of change compared to the levels under S1 (%)		
		S2 2025	S3 2025	S4 2025
Production				
- AGRI	92,112	0.53	-0.43	-0.49
- PFOO	151,084	-0.35	-0.07	-1.03
- INDU	225,546	-3.66	-5.56	-5.97
- FFUE	25,402	0.07	1.40	0.91
- SERV	102,691	1.11	0.22	0.05
- CASA	10,417	-0.09	-4.04	-4.03
- JATR	70	68.63	3,190.99	3,185.69
- ETHA	677	544.87	8.85	544.87
- BDIE	103	69.82	3,216.35	3,216.35
- CERS	35	544.87	8.85	544.87
- CAKE	22	69.82	3,216.35	3,216.35
Consumption				
- AGRI	14,412	-0.00	-0.01	-0.01
- PFOO	41,546	-0.03	-0.01	-0.04
- INDU	75,736	-0.01	-0.01	-0.01
- FFUE	7,435	-1.49	-0.19	-1.80
- SERV	55,354	-0.00	-0.01	-0.01
- CASA	1,078	-3.75	-0.79	-4.59
- ETHA	282	1,289.58	18.00	1,289.58
- BDIE	30	226.91	11,067.88	11,067.88
FOOD composite	28,470	-0.11	-0.03	-0.14
FUEL composite	6,380	7.76	0.90	9.44
Trade				
- AGRI	11,635	5.43	-1.54	2.00
- PFOO	58,234	-0.86	-0.06	-1.93
- INDU	-21,530[a]	22.41	26.80	33.01
- FFUE	-12,712	-1.01	-2.74	-3.16
- SERV	-8,551	-16.83	-11.51	-12.07
- CASA	3,888	-32.33	-6.73	-39.45
- CERS	35	544.87	8.85	544.87
Utility	45,402	0.31	0.03	0.37
Welfare[b]	16.74	-0.00	-0.00	-0.00

a The minus sign means imports for trade results.

b Welfare is calculated as a weighted sum of logarithm of utility as specified in Equation 1.1.

For MTP, the biofuel production targets in Vietnam do not have significant impacts on production and consumption in MTP, except for the consumption of CERS (Appendix 4.4.1). Regarding the international trade of MTP with Vietnam, the production of biofuels in Vietnam reduces the import of cassava to MTP and the export of fossil fuel and services. It increases the export of industrial goods and the import of certified emission reductions in MTP. In the context of other factors unchanged, the implementation of biofuel production policy in Vietnam induces insignificant changes to the shadow prices of endowments in MTP, relative to the numeraire of the wage in Vietnam in the model. This reflects the almost unchanged consumption of all goods in MTP except for CERS, resulting in an overall negligible change in the welfare of MTP as an integrated effect. Regarding the overall impact on welfare of the two regions, the implementation of biofuel targets in Vietnam slightly enhances the utility of Vietnam. Given the negligible change of the utility in MTP and the small share of Vietnam in total utility of both regions, there is almost no impact on the total welfare.

4.4.3 Impacts on the emissions

Table 4.7 Direct impacts of biofuel production policy on CO_2 emission savings.

Items	Baseline 2010	S1	S2	S3	S4
Emission savings (10^3 t CO_2)					
- Ethanol	31.7	78.4	505.4	85.3	505.4
- Biodiesel	8.6	18.8	32.0	624.9	624.9
Total	40.2	97.2	537.4	710.3	1,130.3
% change compared to S1					
- Ethanol			544.8	8.9	544.9
- Biodiesel			69.8	3216.4	3216.4
Total			452.8	630.7	1062.7
Average annual rate of change in 2010-2025 (%)		6.1	18.9	21.1	24.9

Note: see Section 4.2.4 for the calculation of emissions savings.

The impacts of biofuel production policy on the emission attributed to biofuels produced and consumed under different scenarios are shown in Table 4.7. The results show emission savings under the policy scenarios (S2, S3, and S4) due to an increase in biofuel production and consumption. With the biofuel production policy, the emission savings from ethanol produced and consumed increase by 544.9% under S2 and S4, and that from biodiesel produced and consumed increases by 3216.4% under S3 and S4 compared to S1. The total emission savings in 2025 under the single ethanol and biodiesel policy and both biofuel policies are 537, 710, and 1130 thousand tons of CO_2 equivalent respectively. The biofuel implementation pushes the average annual increase in emission savings from biofuel production and utilization of 6.1% under S1 to 18.9%, 21.1%, and 24.9% respectively under S2, S3 and S4 with the specific biofuel targets in the period from 2010 to 2025.

4.4.4 Sensitivity analysis

This model has so far been applied using substitution elasticity between biofuel and fossil fuel and that between ethanol and biodiesel derived from the literature and the context of Vietnam [59,110]. On the basis of the historical simulation, the substitution elasticity between biofuel and fossil fuel found from the literature is in the range of 1 to 1.35 for Brazil, 1.65 to 2.75 for EU, and 2 to 3.95 for the USA, and the default value is 2 for Canada, Japan, India and other countries [1,7,10,59]. This study applies the default value of 1.2 for the elasticity of substitution between biofuel and fossil fuel. We perform a sensitivity analysis in the range of 0.6 to 1.9 for the substitution elasticity in Vietnam. We consider the value of the elasticity of substitution between ethanol and biodiesel to have relatively low values since substitution between ethanol and biodiesel requires substantial modification in the composition of petrol and diesel engines in cars, and thus it should be lower than the elasticity of substitution between biofuel and fossil fuel discussed above. We select 0.6 for the standard value and perform a sensitivity analysis for this parameter in the range of 0.2 to 1.6. The sensitivity analysis results show how the model results react to changes in substitution elasticity. Detailed results are included in Appendix 4.4.

Figure 4.5 shows the results of sensitivity analysis for substitution elasticity of biofuel and fossil fuel in the range of 0.6 to 1.9 and for the substitution elasticity between ethanol and biodiesel equal to 0.6. When the substitution elasticity of biofuel and fossil fuel increases, the production and consumption of biofuels decrease because fossil fuel is relatively cheaper than biofuel. The higher the substitution elasticity, the lower the amount of biofuels produced and consumed in the economy. We also calculated the results for Scenario 1 for the substitution elasticity between ethanol and biodiesel in the range from 0.2 to 1.6 and for the substitution elasticity between biofuel and fossil fuel equal to 1.6. Figure 4.6 shows that the increase in substitution elasticity of ethanol and biodiesel results in a relative increase in the production and consumption of ethanol compared to those of biodiesel due to a decrease in the relative price of ethanol to biodiesel. In addition, an exogenous change in the elasticity of substitution between ethanol and biodiesel in the fuel market results in a slight decrease in the production and consumption of both ethanol and biodiesel in Vietnam. This is explained by two factors. Firstly, the substitute of biodiesel for fossil fuel is easier than that for ethanol because the latter may require more technical changes of vehicle engines. Secondly, the shift of both ethanol and biodiesel to fossil fuel is understandable because of the international market of fossil fuel being more freely and sensitive and the dominant of fossil fuel in consumption structure.

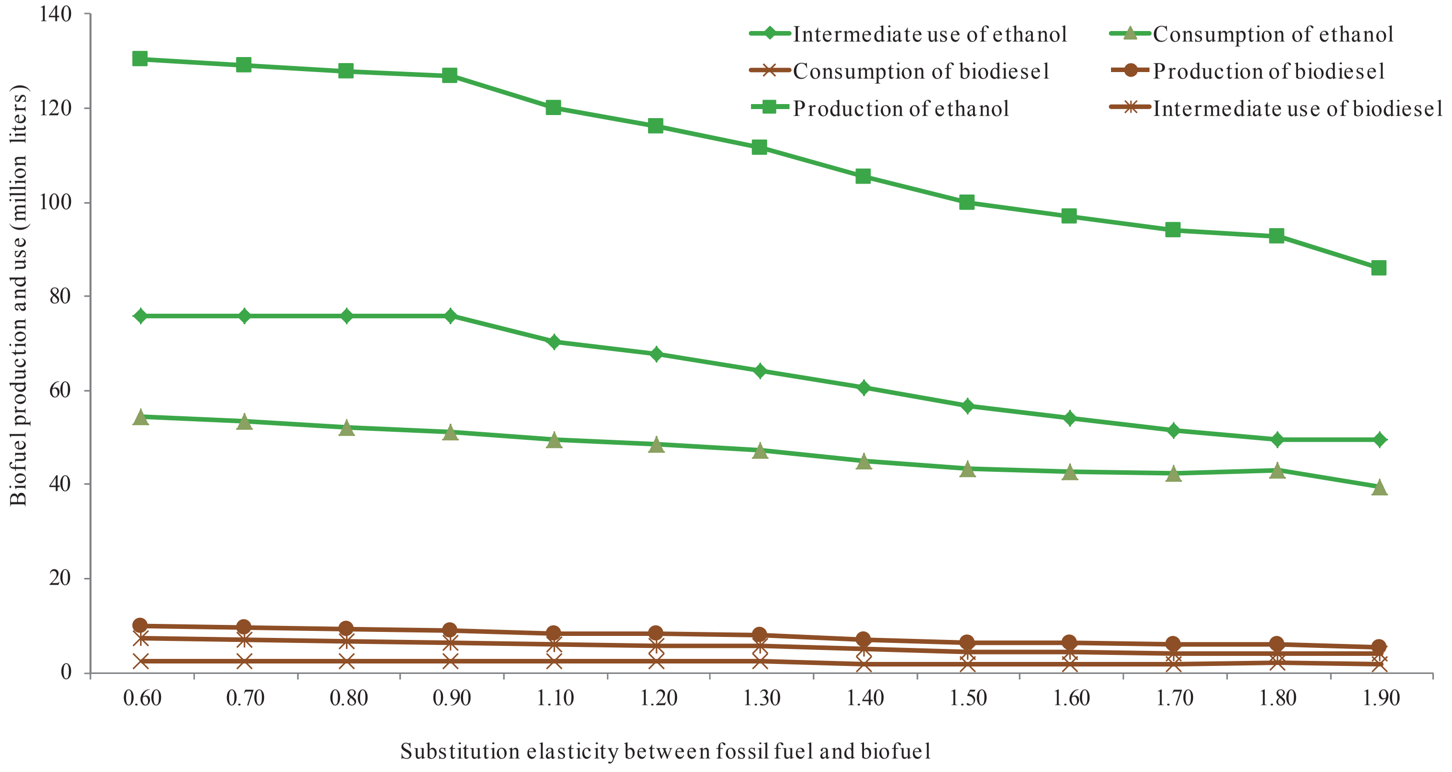

Figure 4.5 Sensitivity analysis for substitution elasticity of biofuel and fossil fuel.

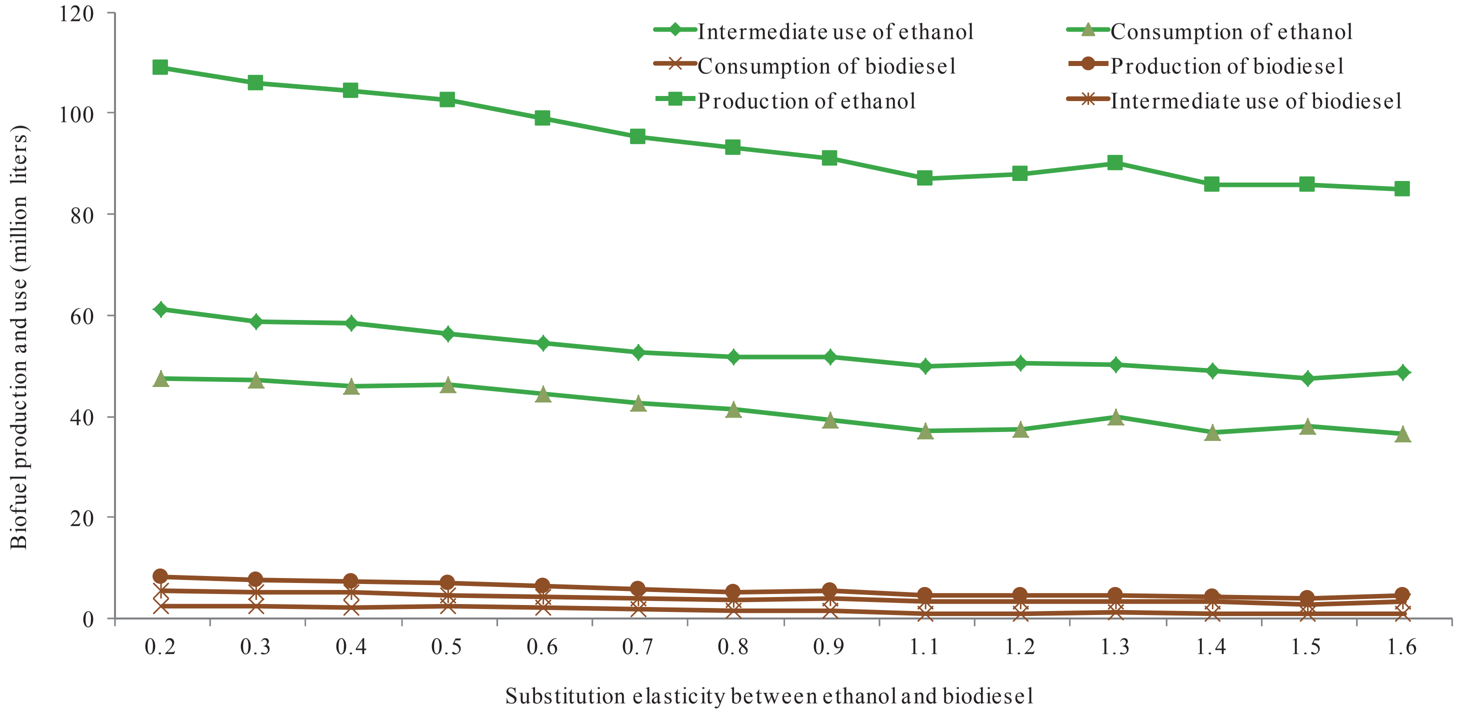

Figure 4.6 Sensitivity analysis for substitution elasticity of ethanol and biodiesel.

4.5 Conclusion

This paper aims to investigate the impacts of biofuel production policy in Vietnam on the welfare, production, consumption and international trade for Vietnam and its main trading partners. With the simulation of biofuel production targets in an applied general equilibrium model for these regions, we can show how the exogenous increase in production and consumption of biofuels results in changes in production, consumption, trade and welfare. We have also studied the direct emission savings for Vietnam under the biofuel production policy.

Our findings indicate that accompanied with a slight decrease in the final consumption the cassava sector shifts its output from export to the domestic intermediate use for ethanol production. With an insignificant decline in food production and consumption, the competition of land use for food and biofuel feedstock production seems to be relatively small under the biofuel production policy in Vietnam, but evidently the production of cassava for export is substantially reduced. This can be explained by the low requirement of land use for jatropha for biodiesel production and by shifting cassava export from Vietnam to its main trading partners to intermediate use for ethanol production. The production of the industrial sector in Vietnam decreases while consumption of industrial products remains unchanged and imports of these products increases. The biofuel production policy results in an enhancement of energy security in Vietnam by increasing domestic production of fossil fuel by 0.9% and decreasing its import by 3.2% and its domestic use by 0.5%.

As an integrated effect on the economy, the welfare increases by 0.4% under the implementation of the biofuel production policy in Vietnam. Vietnam better allocates its resources and shifts its international trade towards utilizing its comparative advantages. This results in a decrease in the shadow price of capital and an increase in the shadow price of land. These effects increase the income, which is reflected in an increase in consumption and utility in Vietnam. For MTP, the implementation of the biofuel production policy in Vietnam induces changes in international trade between MTP and Vietnam, particularly reducing the export of fossil fuel and services and import of cassava, and increasing the export of industrial goods. At the same time the import of certified emission reductions increases. Overall, there is a negligible change in the welfare of MTP as an integrated effect. The slight increase in the utility of Vietnam and the negligible change of the utility in MTP has almost no impact on the total welfare of the two regions because of the small share of Vietnam. According to our model specification, the biofuel production policy leads to a direct increase in the annual rate of emission savings of 19% as compared to the reference scenario in the period from 2010 to 2025. In this AGE model, we follow the approach of modeling biofuels as latent technologies due to the unavailability of data on biofuel sectors in the social accounting matrix of Vietnam and it main trading partners. We assume that all biofuels produced in Vietnam are for domestic use and restrict modeling biofuels in MTP countries due to the insufficient of data on production, consumption, and trade flows of biofuels in these countries. As our study focuses on the direct impact of the production and utilization of biofuels as substitutes for fossil fuel in transportation, we put a limit on the emission impacts as a partial analysis without modeling the emissions in other sectors. These issues could be investigated in further researches.

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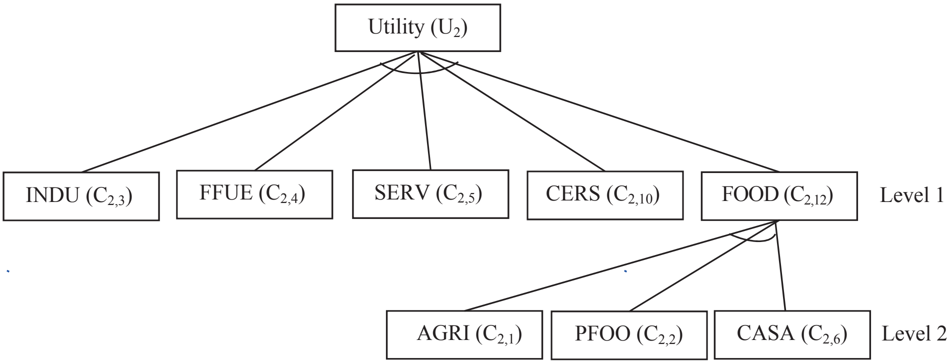
Appendices

Appendix 4.1 Detailed model specification

Appendix 4.1.1 Structure of utility function for MTP



Appendix 4.1.2 Calibration for CES function

The CES function is applied only for Vietnam; therefore, in this presentation the subscript i =1 for Vietnam is omitted to make the notation easier.

CES function in utility function

Following the approach applied in [68,69], for model calibration, the CES function for biofuel composite and fuel composite in the utility function, we use

$$C_{1,14} = B_{14}\left[\bar{\beta}_{14} C_{1,4}^{\frac{\sigma_{14}-1}{\sigma_{14}}} + (1-\bar{\beta}_{14}) C_{1,13}^{\frac{\sigma_{14}-1}{\sigma_{14}}}\right]^{\frac{\sigma_{14}}{\sigma_{14}-1}} \quad \text{(A4.1)}$$

$$C_{1,13} = B_{13}\left[\bar{\beta}_{13} C_{8}^{\frac{\sigma_{13}-1}{\sigma_{13}}} + (1-\bar{\beta}_{13}) C_{9}^{\frac{\sigma_{13}-1}{\sigma_{13}}}\right]^{\frac{\sigma_{13}}{\sigma_{13}-1}} \quad \text{(A4.2)}$$

where $\bar{\beta}_{13}$ is the share parameter of ethanol in CES function of biofuel, and $\bar{\beta}_{14}$ is the share parameter of fossil fuel in the CES function of FUEL, B_{13} is the scaling term in the nested CES in utility function. In case that the composite is nested in the Cobb-Douglas utility function, the scaling term B_{14} does not influence the result and can be chosen as one (see [36,68]).

$$\bar{\beta}_{13} = \frac{\beta_{13}^{\frac{1}{\sigma_{13}}}}{\beta_{13}^{\frac{1}{\sigma_{13}}} + (1-\beta_{13})^{\frac{1}{\sigma_{13}}}} \quad \text{(A4.3)}$$

$$B_{13} = \left(\bar{\beta}_{13}^{\sigma_{13}} + \left(1-\bar{\beta}_{13}\right)^{\sigma_{13}}\right)^{\frac{1}{\sigma_{13}-1}} \quad \text{(A4.4)}$$

$$\bar{\beta}_{14} = \frac{\beta_{14}^{\frac{1}{\sigma_{14}}}}{\beta_{14}^{\frac{1}{\sigma_{14}}} + (1-\beta_{14})^{\frac{1}{\sigma_{14}}}} \quad \text{(A4.5)}$$

$$B_{14} = 1 \quad \text{(A4.6)}$$

CES functions for biofuel and fuel composites as intermediate inputs in production function of service sector of Vietnam

Similar to the calibration of CES function in utility function, the CES function for biofuel composite and fuel composite in the production function of service sector of Vietnam, we use

$$\mathrm{INT}_{1,14,5} = \mathrm{D}_{14}\left[\bar{\delta}_{14}\mathrm{INT}_{1,4,5}{}^{\frac{\sigma_{14}-1}{\sigma_{14}}} + (1-\bar{\delta}_{14})\mathrm{INT}_{1,13,5}^{\frac{\sigma_{14}-1}{\sigma_{f14}}}\right]^{\frac{\sigma_{14}}{\sigma_{14}-1}} \quad \text{(A4.7)}$$

$$\mathrm{INT}_{1,13,5} = \mathrm{D}_{13}\left[\bar{\delta}_{13}\mathrm{INT}_{1,8,5}^{\frac{\sigma_{13}-1}{\sigma_{13}}} + (1-\bar{\delta}_{13})\mathrm{INT}_{1,9,5}^{\frac{\sigma_{13}-1}{\sigma_{13}}}\right]^{\frac{\sigma_{13}}{\sigma_{13}-1}} \quad \text{(A4.8)}$$

where $\bar{\delta}_{13}$ is the share parameter of ethanol in CES function of biofuel, and $\bar{\delta}_{14}$ is the share parameter of fossil fuel in the CES function of FUEL, D_{13} is the scaling term in the nested CES in production function of service sector of Vietnam. In case that the composite is nested in the Cobb-Douglas utility function, the scaling term D_{14} does not influence the result and can be chosen as one (see [36,68]).

$$\bar{\delta}_{13} = \frac{\delta_{13}^{\frac{1}{\sigma_{13}}}}{\delta_{13}^{\frac{1}{\sigma_{13}}}+(1-\delta_{13})^{\frac{1}{\sigma_{13}}}} \quad \text{(A4.9)}$$

$$\mathrm{D}_{13} = \left(\bar{\delta}_{13}^{\sigma_{13}} + \left(1-\bar{\delta}_{13}\right)^{\sigma_{13}}\right)^{\frac{1}{\sigma_{13}-1}} \quad \text{(A4.10)}$$

$$\bar{\delta}_{14} = \frac{\delta_{14}^{\frac{1}{\sigma_{14}}}}{\delta_{14}^{\frac{1}{\sigma_{14}}}+(1-\delta_{14})^{\frac{1}{\sigma_{14}}}} \quad \text{(A4.11)}$$

$$\mathrm{D}_{14} = 1 \quad \text{(A4.12)}$$

Appendix 4.1.3 Balance equations of goods and endowments

Balance equations of goods

$\mathrm{C}_{i,1} + \mathrm{XNET}_{i,1} + \mathrm{INT}_{i,1,1} + \mathrm{INT}_{i,1,2} + \mathrm{INT}_{i,1,4} \leq \mathrm{Q}_{i,1}$ for agricultural good (j=1) (A4.13)

$\mathrm{C}_{i,2} + \mathrm{XNET}_{i2} + \mathrm{INT}_{i,2,1} + \mathrm{INT}_{i,2,2} + \mathrm{INT}_{i,2,6} \leq \mathrm{Q}_{i,2}$ for industrial food (j=2) (A4.14)

$\mathrm{C}_{1,3} + \mathrm{XNET}_{1,3} + \mathrm{INT}_{1,3,1} + \mathrm{INT}_{1,3,2} + \mathrm{INT}_{1,3,3} + \mathrm{INT}_{1,3,4} + \mathrm{INT}_{1,3,5} + \mathrm{INT}_{1,3,6} + \mathrm{INT}_{1,3,7} + \mathrm{INT}_{1,3,8} + \mathrm{INT}_{1,3,9} + \mathrm{INT}_{1,3,10} + \mathrm{INT}_{1,3,11} \leq \mathrm{Q}_{1,3}$ for other industrial good of VNM (j=3, i=1) (A4.15)

$\mathrm{C}_{2,3} + \mathrm{XNET}_{2,3} + \mathrm{INT}_{2,3,1} + \mathrm{INT}_{2,3,2} + \mathrm{INT}_{2,3,3} + \mathrm{INT}_{2,3,4} + \mathrm{INT}_{2,3,5} + \mathrm{INT}_{2,3,6} \leq \mathrm{Q}_{2,3}$
for other industrial good of MTP (j=3, i=2) (A4.16)

$\mathrm{C}_{1,4} + \mathrm{XNET}_{1,4} + \mathrm{INT}_{1,4,1} + \mathrm{INT}_{1,4,3} + \mathrm{INT}_{1,4,4} + \mathrm{INT}_{1,4,5} + \mathrm{INT}_{1,4,6} + \mathrm{INT}_{1,4,7} + \mathrm{INT}_{1,4,8} + \mathrm{INT}_{1,4,9} + \mathrm{INT}_{1,4,10} + \mathrm{INT}_{1,4,11} \leq \mathrm{Q}_{1,4}$ for fossil fuel of VNM (j=4, i=1) (A4.17)

$\mathrm{C}_{2,4} + \mathrm{XNET}_{2,4} + \mathrm{INT}_{2,4,1} + \mathrm{INT}_{2,4,3} + \mathrm{INT}_{2,4,4} + \mathrm{INT}_{2,4,5} + \mathrm{INT}_{2,4,6} \leq \mathrm{Q}_{2,4}$
for fossil fuel of MTP (j=4, i=2) (A4.18)

$\mathrm{C}_{i,5} + \mathrm{XNET}_{i,5} + \mathrm{INT}_{i,5,1} + \mathrm{INT}_{i,5,2} + \mathrm{INT}_{i,5,3} + \mathrm{INT}_{i,5,4} + \mathrm{INT}_{i,5,5} \leq \mathrm{Q}_{i,5}$ for services (j=5) (A4.19)

$\mathrm{C}_{1,6} + \mathrm{XNET}_{1,6} + \mathrm{INT}_{1,6,2} + \mathrm{INT}_{1,6,3} + \mathrm{INT}_{1,6,6} + \mathrm{INT}_{1,6,8} + \mathrm{INT}_{1,6,10} \leq \mathrm{Q}_{1,6}$
for cassava of VNM (j=6, i=1) (A4.20)

$\mathrm{C}_{2,6} + \mathrm{XNET}_{2,6} + \mathrm{INT}_{2,6,2} + \mathrm{INT}_{2,6,3} + \mathrm{INT}_{2,6,6} \leq \mathrm{Q}_{2,6}$ for cassava of MTP (j=6, i=2) (A4.21)

$\mathrm{INT}_{1,7,7} + \mathrm{INT}_{1,7,9} + \mathrm{INT}_{1,7,11} \leq \mathrm{Q}_{1,7}$ for jatropha of VNM (j=7, i=1) (A4.22)

$\mathrm{C}_{1,8} + \mathrm{INT}_{1,8,5} \leq \mathrm{Q}_{1,8}$ for ethanol of VNM (j=8, i=1) (A4.23)

$\mathrm{C}_{1,9} + \mathrm{INT}_{1,9,5} \leq \mathrm{Q}_{1,9}$ for biodiesel of VNM (j=9, i=1) (A4.24)

$\mathrm{XNET}_{1,10} \leq \mathrm{Q}_{1,10}$ for CERS of VNM (j=10, i=1) (A4.25)

$\mathrm{C}_{2,10} + \mathrm{XNET}_{2,10} \leq 0$ for CERS of MTP (j=10, i=2) (A4.26)

$\mathrm{INT}_{1,11,1} \leq \mathrm{Q}_{1,11}$ for seedcake of VNM (j=11, i=1) (A4.27)

Balance equations of goods

$\sum_{\mathrm{i}}^{(\mathrm{i}=1-2)} \mathrm{XNET}_{\mathrm{i,j}} = 0$ for tradable good j=1-6,10 (A4.28)

$\mathrm{XNET}_{1,\mathrm{j}} = 0$ for non tradable good j=7-9,11 (A4.29)

Balance equations of endowments

$\sum_{\mathrm{m}}^{\mathrm{m}=1-11} \mathrm{LB}_{1,\mathrm{m}} \leq \overline{\mathrm{LB}_1}$ for labor of VNM (A4.30)

$\sum_{\mathrm{m}}^{\mathrm{m}=1-6} \mathrm{LB}_{2,\mathrm{m}} \leq \overline{\mathrm{LB}_2}$ for labor of MTP (A4.31)

$\sum_{\mathrm{m}}^{\mathrm{m}=1-11} \mathrm{KL}_{1,\mathrm{m}} \leq \overline{\mathrm{KL}_1}$ for capital of VNM (A4.32)

$\sum_{\mathrm{m}}^{\mathrm{m}=1-6} \mathrm{KL}_{2,\mathrm{m}} \leq \overline{\mathrm{KL}_2}$ for capital of MTP (A4.33)

$\sum_{\mathrm{m}}^{\mathrm{m}=1,6,7} \mathrm{LD}_{1,\mathrm{m}} \leq \overline{\mathrm{LD}_1}$ for land of VNM (A4.34)

$\sum_{\mathrm{m}}^{\mathrm{m}=1,6} \mathrm{LD}_{2,\mathrm{m}} \leq \overline{\mathrm{LD}_2}$ for land of MTP (A4.35)

Appendix 4.2 Social accounting matrix

Table 4.A1 Social Accounting Matrix of Vietnam in 2010.

Items	AGRI	PFOO	INDU	FFUE	SERV	CASA	JATR	ETHA	BDIE	CERS	CAKE	Consumption	Net export	Total
AGRI	27,944	-16,038	-1033	0	0	0	0	0	0	0	0	-7793	-3080	0
PFOO	-3706	34,126	0	0	-2092	0	0	0	0	0	0	-19,447	-8882	0
INDU	-3405	-3582	36,947	-844	-6623	-1845	-11	-63	-4	-3	-1	-29,187	8621	0
FFUE	-1635	0	-2248	4,108	-3658	-279	-2	-5	-0.3	-0.3	-0.1	-4202	7922	0
SERV	-4262	-4450	-7680	-918	46,405	0	0	0	0	0	0	-33,242	4147	0
CASA	0	-933	-1188	0	0	5511	0	-165	0	-9	0	-624	-2592	0
JATR	0	0	0	0	0	0	44	0	-36	0	-8	0	0	0
ETHA	0	0	0	0	-167	0	0	291	0	0	0	-124	0	0
BDIE	0	0	0	0	-35	0	0	0	50	0	0	-15	0	0
CERS	0	0	0	0	0	0	0	0	0	15	0	0	-15	0
CAKE	-11	0	0	0	0	0	0	0	0	0	11	0	0	0
LD	-4493	0	0	0	0	-1024	-1	0	0	0	0	5518	0	0
LB	-8363	-5601	-15995	-526	-21,389	-2073	-28	-20	-5	-1	-1	54,002	0	0
KL	-2069	-3522	-8803	-1820	-12,442	-290	-2	-38	-5	-2	-1	28,994	0	0
Other/Trade	0	0	0	0	0	0	0	0	0	0	0	6121	-6121	0
Total	0	0	0	0	0	0	0	0	0	0	0	0	0	

Positive entries refer to supply and the negative refer to the use of commodities in the SAM.
Source: [27,30,40]

Table 4.A2 Social Accounting Matrix of main trading partner of Vietnam in 2010.

Items	AGRI	PFOO	INDU	FFUE	SERV	CASA	Consumption	Net export	Total
AGRI	1,630,212	-778,618	-218,933	0	0	0	-635,741	3080	0
PFOO	-153,909	2,098,524	0	0	-533,107	0	-1,420,389	8882	0
INDU	-183,567	-268,915	10,180,338	-363,842	-3,358,336	-4,857	-5,992,199	-8621	0
FFUE	-44,242	0	-378,846	1,371,488	-580,884	-1,327	-358,268	-7922	0
SERV	-207,774	-418,404	-3,409,141	-150,423	22,296,377	0	-18,106,488	-4147	0
CASA	0	-14,080	-4,972	0	0	18,228	-1,769	2592	0
CERS	0	0	0	0	0	0	-15	15	0
LD	-271,816	0	0	0	0	-4,093	275,909	0	0
LB	-551,625	-321,555	-3,566,946	-154,222	-10,354,336	-6,789	14,955,473	0	0
KL	-217,279	-296,952	-2,601,500	-703,001	-7,469,714	-1,161	11,289,607	0	0
Other/ Trade	0	0	0	0	0	0	-6121	6121	0
Total	0	0	0	0	0	0	0	0	0

Positive entries refer to supply and the negative refer to the use of commodities in the SAM.
Source: [27,30,40]

Appendix 4.3 Parameters in the model

Table 4.A3 Consumption shares in utility functions.

BETA ($\beta_{i,k}$)	C_{12}	C_{14} for VNM/ C_4 for MTP	C_3	C_5	C_{10}
- VNM	0.294	0.046	0.308	0.351	
- MTP	0.078	0.014	0.226	0.683	5.7E-07

Table 4.A4 Consumption shares of food commodities in food composites.

BETA ($\beta_{i,k}$)	C_1	C_2	C_6
- VNM	0.280	0.698	0.022
- MTP	0.309	0.690	8.6E-04

Table 4.A5 Cost shares in the intermediate input composites of QINT.

DELTA_INT ($\delta_{i,j,m}$)	Intermediate composite for production of good m				
	$QINT_{i,1}$	$QINT_{i,2}$	$QINT_{i,3}$	$QINT_{i,4}$	$QINT_{i,5}$
VNM (i=1), j=1-3,5-6					
- $delta_{1,1,m}$	0.352	0.455	0.020		
- $delta_{1,2,m}$	0.211	0.290			0.115
- $delta_{1,3,m}$		0.102	0.812	0.479	0.363
- $delta_{1,5,m}$	0.243	0.126	0.146	0.521	0.523
- $delta_{1,6,m}$		0.026	0.023		
- $delta_{1,15,m}$	0.194				
MTP (i=2), j=1-3,5-6					
- $delta_{2,1,m}$	0.270	0.405	0.015		
- $delta_{2,2,m}$	0.206	0.230			0.042
- $delta_{2,3,m}$	0.246	0.140	0.748	0.707	0.264
- $delta_{2,5,m}$	0.278	0.218	0.236	0.293	0.694
- $delta_{2,6,m}$		0.007	3.4E-04		

Table 4.A6 Parameters in the final production functions.

$DELTA_{i,j,m}$ ($\delta_{i,j,m}$)	Q_1	Q_2	Q_3	Q_4	Q_5	Q_8	Q_9	Q_{10}	Q_{11}
VNM									
- $A_{1,m}$ in 2010	7.155	5.386	3.834	3.411	4.888	3.241	2.517	3.241	2.475
- $A_{1,m}$ in 2025	9.214	6.441	5.161	3.424	5.504	4.235	3.289	4.235	3.235
- $delta_{1,QINT,m}$	0.515	0.794	0.661	0.182	0.326				
- $delta_{1,3,m}$						0.217	0.078	0.217	0.076
- $delta_{1,4,m}$	0.048		0.028	0.575	0.069	0.018	0.005	0.018	0.005
- $delta_{1,6,m}$						0.566		0.566	
- $delta_{1,7,m}$							0.717		0.725
- $delta_{1,LB,m}$	0.245	0.127	0.200	0.054	0.382	0.070	0.109	0.070	0.106
- $delta_{1,KL,m}$	0.061	0.117	0.110	0.188	0.222	0.129	0.090	0.129	0.088
- $delta_{1,LD,m}$	0.132								
MTP									
- $A_{2,m}$ in 2010	6.791	5.713	3.740	2.761	4.264				
- $A_{2,m}$ in 2025	8.554	6.833	4.964	2.753	4.636				
- $delta_{2,QINT,m}$	0.408	0.756	0.688	0.122	0.409				
- $delta_{2,4,m}$	0.024		0.018	0.675	0.019				
- $delta_{2,LB,m}$	0.301	0.127	0.170	0.037	0.333				
- $delta_{2,KL,m}$	0.119	0.117	0.124	0.167	0.240				
- $delta_{2,LD,m}$	0.148								

Table 4.A7 Parameters in cassava and jatropha production functions.

GAMMA (γ)	INT_3	INT_4	INT_6	INT_7	LB	KL	LD
For 2010							
-$\gamma_{1,j,6}$ for VNM	3.142	20.762	20.292		2.796	20.001	5.662
- $\gamma_{1,j,7}$ for VNM	4.192	30.203		31.464	1.608	22.225	33.947
- $\gamma_{2,j,6}$ for MTP	3.985	14.591	17.135		2.851	16.667	4.729
For 2025							
-$\gamma_{1,j,6}$ for VNM	4.551	30.069	29.388		4.049	28.967	8.200
- $\gamma_{1,j,7}$ for VNM	5.397	38.892		40.517	2.070	28.619	43.713
- $\gamma_{2,j,6}$ for MTP	5.132	18.789	22.065		3.671	21.462	6.090

Table 4.A8 Parameters of biofuel in utility function and and production function of service for Vietnam.

Parameter	Description	Value
Substitution elasticity		
SIGMA_BFUE (σ_{13})	Substitution elasticity between ethanol and biodiesel	0.6
SIGMA_FUEL (σ_{14})	Substitution elasticity between biofuel and fossil fuel	1.2
In utility function of Vietnam		
$\bar{\beta}_{13}$	Share parameter of ethanol in the CES function of biofuel	0.972
$\bar{\beta}_{14}$	Share parameter of fossil fuel in the CES function of FUEL	0.945
B_{13}	Scaling term in the nested CES of biofuel composite	0.787
BETA_BFUE (β_{13})	Expenditure share of ethanol in biofuel composite	0.893
BETA_FUEL (β_{14})	Expenditure share of fossil fuel in fuel composite	0.969
Production function of service in Vietnam		
$\bar{\delta}_{13}$	Share parameter of ethanol in CES function of biofuel for service production	0.931
$\bar{\delta}_{14}$	Share parameter of fossil fuel in CES function of fuel for service production	0.918
D_{13}	Scaling term in the nested CES of biofuel composite	0.691
DELTA_BFUE (δ_{13})	Cost share of ethanol in BIO composite for service production	0.826
DELTA_FUEL (δ_{14})	Cost share of fossil fuel in fuel composite for service production	0.948

Appendix 4.4 Model results

Table 4.A9 Impacts of biofuel production policies for MTP in percentage change compared to the levels for scenario 1.

Items	Scenario S1 (unit)	Rate of change compared to S1 (%)		
		S2	S3	S4
Production				
- AGRI	3,167,507	-0.02	0.00	-0.00
- PFOO	5,059,292	-0.02	-0.01	-0.01
- INDU	51,259,809	0.01	0.02	0.02
- FFUE	7,009,537	-0.01	-0.01	-0.02
- SERV	48,829,850	-0.01	-0.01	-0.01
- CASA	31,164	-	-	-
Consumption				
- AGRI	1,107,437	-0.00	-0.01	-0.01
- PFOO	2,858,592	-0.03	-0.01	-0.04
- INDU	14,647,421	-0.01	-0.01	-0.01
- FFUE	596,480	-0.00	-0.01	-0.01
- SERV	28,401,431	-0.00	-0.01	-0.01
- CASA	2,878	-3.75	-0.79	-4.59
- CERS	35	544.87	8.85	544.87
FOOD composite	2,120,067	-0.02	-0.01	-0.04
Trade				
- AGRI	-11,635	5.43	-1.54	2.00
- PFOO	-58,234	-0.86	-0.06	-1.93
- INDU	21,530	22.41	26.80	33.01
- FFUE	12,712	-1.01	-2.74	-3.16
- SERV	8,551	-16.83	-11.51	-12.07
- CASA	-3,888	-32.33	-6.73	-39.45
- CERS	-35	544.87	8.85	544.87
Welfare	18,976,102	-0.01	-0.01	-0.01

Table 4.A10 Changes in relative prices of goods and production input factors.

Items	S1	S2	S3	S4	Change compared to S1 (%)		
					S2	S3	S4
AGRI	0.5276	0.5293	0.52539	0.5256	0.3124	-0.4242	-0.3850
PFOO	0.4567	0.4582	0.45477	0.4551	0.3369	-0.4222	-0.3558
INDU	0.3760	0.3772	0.37440	0.3746	0.3131	-0.4275	-0.3862
FFUE	0.5521	0.5538	0.54969	0.5499	0.3115	-0.4280	-0.3883
SERV	0.5860	0.5878	0.58345	0.5837	0.3118	-0.4278	-0.3877
CASA	0.5649	0.5887	0.56682	0.5896	4.2173	0.3493	4.3854
JATR	0.6347	0.6393	0.63455	0.6389	0.7391	-0.0159	0.6624
ETHA	0.4083	0.0365	0.41258	0.0502	-91.0699	1.0538	-87.7075
BDIE	0.5078	0.5077	-	0.0019	-0.0150	-100.0000	-99.6173
CERS	0.3951	0.0615	0.36139	0.0610	-84.4453	-8.5295	-84.5547
CAKE	0.3771	0.3785	0.37440	0.3746	0.3673	-0.7102	-0.6690
KL	0.5258	0.5278	0.51956	0.5210	0.3714	-1.1929	-0.9158
LD	1.4721	1.6577	1.49307	1.6729	12.6036	1.4226	13.6380
LB	1.0000	1.0000	1.00000	1.0000	-	-	-

Table 4.A11 Biofuel production and use (in terms of unit) sensitive to the elasticity of biofuel and fossil fuel.

Items	0.60	0.70	0.80	0.90	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90
Production of ethanol	758.96	752.16	745.03	739.72	699.21	676.62	649.99	614.60	582.65	565.00	547.36	540.51	500.96
Production of biodiesel	125.39	120.82	115.51	112.56	104.71	102.55	98.82	87.11	79.80	77.31	74.82	75.68	68.39
Consumption of ethanol	317.71	310.90	303.77	298.47	289.16	282.24	275.19	262.16	252.16	249.66	247.16	250.85	229.20
Consumption of biodiesel	32.70	32.33	31.45	31.35	29.87	29.62	29.12	24.58	24.05	24.19	24.32	24.88	21.34
Intermediate use of ethanol	441.25	441.25	441.25	441.25	410.05	394.37	374.80	352.44	330.49	315.34	300.20	289.66	289.66
Intermediate use of biodiesel	92.69	88.49	84.06	81.22	74.84	72.93	69.70	62.52	55.74	53.12	50.49	50.80	50.80

Table 4.A12 Results of sensitivity analysis for the elasticity of ethanol and biodiesel (σ_{13}) in the range from 0.2 to 1.6 and for σ_{14} equal to 1.6.

Sigma =1.6; Sigma bio	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.6
XNET														
Fossil fuel	-12722.23	-12732.62	-12756.54	-12773.57	-12,793.19	-12812.80	-12830.82	-12841.96	-12866.80	-12873.50	-12870.97	-12881.67	-12888.89	-12890.97
Consumption														
Fossil fuel (C4)	7,430.81	7,435.29	7,442.27	7,445.26	7,453.65	7,462.03	7,468.66	7,477.18	7,488.80	7,490.48	7,488.14	7,495.87	7,495.26	7,499.72
Ethanol (C8)	276.97	274.48	267.41	269.40	258.75	248.09	240.85	228.97	216.07	218.34	232.03	214.21	222.70	212.22
Biodiesel (C9)	31.11	30.14	27.81	30.36	27.34	24.33	19.70	18.25	13.61	13.60	15.33	13.62	13.69	13.84
Production														
Fossil fuel (Q4)	25,401.57	25,413.18	25,405.19	25,402.16	25,401.63	25,401.09	25,398.67	25,400.66	25,397.54	25,398.32	25,397.42	25,395.73	25,398.07	25,399.06
Ethanol (Q8)	634.10	617.57	608.05	597.27	576.01	554.75	542.02	529.97	507.67	512.70	525.40	499.44	499.98	495.27
Biodiesel (Q9)	101.84	95.99	91.18	89.32	81.99	74.66	66.54	67.26	57.41	56.34	57.30	54.87	50.00	56.69
Price														
Fossil fuel (P4)	0.55202	0.55201	0.55201	0.55201	0.55201	0.55200	0.55202	0.55199	0.55199	0.55202	0.55200	0.55197	0.55200	0.55199
Ethanol (P8)	0.41378	0.41645	0.40986	0.41115	0.41184	0.41252	0.41099	0.40967	0.40973	0.40468	0.40318	0.40833	0.41376	0.40710
Biodiesel (P9)	0.56557	0.56943	0.56041	0.56496	0.57743	0.58991	0.60116	0.54582	0.55757	0.55204	0.54327	0.53444	0.56825	0.50073
Intermediate use of fuel for service prod (qqint)														
Fossil fuel (qqint4)	7,170.31	7,181.16	7,193.93	7,205.72	7,215.62	7,225.52	7,234.97	7,239.84	7,250.96	7,260.59	7,260.16	7,258.35	7,266.28	7,268.48
Ethanol (qqint8)	357.13	343.09	340.64	327.87	317.26	306.66	301.17	301.00	291.60	294.36	293.37	285.23	277.28	283.06
Biodiesel (qqint9)	70.73	65.85	63.36	58.96	54.65	50.33	46.84	49.01	43.80	42.75	41.97	41.25	36.32	42.85
Total qqint of fossil fuel for production of all goods	30692.99	30710.50	30719.47	30730.48	30,741.17	30751.86	30760.83	30765.44	30775.54	30781.34	30780.25	30781.53	30791.70	30790.30
Q8:Q9	6.22664	6.43392	6.66889	6.68684	7.02535	7.43032	8.14642	7.87950	8.84235	9.09941	9.16882	9.10276	9.99871	8.73663
Q8:Q4	0.02496	0.02430	0.02393	0.02351	0.02268	0.02184	0.02134	0.02086	0.01999	0.02019	0.02069	0.01967	0.01969	0.01950
Q9:Q4	0.00401	0.00378	0.00359	0.00352	0.00323	0.00294	0.00262	0.00265	0.00226	0.00222	0.00226	0.00216	0.00197	0.00223
C8:C9	8.90247	9.10697	9.61431	8.87444	9.46243	10.19603	12.22644	12.54842	15.87436	16.06026	15.13218	15.73315	16.27228	15.32938
C8:C4	0.03727	0.03692	0.03593	0.03618	0.03471	0.03325	0.03225	0.03062	0.02885	0.02915	0.03099	0.02858	0.02971	0.02830
C8:C4	0.00419	0.00405	0.00374	0.00408	0.00367	0.00326	0.00264	0.00244	0.00182	0.00182	0.00205	0.00182	0.00183	0.00185
qqint8:qqint9	5.04956	5.21044	5.37599	5.56055	5.80584	6.09322	6.43037	6.14135	6.65718	6.88571	6.99012	6.91440	7.63469	6.60645
qqint8:qqint4	0.04981	0.04778	0.04735	0.04550	0.04397	0.04244	0.04163	0.04158	0.04021	0.04054	0.04041	0.03930	0.03816	0.03894
qqint9:qqint4	0.00986	0.00917	0.00881	0.00818	0.00757	0.00697	0.00647	0.00677	0.00604	0.00589	0.00578	0.00568	0.00500	0.00589
P8:P9	0.7316	0.7313	0.7314	0.7278	0.7132	0.6993	0.6837	0.7506	0.7349	0.7331	0.7421	0.7640	0.7281	0.8130
P8:P4	0.7496	0.7544	0.7425	0.7448	0.7461	0.7473	0.7445	0.7422	0.7423	0.7331	0.7304	0.7398	0.7496	0.7375
P9:P4	1.0246	1.0316	1.0152	1.0234	1.0461	1.0687	1.0890	0.9888	1.0101	1.0000	0.9842	0.9682	1.0294	0.9071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Chapter 5

A tax on fossil fuel and biofuel subsidies in Vietnam: an applied general equilibrium analysis

For reaching targets for biofuels in Vietnam a system of a tax on fossil fuels and subsidies on biofuels could be considered. In this paper, we apply a general equilibrium model for Vietnam and its main trading partners to study how a tax on fossil fuel and subsidies on biofuels may affect the production and consumption structures, the international trade pattern, and welfare in the context of adopting the biofuel mandate in Vietnam. We find that an imposition of 10% tax on fossil fuels causes the outputs of industrial goods, fossil fuel, and services to decrease as compared to the reference scenario. The redistribution of tax revenue to consumers enhances the consumption by 0.4% for all goods except for biofuels. These biofuel incentive policies mostly affect the international trade between Vietnam and its main trading partners with a decrease in net exports by 0.4% for agricultural goods, by 0.3% for processed food, and by 0.2% for cassava and an increase in net imports by 1.1% for industrial goods, by 0.3% for fossil fuel, and by 3.1% for services. An additional introduction of a subsidy on biofuel increases the domestic production of services and slightly shifts the fossil fuel sector towards less production and more imports. Welfare in Vietnam increases by 0.4% under the implementation of a 10% tax on fossil fuel and 10% subsidy on biofuels as a result of redistributing tax revenues to consumers in Vietnam.

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5.1 Introduction

In response to the Vietnamese national green growth strategy under the Decision No. 1393/QD-TTg of 2012, an emphasis has been put on the utilization of bioenergy in the economy, especially ethanol and biodiesel as substitutes for fossil fuel under the roadmap for compulsory use of biofuels from the year of 2015 [1-4]. Together with the nation's biofuel mandate, a law on the environmental protection tax, with fossil fuel being one of taxable subjects, has become effective since 2012 with the rates from 0.05 to 0.20 US dollar per liter of gasoline and from 0.03 to 0.10 US dollar per liter of diesel using the exchange rate of the State Bank of Vietnam at the time of the issuance of the Law in 2011 [5]. The biofuel subsidies have been considered in this industry in terms of capital investment in supply chain infrastructure, tax credits to biofuel producers, and reductions or exemptions of tax on fossil fuel in blends to assist biofuels to compete with their fossil fuel alternatives, and other supports for flex-fuel vehicle companies to promote the use of biofuels [2].

The implementation of a tax on fossil fuel and a subsidy on biofuels contributes to a shift to a green economy. We can also expect that such incentive policies in promoting biofuel production will have an economy-wide impact. However, studies on fossil fuel tax or carbon tax and biofuel subsidy in the literature are mostly focused on developed countries; few studies are available for developing countries [6-10]. Previous studies for developed countries assumed the existence of the country's market power and/or a perfect substitution between biofuel and fossil fuel with all consumers owning flexible-fuel vehicles [6-8,11-13]; other studies dealt with some aspects of the taxation, e.g. the Suits Index to measure the progressivity of taxes [9], the effect on producers' profits [10], the effect on gasoline demand as a response to carbon tax [14], and the analysis based on a theoretical framework [6,15,16]. For developing countries, a study on fuel tax and biofuel subsidy in Costa Rica focused on the change in fuel expenditure and the Suits Index; a study in Argentina developed a model with the assumptions that the labour force and real wage are constant and that there is not investment in the economy [17,18]. The economy in Vietnam is projected to have increases in labor force and investment [19,20]. Studies on the environmental protection tax on fossil fuel in Vietnam have not included the biofuel industry in the economy [21-23]. The biofuel industry in the economy is included in an applied general equilibrium (AGE) model in Le et al. [24], but so far, incentive policies for biofuels in Vietnam have not been addressed.

The objective of this paper is to investigate the economy-wide impacts of biofuel incentive policies in Vietnam. For this purpose, we use applied general equilibrium (AGE) modeling because AGE models are suitable for studying economy-wide impacts [25]. The paper contributes to the existing literature by extending the AGE model with a tax on fossil fuel and biofuel subsidies in the context of adopting the biofuel blending mandate in Vietnam and considering the impacts on welfare with explicit welfare function under the Negishi theorem.

The study also provides an applied equilibrium model for the case of biodiesel from non-edible feedstock of jatropha and considers the co-products of biofuels in the model.

The paper is organized as follows. Section 5.2 presents the specification of an applied general equilibrium model. Section 5.3 describes data for model calibration and the formulation of scenarios. Model results for different policy scenarios are reported and discussed in Section 5.4. Finally, Section 5.5 concludes the study.

5.2 Model specification

An AGE model represents the interaction between policies and economic activities by taking into account the behaviour of all economic agents, and their implications for consumption, production, trade flows and welfare [25]. Its nature permits the assessment of new phenomena, such as the biofuel incentive policy in Vietnam, which is the focus of our study.

Our AGE model is an open-economy model with two regions: Vietnam and its main trading partners (MTP), which include ten countries (Australia, China, Germany, Japan, Korea, Malaysia, Singapore, Taiwan, Thailand, and the United State) with a contribution of 70% of the total trade volume of Vietnam in 2010 [26-28]. The model distinguishes two representative consumers: respectively in Vietnam and MTP, and considers production, consumption and international trade of different commodities. Regarding biofuel feedstock in Vietnam, cassava has been a commodity for exports, whereas jatropha is used for local production of biodiesel [4,27,29-31]. Therefore, cassava is considered as a tradable good and jatropha is non-tradable. In the model, there are six tradable goods: agricultural goods, processed food, other industrial goods, fossil fuels, services, cassava, and three non-tradable goods: jatropha, cassava-based ethanol, and jatropha-based biodiesel for Vietnam. As we focus on the biofuel incentive policy, we additionally consider two co-products of biofuel production. The first co-product is related to ethanol production and refers to the certified emission reductions (CERS). These CERS can be sold to other countries as an ancillary benefit of ethanol production. The second is a co-product in terms of the seedcake that is co-produced in biodiesel production as a compost fertiliser for domestic intermediate use in agriculture (CAKE). As such eleven production goods are included in the model (see Table 5.1). The production factors are labour, capital, and agricultural land.

Our model covers the period from 2010 to 2025 with the year 2010 as the base year. The baseline includes the exogenous trends of labour, capital, land use change, and technical progress till the year 2025 (see Section 5.3.3). The biofuel production in 2025 is based on the government's targets. The model maximizes welfare, subject to production technologies and commodity balances. The model is solved using the General Algebraic Modeling Systems (GAMS) software.

5.2.1 Objective function and utility function

The general competitive equilibrium in the Negishi format is represented through a welfare optimum subject to production technologies and commodity balances with nonzero welfare weights (α_i) for the two regions such that the consumer's budget constraint holds. In the model, the two regions are indexed by i (i=1 for Vietnam and i=2 for MTP). Goods and composites are indexed by j (j=1-15, see Table 5.1); they are used for final consumption (j=1-6, 8-10, 12-14) and for production (j=1-9, 11, 13-15). Eleven producers are indexed by m (m=1-11) respectively for agricultural goods, processed food, other industrial goods, fossil fuel, services, cassava, jatropha, ethanol, biodiesel, co-products of ethanol (CERS) and biodiesel (CAKE).

The model structure is as follows:

$$\mathrm{W} = \max \textstyle\sum_{\mathrm{i}} \alpha_{\mathrm{i}} \log \mathrm{U}_{\mathrm{i}} \tag{5.1}$$

where W is the total welfare, U_i is the utility of the region i, α_i represents the welfare weight of region i and is chosen as such that the budget constraints are satisfied.

The model applied is identical to the model described in Chapter 4 of this thesis and the model has been extended with equations for the tax and subsidies as described in Section 5.2.2.

5.2.2 Introduction of exogenous tax and subsidy

To consider the impacts of the environmental tax on the use of fossil fuel and the subsidy for the use of biofuels on the economy, we introduce exogenous tax-ridden price of fossil fuel and subsidy-ridden price of biofuels in the model. For the former, we follow the government policy for the period from 2010 to 2025 and the CIF (including cost, insurance, and freight) import price of fossil fuel to formulate the tax rate at 10% [5,27,33]. For the latter, although the Vietnamese government has not provided any direct subsidy to the biofuel industry, it has gradually created the incentives for biofuel production and utilization, for instance through research and development projects, a 20-year land use right for biofuel investors, capital supports for promotion, blending and distribution systems in the country [2,34,35]. In our analysis, we use a direct subsidy rate of 10% to capture this incentive scheme. We distinguish two cases: i) a fixed tax rate on the final and intermediate use of fossil fuel, and ii) a fixed tax rate on the final consumption and intermediate use of fossil fuel together with a fixed subsidy rate on the final consumption and intermediate use of biofuels.

Table 5.1 Notations used in the model.

Name	Notation	Set
Goods and composites		j
Agricultural goods	AGRI	1
Processed food	PFOO	2
Other industrial goods	INDU	3
Fossil fuel	FFUE	4
Service	SERV	5
Cassava	CASA	6
Jatropha	JATR	7
Ethanol	ETHA	8
Biodiesel	BDIE	9
Co-product of ethanol	CERS	10
Co-product of biodiesel	CAKE	11
Food composite of AGRI, PFOO, CASA	FOOD	12
Biofuel composite of ETHA and BDIE	BFUE	13
Fuel composite of FFUE and BFUE	FUEL	14
Composite of INDU and CAKE	INCA	15
Goods and composites for consumption		
Good j used as final consumption in the region i	$C_{i,j}$	j=1-6, 8-10, 12-14
Goods and composites for production		
Good j is used as an intermediate input for production of good m (m being 1 for AGRI, 2 for PFOO, 3 for INDU, 4 for FFUE, 5 for SERV, 6 for CASA, 7 for JATR, 8 for ETHA, 9 for BDIE, and 10 for CERS, and 11 for CAKE) in region i	$INT_{i,j,m}$	j=1-9, 11, 13-15
Intermediate composite for production of good m in region i	$QINT_{i,m}$	
Production factor inputs		
Agricultural land in the region i for production of good m	$LD_{i,m}$	
Labor in the region i for production of good m	$LB_{i,m}$	
Capital in the region i for production of good m	$KL_{i,m}$	
Others		
Utility of the region i (i being 1 for VNM, 2 for MTP)	U_i	
Production output of good m in region i	$Q_{i,m}$	
Net export of good j in region i	$XNET_{i,j}$	

In the first case, the tax revenue will be distributed to the consumer as a lump-sum transfer. In the second case, the tax revenue should cover the subsidy. When there is a fixed tax rate on the use of fossil fuel or a subsidy rate on the use of biofuels, the consumer prices should be adjusted accordingly:

Tax ridden price of fossil fuel: $p_{1,4}^{c} = (1 + \tau_4)p_{1,4}$ (5.2)
Subsidy ridden price of ethanol: $p_{1,8}^{c} = (1 - \tau_8)p_{1,8}$ (5.3)
Subsidy ridden price of biodiesel: $p_{1,9}^{c} = (1 - \tau_9)p_{1,9}$ (5.4)

where τ_4 is the tax rate on fossil fuel (in percentage), τ_8 and τ_9 are the subsidy rate on ethanol and biodiesel, $p_{1,4}^{c}$ is tax ridden price of fossil fuel for consumers; $p_{1,8}^{c}$ and $p_{1,9}^{c}$ are subsidy ridden prices of ethanol and biodiesel for consumers in Vietnam; p_4, $p_{1,8}$, and $p_{1,9}$ are the market clearing prices of fossil fuel, ethanol, and biodiesel.

The imposition of tax on fossil fuel will adjust the equilibrium through the tax-ridden price of fossil fuel, which is applied to the consumers in Vietnam for final consumption and to producers in Vietnam for their intermediate use of fossil fuel. In the first case, the government will redistribute the tax proceeds (T) to the consumers in Vietnam as a lump-sum transfer. The model is adjusted, such that the budget constraint for the representative consumer in Vietnam is formulated as follows:

$$T = \tau_4 p_{1,4}\left(C_{1,4} + \sum_{j=1-11} INT_{1,4,j}\right) \tag{5.5}$$

$$\sum_{k}^{k=1-3,5-6} p_k C_{1,k} + p_{1,4}^{c} C_{1,4} + p_8 C_{1,8} + p_9 C_{1,9} \leq Y^1 + T \tag{5.6}$$

where Y^1 is the income after tax.

In the second case, the subsidy is given to the biofuel users including consumers and service producers. The model is then adjusted, such that the new profit function of the service sector, which uses the subsidised price of biofuels, is formulated as follows:

$$\Pi_5(p_5) = p_5 Q_{1,5} - r_1 KL_{1,5} - w_1 LB_{1,5} - p_2 INT_{1,2,5} - p_3 INT_{1,3,5} - p_4^{c} INT_{1,4,5} - p_5 INT_{1,5,5} - p_8^{c} INT_{1,8,5} - p_9^{c} INT_{1,9,5} \tag{5.7}$$

The subsidy paid to the users of biofuels (S) is:

$$S = \tau_8 p_{1,8}\left(C_{1,8} + INT_{1,8,5}\right) + \tau_9 p_{1,9}\left(C_{1,9} + INT_{1,9,5}\right) \tag{5.8}$$

The amount of subsidy will be covered by the tax proceeds before the government redistributes the tax proceeds to the consumers:

$$S \leq T \tag{5.9}$$

The budget constraint in this case is:

$$\sum_{k}^{k=1-3,5-6} p_k C_{1,k} + p_4^{c} C_{1,4} + p_8^{c} C_{1,8} + p_9^{c} C_{1,9} \leq Y^2 + T - S \tag{5.10}$$

where Y^2 is the income after tax and subsidy.

5.3 Data and calibration

5.3.1 Data

For the model calibration, we use the GTAP 8 database [26] for the Social Accounting Matrices (SAMs) of the ten trading partners of Vietnam. For Vietnam, we use the most recent Social Accounting Matrix in Vietnam in 2007 [36]. All data are converted to the base year of 2010 based on GDP growth rates [37].

To construct the SAMs for Vietnam and MTP for the calibration of the model, we firstly aggregate it into five sectors: agricultural goods, processed food, other industrial goods, fossil fuel, and services (see Appendix 4.2). Secondly, for Vietnam, we separate cassava from the agricultural sector based on the total output, trade volume, intermediate and final use of cassava, and the cost structure in Vietnam in 2010 from previous studies [29,38-42]. For MTP, we separate cassava from the vegetable-fruit-nut sector in the GTAP database for the three cassava producing countries of MTP (Thailand, Malaysia, and China) on the basis of the total output, trade volume, and intermediate and final use of cassava from [42] and cost structure of the vegetable-fruit-nut sector in GTAP 8 [26]. Thirdly, we add three sectors for jatropha, ethanol and biodiesel in the SAM of Vietnam using the 2010 production quantities under the government's policies [3,4] and the cost structures from our previous studies [38,39]. Jatropha is fully used for biodiesel production in Vietnam; biofuels are for domestic consumption and for intermediate use in the service sector following the government's policy [3,4].

5.3.2 Calibration

The SAM data contain monetary values. As in the literature of applied general equilibrium analysis, we follow the Harberger convention to calibrate the model using the base year SAMs. As a result, all prices of goods and factors are set equal to one, and the quantities of consumption and production goods are equal to the monetary values of the SAMs in the base year. This is the baseline 2010. We then project the economy to the year 2025 using the exogenous growth rates of endowments and total factor productivity (TFP), and this is the baseline 2025. The reference in this study is simulated with the biofuel production targets and without biofuel incentive policies. Following this convention, we can analyze the effects of simulated policies on biofuel incentives using the relative changes with respect to the reference. We calibrate the parameters in production functions and utility functions based on the cost shares of inputs in total production output and expenditure shares of consumption goods in total expenditure (see Appendix 4.3 for the parameter values).

5.3.3 Definition of scenarios

To investigate the impacts of the biofuel incentive policies in Vietnam, we examine three scenarios: i) S1: the reference scenario without biofuel incentive policies, ii) S2: the scenario for the implementation of a tax on fossil fuel; iii) S3: the scenario for the implementation of a tax on fossil fuel and a subsidy on biofuels. In the three scenarios, we included the biofuel production targets. To identify the impacts of the biofuel incentive policies in Vietnam on the economy, we compare the results of S2 and S3 with those of the reference scenario S1 (see Table 5.2). A sensitivity analysis of the tax rate is conducted to address the implications of the optimal tax.

Table 5.2 Description of scenarios.

Scenario	Description
Baseline 2010	Baseline in 2010; biofuel production in 2010: 49.84 million liters of ethanol, 4.02 million liters of biodiesel
Baseline 2025	- Projection for 2025 without any policy;
Scenario 1 (S1)	- Targeted biofuel production in 2025
Scenario 2 (S2)	- 10% tax on fossil fuel; targeted biofuel production in 2025
Scenario 3 (S3)	- 10% tax on fossil fuel and 10% subsidy on biofuels; targeted biofuel production in 2025
Sensitivity analysis	Based on Scenario 3 we calculate the results for a tax rate on fossil fuel in the range from 0% to 30% for Vietnam

After calibrating the model for the year 2010 (Baseline in 2010), we project the economy to the year 2025 using the exogenous growth of endowments and total factor productivity (TFP) from 2010 to 2025 as indicated in Tables 5.3 and 5.4. On the basis of the reference scenario (Baseline 2025), we analyze Scenario 1 by setting the exogenous biofuel production targets of 748.7 and 273.0 million liters for ethanol and biodiesel following the government's policies [3,4]. From Scenario 1, we add an exogenous tax rate of 10% on fossil fuel in S2 for Vietnam. In the S3, a 10% of subsidy rate is implemented together with a 10% tax on fossil fuel for Vietnam. In comparison with Scenario 1, the results of Scenarios 2 and 3 with the incentive policies will show the welfare effects and other impacts of the incentive policies. To examine the impacts of different rates of tax on fossil fuel on the economy and welfare, a sensitivity analysis of tax rate is conducted in this study by step wise increasing the tax rate from zero to 30%.

To limit the specialization effects in the model with free trade, we added two constraints in the model. The first is on the service sector of Vietnam to make sure that services, such as public administration, defense and compulsory social security, ownership of dwellings, communication, and personal services are provided from domestic production. As the consumption of these services contributes 32.6% in the total consumption, we set a constraint to assure this portion will be domestically produced in Vietnam. The second constraint is on the cassava sector of MTP to limit the specialization effect of possibly shifting all cassava production to Vietnam. We set a constraint on land use for cassava production in MTP countries, assuming that the cassava sector of MTP will grow at least at the average annual rate of growth of the area of agricultural land in cassava-producing MTP countries (0.058%).

Table 5.3 Average annual growth rates of endowments for Vietnam and MTP for the period 2010-2025.

Region	Vietnam			MTP		
Factors	Labour	Capital	Land	Labour	Capital	Land
Average annual growth rate (% per annum)	1.14	5.50	0.29	0.28	3.00	-0.63

Source: [19,42-48]

The scenarios for the year 2025 are projected on the basis of the annual growth rates of labor, capital, agricultural land, and the total factor productivity (TFP) in each sector (Tables 5.3 and 5.4). We use the average annual growth rate of labor force based on the projection of the International Labour Organization [19]. For land, the projected average annual growth rates of agricultural land are derived from [43] for Vietnam and from [44-46] for MTP. For capital, we use the projected capital growth rate from [20] for each MTP country and then take the weighted average of 10 MTP countries based on the weights of their capital stock in the SAMs.

Table 5.4 Percentage average annual growth rate of total factor productivity per sector.

Region	AGRI	PFOO	INDU	FFUE	SERV	CASA	JATR	ETHA	BDIE	CERS	CAKE
-VNM	1.70	1.20	2.00	0.03	0.83	2.50	1.70	1.80	1.80	1.80	1.80
- MTP	1.55	1.20	1.90	-0.02	0.56	1.70					

Source: [21,46-67]

The projection of TFP growth rates is based on the historical data of Vietnam and each MTP. The average of TFP of MTP is calculated based on the projected TFP of each MTP and the weights of corresponding output in each sector. We use the EU KLEMS Database for USA, Japan, Australia, Germany, Korea, and Taiwan [47,49]. We also refer to the KIP database from [49] for Korea, and the JIP database from [50] for Japan. For Singapore, Thailand, Malaysia, and China, we use the FAO reports [44,51] for agricultural sectors; other studies [52-58] for remaining sectors. For Vietnam, we refer to the FAO reports [44,51] for the agricultural sector and other studies [59-67] for the remaining sectors.

5.4 Results and discussion

5.4.1 Baseline, Scenario 1, and Scenario 2

The model parameters are calibrated by the base year 2010 data (Appendix 4.3). The model results of production, consumption and international trade for the baseline 2010 and 2025 and the reference scenario with biofuel production target in 2025 (Scenario 1) are presented in Table 5.5. The reference scenario is used for comparing with the scenarios of a tax on fossil fuel and biofuel subsidies (S2 and S3).

Comparing the results in 2025 with those in 2010, we obtained the average annual growth rate of production, consumption, and trade in the period from 2010 to 2025. The production pattern in Vietnam in 2025 is attributed to its comparative advantages and international trade. The sectors of agriculture, processed food, and other industry achieve relatively high annual growth rates of 6.9%, 8.6%, and 7.4% followed by the fossil fuel sector at 6.6% and the service sector at 4.0%. The cassava sector has an annual growth rate of 3.9%. Overall, Vietnam attains a higher production growth in comparison with its MTP due to the effect of higher growth rates of productivity and endowments. Compared to other sectors especially the other industrial sector, the biofuel sectors obtain the lower growth rates of 6.2% and 5.4% for ethanol and biodiesel respectively.

On the consumption side, the results indicate a higher increase in the demand for other industrial goods and processed food at average annual rates of 6.1% and 4.8% respectively. The demand for goods and services from other sectors increases at an average annual growth rate of 3.8% for agricultural goods, 3.5% for fossil fuel, and 3.1% for services. The average annual rate of increase in final consumption of ethanol is 5.6%, which is higher than that of biodiesel at 4.5%. The average annual growth rate of demand for food (4.5%) is greater than for fuel (3.5%) in Vietnam.

For international trade, Vietnam increases its net exports of agricultural goods and processed food at high average annual growth rates of 10.3% and 14.8%. The net imports annually grow at 4.3% for industry sector, 3.7% for service, and 2.9% for fossil fuel. Cassava exported to MTP increases on average by 2.5%. The changes in utility between the baseline 2010 and 2025 reflects the improvement of welfare, with an annual growth rate of 4.4% for Vietnam and 3.9% for MTP.

Table 5.5 Production, consumption and international trade, their annual growth rates from 2010 to 2015 and percentage change due to biofuel target in 2025 for Vietnam.

Items	Baseline (2010)	Baseline (2025)	S1 (biofuel target 2025)	Average annual rate in period of 2010-2025 (%)	% change of S1 compared to baseline 2025
Production					
AGRI	34,004	92,112	91,661	6.87	-0.49
PFOO	43,960	151,084	149,521	8.58	-1.03
INDU	77,696	225,546	212,091	7.36	-5.97
FFUE	9,692	25,402	25,632	6.63	0.91
SERV	57,153	102,691	102,747	3.98	0.05
CASA	5901	10,417	9,997	3.86	-4.03
JATR	41	70	2,309	3.63	3,185.69
ETHA	274	677	4,363	6.22	544.87
BDIE	47	103	3,401	5.40	3,216.35
CERS	14	35	226	6.22	544.87
CAKE	10	22	741	5.40	3,216.35
Consumption					
AGRI	8,271	14,412	14,410	3.77	-0.01
PFOO	20,638	41,546	41,528	4.77	-0.04
INDU	30,977	75,736	75,727	6.14	-0.01
FFUE	4,471	7,435	7,301	3.45	-1.80
SERV	35,282	55,354	55,348	3.05	-0.01
CASA	663	1,078	1,029	3.30	-4.59
ETHA	125	282	3,922	5.59	1,289.58
BDIE	15	30	3,308	4.49	11,067.88
CERS					
FOOD composite	14,796	28,470	28,431	4.46	-0.14
FUEL composite	3,803	6,380	6,982	3.51	9.44
Intermediate use					
AGRI	23,065	66,065	65,383	7.27	-1.03
PFOO	15,960	51,304	50,885	8.10	-0.82
INDU	58,231	171,341	165,002	7.46	-3.70
FFUE	13,448	30,679	30,641	5.65	-0.12
SERV	26,803	55,888	54,918	5.02	-1.74
CASA	2,534	5,450	6,614	5.24	21.35
JATR	41	70	2,309	3.63	3,185.69
ETHA	149	394	441	6.72	11.89
BDIE	31	73	93	5.81	27.55
CAKE	10	22	741	5.40	3,216.35
Trade					
AGRI	2,669	11,635	11,868	10.31	2.00
PFOO	7,361	58,234	57,107	14.78	-1.93
INDU	-11,512[a]	-21,530	-28,638	4.26	33.01
FFUE	-8,227	-12,712	-12,311	2.94	-3.16
SERV	-4,932	-8,551	-7,519	3.74	-12.07
CASA	2,703	3,888	2,354	2.45	-39.45
CERS	14	35	226	6.22	544.87
Utility	23,693	45,402	45,569	4.43	0.37
Welfare[b]	16.1683	16.7359	16.7358	0.23	-0.00

a The minus sign means net imports for trade results.

b Welfare is calculated as a weighted sum of logarithm of utility as specified in Equation 5.1.

As compared to the baseline 2025, the results of S1 demonstrate the economy-wide impacts of the biofuel production policy in Vietnam. This policy needs to increase the current biofuel production by a factor of 5.5 for ethanol and 32 for biodiesel. Compared to the baseline 2025, the cassava production decreases by 4.0%, while its export substantially decreases by 39.5% and its final use decrease by 4.6% under S1 to meet the increase in intermediate use for ethanol production. Jatropha production increases by 3185.7% under S1 for biodiesel production. The biofuel production simulation decreases the production of industrial sector by 6.0% while the consumption remains unchanged and its import increases by 33.0%. A small increase in production of the service sector is related to intermediate use since its consumption remained almost stable and its exports decreased. The biofuel implementation achieves its target on the fossil fuel with the decreases of 3.2% in net import and 1.8% in final consumption, and a slight increase in production by 0.9% compared to the base 2025.

In comparison with the baseline 2025, the production of agricultural food decreases slightly by 0.5% under S1, revealing that land use competition between food and biofuel feedstock production seems not very strong under the biofuel production policy in Vietnam. The biofuel production target does not require a large area of additional agricultural land because the demand for cassava can be achieved by exporting less and some land is released for jatropha production. The production of processed food also decreases under S1 with the decline in intermediate use of cassava. Food consumption decreases slightly by 0.1% in terms of the composite food under S1.

In terms of welfare, the biofuel production policy increases welfare in Vietnam by 0.4% in Vietnam. Under this policy, Vietnam attains a better allocation of resources with its comparative advantages. As a result, it exports more agricultural products and imports more industrial products. This change results in a decrease in the shadow price of capital and an increase in the shadow price of land relative to the numeraire of the wage in Vietnam. Changes in relative prices of factor endowments and international trade, especially exporting CERs increase the consumer income in Vietnam, which leads to higher consumption and utility. Overall, welfare gains do not have a significant impact on consumption of food and other goods.

For MTP, the biofuel production targets in Vietnam do not have significant impacts on production and consumption in MTP, except for the consumption of certified emission reduction credits for carbon (CERS) (Appendix 5). Overall, there are negligible changes in the welfare of MTP. Given the negligible change of the utility in MTP and the small share of Vietnam in total utility of both regions, there is almost no impact on the total welfare.

5.4.2 Impacts of biofuel incentive policy in Vietnam

For the interpretation of the results, it is worth noting that in this AGE model we have assumed that all biofuels produced in Vietnam are for domestic use, and we did not explicitly model biofuels in MTP countries due to insufficient data on production, consumption, and trade flows of biofuels in these countries. These assumptions were made because our study focuses on the direct impact of the production and utilization of biofuels as substitutes for fossil fuel in transportation in Vietnam and the biofuels are not meant to be used for export purposes. For the introduction of tax and subsidy, the international trade remains in a competitive setting with free trade between Vietnam and its main trading partners for all tradable goods including fossil fuels before and after biofuel incentive policies. The tax proceeds after covering the subsidies (if any) are redistributed to the consumers in Vietnam as a lump-sum transfer without any administration cost of tax and subsidy performance.

Compared to S1, results of S2 (with 10% tax on fossil fuel) and S3 (with both 10% tax on fossil fuel and 10% subsidy on biofuel) demonstrate the impacts of incentive policies in Vietnam (Table 5.6). Table 5.6 shows the change in production, consumption, trade, and welfare of Vietnam under the incentive policy. In comparison with the reference scenario (S1), the imposition of a tax on fossil fuels under S2 causes the outputs of agricultural goods, processed food, and jatropha increase and that of cassava almost stay the same because fossil fuel is not utilized in the production these sectors. In contrast, the outputs of industrial goods, fossil fuel, and services decrease due to an increase in the price of intermediate input of fossil fuel in the production. The redistribution of tax revenue to consumers results in increases in consumption by 0.4% of all goods except for biofuels. The international trade with MTP is mostly affected to meet the increase in consumption given the changes in production because of tax imposition on fossil fuel. Vietnam decreases its net exports of agricultural goods by 0.5%, of processed food by 0.3% and of cassava by 0.2% under S2. The net imports increase by 1.1% for industry, 0.2% for fossil fuel, and 3.2% for service under S2.

Compared to S1, the changes in production, consumption and international trade in Vietnam under S3 are similar to those under S2, except that the output of processed food decreases, that of services increases, and that of jatropha is almost unchanged. The additional introduction of a subsidy on biofuel enhances the production of services because biofuels are used as intermediate inputs for the service production. An increase in the production of jatropha compensates for the decline in the intermediate use of fossil fuel for seedcake production under S2; however, this decline is reconciled with other intermediate inputs under S3, resulting to the output of jatropha almost unchanged under S3. The production of processed food decreases as the consumption, exports, and intermediate use of the sector all decrease under S3.

Table 5.6 Impacts of biofuel incentive policies for Vietnam in percentage change compared to the levels for scenario S1.

Items	S1 2025 (unit)	S2 2025 (unit)	S3 2025 (unit)	% change compared to S1 (%)		% change of S3 compared to S2
				S2	S3	
Production						
- AGRI	91,661	91,666	91,670	0.01	0.01	0.00
- PFOO	149,521	149,527	149,519	0.00	-0.00	-0.01
- INDU	212,091	212,085	212,089	-0.00	-0.00	0.00
- FFUE	25,632	25,629	25,630	-0.01	-0.01	0.00
- SERV	102,747	102,745	102,750	-0.00	0.00	0.01
- CASA	9997	9997	9997	-0.00	0.00	0.00
- JATR	2309	2311	2309	0.11	-0.00	-0.11
- ETHA	4363	4363	4363	-	-	-
- BDIE	3401	3401	3401	-	-	-
- CERS	226	226	226	-	-	-
- CAKE	741	741	741	-	-	-
Consumption						
- AGRI	14,410	14,470	14,469	0.42	0.41	-0.01
- PFOO	41,528	41,703	41,700	0.42	0.41	-0.01
- INDU	75,727	76,045	76,041	0.42	0.41	-0.01
- FFUE	7301	7332	7332	0.42	0.42	-0.01
- SERV	55,348	55581	55,578	0.42	0.41	-0.01
- CASA	1029	1033	1033	0.41	0.39	-0.02
- ETHA	3922	3922	3922	-	-	-
- BDIE	3308	3308	3308	-	-	-
FOOD composite	28,431	28,550	28,548	0.42	0.41	-0.01
FUEL composite	6982	7010	7010	0.40	0.40	-0.01
Intermediate use						
- AGRI	65,383	65,384	65,384	0.00	0.00	-0.00
- PFOO	50,885	50,887	50,885	0.00	0.00	-0.00
- INDU	165,002	165,004	165,007	0.00	0.00	0.00
- FFUE	30,641	30,637	30,641	-0.01	-0.00	0.01
- SERV	54,918	54,919	54,921	0.00	0.01	0.00
- CASA	6614	6613	6614	-0.01	0.00	0.01
- JATR	2309	2311	2309	0.11	-0.00	-0.11
- ETHA	441	441	441	-	-	-
- BDIE	93	93	93	-	-	-
- CAKE	741	741	741	-	-	-
Trade						
- AGRI	11,868	11,812	11,817	-0.48	-0.44	0.04
- PFOO	57,107	56,937	56,933	-0.30	-0.30	-0.01
- INDU	-28,638[a]	-28,965	-28,959	1.14	1.12	-0.02
- FFUE	-12,311	-12,341	-12,343	0.24	0.26	0.02

- SERV	-7519	-7756	-7748	3.15	3.05	-0.10
- CASA	2354	2350	2350	-0.17	-0.17	0.00
- CERS	226	226	226	-	-	-
Utility	45,569	45,760	45,757	0.42	0.41	-0.01
Welfare[b]	16.7358	16.7356	16.7356	-0.00	-0.00	0.00

a The minus sign means net imports for trade results.

b Welfare is calculated as a weighted sum of logarithm of utility as specified in Equation 5.1.

In comparison to S2, a portion of tax proceeds is used to finance the biofuel subsidy before redistributing to consumers leads to a decrease in consumption of all goods and corresponding changes in the international trade in Vietnam under S3. The biofuel incentive policies reduce the exports of agricultural goods, processed food, and cassava and increase the imports of industrial goods, fossil fuel, and services, meaning that the trade of Vietnam with MTP seems to be slightly disadvantaged under both S2 and S3. Compared to S2, the import of services decreases under S3 because the production of services increases with subsidy on intermediate inputs of biofuels. That the clearing prices of biofuels increase results in an increase in the import of fossil fuel under S3 as biofuels are used as substitutes for fossil fuel.

The implementation of biofuel incentive policies contribute to an increase in utility of 0.42% under S2 and 0.41% under S3. The increase in welfare in Vietnam indicates the gain from an increase in consumption because of higher income owing to the transfer of tax proceeds. That the subsidy for biofuel use is deducted from tax proceeds before the redistribution to consumers slightly reduces the welfare under S3 compared to S2. Regarding MTP, the implementation of biofuel incentive polices in Vietnam seems not to have impacts on production and consumption of MTP but the changes in trade with Vietnam. Similar to the biofuel production policy, insignificant increase in utility of Vietnam and the unchanged of the utility in MTP have no impacts on the total welfare in the two regions.

5.4.3 Sensitivity analysis

The study has so far considered the tax rate on fossil fuel of 10% of its clearing price under S2 and S3 for Vietnam. The environmental protection tax on fossil fuel has been promulgated in the Law on environmental protection tax [5] ranging from 0.05 to 0.20 $ per liter for gasoline and from 0.03 to 0.10 $ per liter for diesel using the exchange rate of the State Bank of Vietnam at the time of the issuance of the Law in 2011 [5]. These ranges are specified the applicable absolute rates of 0.05 $ per liter for gasoline and 0.03 $ per liter for diesel from 2012 by the National Assembly [68]. Based on the CIF (cost, insurance, and freight) import price of fossil fuel and the applicable absolute rates, the tax rate has fluctuated in the range of 3.1 to 9.4% depending on the import price during the period from 2010 to 2014 [27]. Therefore, we perform the sensitivity analysis in the range of 0 to 30% for the tax rate on fossil fuel in Vietnam.

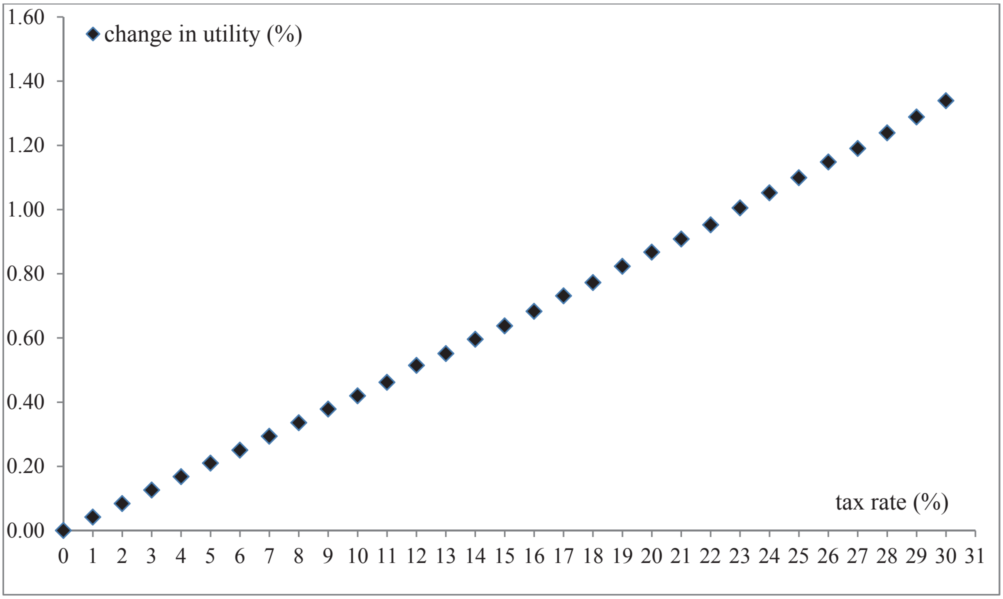

Figure 5.1 Sensitivity analysis for the tax rate of fossil fuel in Vietnam from 0 to 30%.

In this section, a sensitivity analysis of tax rates is conducted to show the robustness of the model and the implication of the optimal tax. Considering the intended policy of a 10% tax rate on fossil fuel, we choose a range from 0 to 30% for the sensitivity analysis. Figure 5.1 shows that Vietnam obtains more utility for the higher the tax rate. Higher tax brings more welfare for Vietnam because the redistribution of tax revenue increases the income and benefits all consumers.

5.4.4 Further remarks

From the economic view point, the analysis of impacts of biofuel incentive policies suggests that Vietnam can improve its welfare by a combined policy of subsidies on biofuels and a tax on fossil fuel in the context of adopting the biofuel mandate. Although such a system seems to be efficient from an economic point of view, it may be difficult to gain sufficient political support for the fossil fuel tax to be imposed and for biofuel subsidy to be efficiently performed. The policies are not necessary adopted only because of welfare maximization; the political outcomes are actually derived from the interactions among different interested groups and reflect considerations both in macro and micro levels. Macro-level considerations include fiscal balance which is affected by the tax proceeds and government expenditure for biofuel subsidies, trade balance which is affected by imports of fuels and international trade of other related commodities, and other aspects of energy security, economic growth, unemployment, and greenhouse gas emission [69]. Micro-level considerations are involved in the attitudes of various interested groups (e.g. food and fuel consumers, farmers, biofuel producers, oil companies and automobile companies, and environmentalists) and their impacts on the policy development [69].

Fuels are fundamental inputs for transportation and several productive activities. An imposition of tax on fossil fuel affects the production capacity of fuel intensive industries and other sectors. This may cause instability in the economy. There is also a trade-off between the environmental performance and economic growth regarding the imposition of tax on fossil fuel especially in developing countries. In response to a tax on fossil fuel, while the environmental effects come in the long-run, the effects on productive activities and economic growth are visible in the short run. The protection of biofuel industry as an infant industry may lead to market failure in long term. Biofuel subsidies may lower the fuel cost of driving and increase the fuel consumption and GHG emissions as a result [70]. The use of biofuels may be inefficient especially in the context of low prices of crude oil and have an adverse impact on fiscal balance [70,71]. For formulating the energy policy, it is essential to balance all aspects in both macro and micro levels and to incorporate the impacts of these aspects. A more governance oriented approach based on setting specific targets for biofuels may be more feasible and effective.

5.5 Conclusion

The paper has addressed subsidies on biofuels and a tax on fossil fuels in Vietnam, and their impacts on welfare, and the production and consumption of food and energy for Vietnam and its main trading partners. With the simulation of a tax on fossil fuel and subsidies on biofuels for Vietnam in an applied general equilibrium model, we show their impacts on welfare in the context of adopting the biofuel blending mandate in Vietnam.

The imposition of a tax on fossil fuels causes the outputs of industrial goods, fossil fuel, and services to decrease due to an increase in the price of intermediate input of fossil fuel in the production as compared to the reference scenario. The redistribution of tax revenue to consumers results in increases in consumption by 0.4% of all goods except for biofuels. The tax policy mostly affects the international trade with MTP with the decreases in its net exports by 0.4% for agricultural goods, by 0.3% for processed food, and by 0.2% for cassava, and with the increases in net imports by 1.1% for industrial goods, by 0.3% for fossil fuel, and by 3.1% for services. The additional introduction of a subsidy on biofuel enhances the production and decreases the import of services because biofuels are used as intermediate inputs for the service production. An increase in the clearing prices of biofuels as substitutes for fossil fuel increases the import of fossil fuel under the scenario with both tax and subsidy. That a portion of tax proceeds is used to finance the biofuel subsidy before redistributing to consumers leads to a decrease in consumption of all goods. Under the biofuel incentive policies the trade of Vietnam with MTP seems to be slightly disadvantaged, reducing the exports of agricultural goods, processed food, and cassava and increasing the imports of industrial goods, fossil fuel, and services.

Welfare in Vietnam increases by 0.42% under the implementation of a 10% tax on fossil fuel and by 0.41% under the implementation of both 10% tax on fossil fuel and 10% subsidy on biofuel incentive policies in Vietnam. This indicates the gain from higher consumption that is the result of the overall impacts of the policies. Regarding the impacts on the MTP, the implementation of biofuel incentive polices in Vietnam mostly affects the trade between MTP and Vietnam. The small increase in utility of Vietnam and an unchanged utility of MTP leads to almost no impact on the total welfare of the two regions.

The results suggest that Vietnam can improve its welfare by a combined policy of a tax on fossil fuel and subsidies on biofuels in the context of adopting the biofuel mandate from an economic point of view. However, it may be difficult to gain sufficient political support for the fossil fuel tax to be imposed and for biofuel subsidy to be efficiently performed. In that case, a more governance oriented approach based on setting specific targets for biofuels may be more feasible and effective.

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Appendix

Table 5.A1 Production, consumption and international trade in the base run, Scenarios 1 and 2 for MTP.

Items	Results in terms of unit			Average annual rate of change in 2010-2025 (%)	% change of S2 compared to S1
	Baseline	S1	S2		
Production					
AGRI	1,832,214	3,167,507	3,167,381	3.72	-0.00
PFOO	2,541,122	5,059,292	5,058,536	4.70	-0.01
INDU	20,989,178	51,259,809	51,269,008	6.13	0.02
FFUE	4,215,243	7,009,537	7,008,282	3.45	-0.02
SERV	31,136,906	48,829,850	48,825,830	3.05	-0.01
CASA	19,247	31,164	31,164	3.26	-
Consumption					
AGRI	635,562	1,107,437	1,107,295	3.77	-0.01
PFOO	1,420,047	2,858,592	2,857,378	4.77	-0.04
INDU	5,990,901	14,647,421	14,645,669	6.14	-0.01
FFUE	358,190	596,480	596,421	3.46	-0.01
SERV	18,102,583	28,401,431	28,398,482	3.05	-0.01
CASA	1768	2878	2746	3.30	-4.59
CERS	14	35	226	6.22	544.87
FOOD composite	1,101,402	2,120,067	2,119,276	4.46	-0.04
Trade					
AGRI	-2669	-11,635[a]	-11,868	10.31	2.00
PFOO	-7361	-58,234	-57,107	14.78	-1.93
INDU	11,512	21,530	28,638	4.26	33.01
FFUE	8227	12,712	12,311	2.94	-3.16
SERV	4932	8551	7519	3.74	-12.07
CASA	-2703	-3888	-2354	2.45	-39.45
CERS	-14	-35	-226	6.22	544.87
Utility	10,760,266	18,976,102	18,973,689	3.85	-0.01

[a] The minus sign means net imports for trade results.

Table 5.A2 Impacts of biofuel production policies for MTP in percentage change compared to the levels for Scenario 1.

Items	S2 (unit)	S3 (unit)	S4 (unit)	% change compared to S2		% change of S4 compared to S3
				S3	S4	
Production						
- AGRI	3,167,381	3,167,460	3,167,455	0.00	0.00	-0.00
- PFOO	5,058,536	5,058,680	5,058,685	0.00	0.00	0.00
- INDU	51,269,008	51,269,217	51,269,211	0.00	0.00	-0.00
- FFUE	7,008,282	7,008,349	7,008,355	0.00	0.00	0.00
- SERV	48,825,830	48,825,622	48,825,619	-0.00	-0.00	-0.00
- CASA	31,164	31,164	31,164	-	-	-
Consumption						
- AGRI	1,107,295	1,107,273	1,107,273	-0.00	-0.00	0.00
- PFOO	2,857,378	2,857,325	2,857,327	-0.00	-0.00	0.00
- INDU	14,645,669	14,645,440	14,645,442	-0.00	-0.00	0.00
- FFUE	596,421	596,412	596,412	-0.00	-0.00	0.00
- SERV	28,398,482	28,398,037	28,398,044	-0.00	-0.00	0.00
- CASA	2,746	2,746	2,746	-0.01	-0.02	-0.01
- CERS	226	226	226	-		
FOOD composite	2,119,276	2,119,235	2,119,237	-0.00	-0.00	0.00
Trade						
- AGRI	-11,868	-11,812	-11,817	-0.48	-0.44	0.04
- PFOO	-57,107	-56,937	-56,933	-0.30	-0.30	-0.01
- INDU	28,638	28,965	28,959	1.14	1.12	-0.02
- FFUE	12,311	12,341	12,343	0.24	0.26	0.02
- SERV	7,519	7,756	7,748	3.15	3.05	-0.10
- CASA	-2,354	-2,350	-2,350	-0.17	-0.17	0.00
- CERS	-226	-226	-226	-	-	-
Utility	18,973,689	18,973,386	18,973,391	-0.00	-0.00	0.00

Table 5.A3 Sensitivity analysis for the tax rate of fossil fuel.

Tax rate	Utility		Welfare	‰ change compared to the case without tax rate		
				Utility		Welfare
	VNM	MTP		VNM	MTP	
0	45,569	18,973,689	16.7358			
1	45,588	18,973,658	16.7358	0.419	-0.002	-0.001
2	45,607	18,973,627	16.7358	0.839	-0.003	-0.002
3	45,626	18,973,599	16.7357	1.259	-0.005	-0.003
4	45,645	18,973,568	16.7357	1.679	-0.006	-0.005
5	45,664	18,973,538	16.7357	2.098	-0.008	-0.006
6	45,683	18,973,509	16.7357	2.505	-0.009	-0.007
7	45,703	18,973,478	16.7357	2.938	-0.011	-0.008
8	45,722	18,973,447	16.7356	3.357	-0.013	-0.009
9	45,741	18,973,417	16.7356	3.782	-0.014	-0.010
10	45,760	18,973,386	16.7356	4.196	-0.016	-0.012
11	45,779	18,973,356	16.7356	4.616	-0.018	-0.013
12	45,803	18,973,319	16.7356	5.147	-0.020	-0.014
13	45,820	18,973,292	16.7355	5.513	-0.021	-0.015
14	45,840	18,973,260	16.7355	5.957	-0.023	-0.016
15	45,859	18,973,231	16.7355	6.377	-0.024	-0.018
16	45,880	18,973,198	16.7355	6.828	-0.026	-0.019
17	45,902	18,973,163	16.7355	7.312	-0.028	-0.020
18	45,921	18,973,134	16.7354	7.726	-0.029	-0.021
19	45,944	18,973,096	16.7354	8.233	-0.031	-0.023
20	45,964	18,973,065	16.7354	8.671	-0.033	-0.024
21	45,983	18,973,036	16.7354	9.083	-0.034	-0.025
22	46,003	18,973,004	16.7354	9.524	-0.036	-0.026
23	46,027	18,972,965	16.7353	10.049	-0.038	-0.027
24	46,048	18,972,932	16.7353	10.520	-0.040	-0.029
25	46,070	18,972,898	16.7353	10.992	-0.042	-0.030
26	46,092	18,972,863	16.7353	11.480	-0.044	-0.031
27	46,111	18,972,833	16.7353	11.905	-0.045	-0.032
28	46,133	18,972,798	16.7352	12.391	-0.047	-0.034
29	46,156	18,972,762	16.7352	12.883	-0.049	-0.035
30	46,179	18,972,726	16.7352	13.391	-0.051	-0.036

Table 5.A4 Changes in relative prices of goods and production input factors.

Goods and input factors	Baseline 2010	Baseline 2025	S1	S2	S3	Change compared to S1 (‰)		Change of S3 compared to S2 (‰)
						S2	S3	
AGRI	1.000101	0.527632	0.525601	0.525606	0.525613	0.01	0.02	0.01
PFOO	1.000060	0.456694	0.455069	0.455074	0.455079	0.01	0.02	0.01
INDU	1.000037	0.376007	0.374555	0.374557	0.374562	0.01	0.02	0.01
FFUE	1.000037	0.552055	0.549911	0.549915	0.549922	0.01	0.02	0.01
SERV	1.000036	0.585955	0.583683	0.583688	0.583694	0.01	0.02	0.01
CASA	1.000121	0.564851	0.589622	0.589737	0.589704	0.20	0.14	-0.06
JATR	1.000037	0.634652	0.638856	0.638873	0.638874	0.03	0.03	0.00
ETHA	0.994101	0.408279	0.050188	0.050365	0.050384	3.54	3.91	0.37
BDIE	1.000041	0.507780	0.001943	0.001950	0.001951	3.54	3.91	0.37
CERS	1.124963	0.395090	0.061023	0.061023	0.061023	-0.01	0.00	0.01
CAKE	1.000037	0.377077	0.374555	0.374554	0.374562	-0.00	0.02	0.02
KL	1.000242	0.525836	0.521020	0.520998	0.521054	-0.04	0.06	0.11
LD	1.000505	1.472126	1.672896	1.673872	1.673521	0.58	0.37	-0.21
LB	1.000000	1.000000	1.000000	1.000000	1.000000	-	-	-

Table 5.A5 Changes in intermediate use.

Intermediate input	Production goods	S1	S2	S3	Change compared to S1 (%)		Change of S3 compared to S2 (%)
					S2	S3	
LD	AGRI	4,492.90	4,492.90	4,492.90	-	-	-
LD	CASA	1,219.19	1,219.13	1,219.19	-0.00	0.00	0.00
LD	JATR	52.81	52.87	52.81	0.11	-0.00	-0.11
LB	AGRI	11,806.39	11,807.08	11,807.99	0.01	0.01	0.01
LB	PFOO	8,594.08	8,594.11	8,594.37	0.00	0.00	0.00
LB	INDU	15,994.86	15,994.86	15,994.86	-	-	-
LB	FFUE	766.83	766.53	766.80	-0.04	-0.00	0.04
LB	SERV	22,927.19	22,926.73	22,928.30	-0.00	0.00	0.01
LB	CASA	2,468.86	2,468.74	2,468.86	-0.00	0.00	0.00
LB	JATR	1,115.22	1,116.41	1,115.20	0.11	-0.00	-0.11
LB	ETHA	127.39	127.37	127.38	-0.01	-0.01	0.01
LB	BDIE	179.46	179.54	179.45	0.05	-0.00	-0.05
LB	CERS	6.65	5.50	3.72	-17.23	-44.11	-32.48
LB	CAKE	38.06	38.12	38.06	0.17	0.00	-0.16
KL	AGRI	5,604.99	5,605.69	5,605.71	0.01	0.01	0.00
KL	PFOO	10,371.79	10,371.99	10,371.29	0.00	-0.00	-0.01
KL	INDU	16,822.71	16,821.76	16,820.47	-0.01	-0.01	-0.01
KL	FFUE	5,089.93	5,087.82	5,088.58	-0.04	-0.03	0.01
KL	SERV	25,597.83	25,595.95	25,597.12	-0.01	-0.00	0.00
KL	CASA	345.12	345.10	345.12	-0.00	0.00	0.00
KL	JATR	80.67	80.75	80.67	0.11	-0.00	-0.11
KL	ETHA	448.98	449.45	449.59	0.11	0.14	0.03
KL	BDIE	283.71	283.84	283.77	0.05	0.02	-0.03
KL	CERS	20.36	23.57	23.80	15.76	16.86	0.95
KL	CAKE	60.18	60.34	60.17	0.26	-0.01	-0.27

AGRI	AGRI	16,608.47	16,609.37	16,610.14	0.01	0.01	0.00
AGRI	PFOO	46,818.74	46,821.09	46,818.21	0.01	-0.00	-0.01
AGRI	INDU	1,956.14	1,954.02	1,956.05	-0.11	-0.00	0.10
PFOO	AGRI	11,497.23	11,497.78	11,498.32	0.00	0.01	0.00
PFOO	PFOO	34,460.40	34,462.02	34,459.86	0.00	-0.00	-0.01
PFOO	SERV	4,927.22	4,927.02	4,927.30	-0.00	0.00	0.01
INDU	AGRI	12,134.35	12,135.16	12,135.65	0.01	0.01	0.00
INDU	PFOO	14,326.36	14,326.36	14,326.36	-	-	-
INDU	INDU	113,883.36	113,882.19	113,885.28	-0.00	0.00	0.00
INDU	FFUE	2,954.50	2,954.50	2,954.50	-	-	-
INDU	SERV	17,551.64	17,551.64	17,551.64	-	-	-
INDU	CASA	2,196.80	2,196.70	2,196.80	-0.00	0.00	0.00
INDU	JATR	427.78	428.24	427.77	0.11	-0.00	-0.11
INDU	ETHA	1,055.92	1,056.32	1,056.53	0.04	0.06	0.02
INDU	BDIE	343.34	341.57	343.34	-0.52	-0.00	0.52
INDU	CERS	55.14	55.54	56.45	0.74	2.38	1.62
INDU	CAKE	72.83	76.00	72.83	4.36	0.01	-4.17
FFUE	AGRI	4,196.63	4,196.87	4,197.04	0.01	0.01	0.00
FFUE	INDU	4,070.38	4,069.77	4,070.11	-0.01	-0.01	0.01
FFUE	FFUE	14,746.43	14,746.37	14,745.35	-0.00	-0.01	-0.01
FFUE	SERV	7,155.68	7,155.59	7,156.18	-0.00	0.01	0.01
FFUE	CASA	332.47	332.45	332.47	-0.00	0.00	0.00
FFUE	JATR	59.36	59.42	59.36	0.11	-0.00	-0.11
FFUE	ETHA	58.97	59.09	59.02	0.20	0.08	-0.13
FFUE	BDIE	15.05	15.08	15.05	0.18	-0.01	-0.18
FFUE	CERS	3.11	1.99	3.10	-35.94	-0.17	55.85
FFUE	BDIE	3.17	0.82	3.17	-74.00	0.03	284.78
SERV	AGRI	10,306.73	10,307.34	10,307.78	0.01	0.01	0.00
SERV	PFOO	11,696.71	11,697.33	11,696.65	0.01	-0.00	-0.01
SERV	INDU	13,098.46	13,099.04	13,099.21	0.00	0.01	0.00
SERV	FFUE	2,291.12	2,290.96	2,291.15	-0.01	0.00	0.01
SERV	SERV	17,524.79	17,524.64	17,526.02	-0.00	0.01	0.01
CASA	PFOO	2,428.00	2,428.75	2,427.64	0.03	-0.01	-0.05
CASA	INDU	2,005.58	2,004.94	2,004.39	-0.03	-0.06	-0.03
CASA	CASA	340.18	340.16	340.18	-0.00	0.00	0.00
CASA	ETHA	1,747.08	1,746.32	1,746.12	-0.04	-0.06	-0.01
CASA	CERS	92.84	92.96	95.44	0.13	2.79	2.66
JATR	JATR	56.98	57.04	56.98	0.11	-0.00	-0.11
JATR	BDIE	1,844.94	1,845.72	1,844.89	0.04	-0.00	-0.04
JATR	CAKE	406.69	408.32	406.69	0.40	-0.00	-0.40
ETHA	SERV	441.25	441.25	441.25	-	-	-
BDIE	SERV	93.02	93.02	93.02	-	-	-
CAKE	AGRI	741.39	741.39	741.39	-	-	-


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Chapter 6

Synthesis and conclusions

The thesis aims to study the energy efficiencies, GHG emission savings and the cost-effectiveness of biofuels as substitutes for fossil fuels and the socioeconomic impacts of biofuel policies in Vietnam. In Chapters 2 and 3, the analysis focuses on the biofuel industry with the consideration of energy and GHG balances and economic viability of the biofuel production and utilization. In Chapters 4 and 5, an AGE model is developed to study the economy-wide impacts of biofuel production targets and incentive policies of a tax on fossil fuels and subsidy on biofuel on food production, welfare, and emission. In this chapter, I first discuss the research questions and findings in Section 6.1. Then, I synthesize and discuss the significance of the thesis regarding the methodology and policy in Sections 6.2 and 6.3. Finally, the limitations and recommendations are provided for further research in Section 6.4.

6.1 Key findings

6.1.1 Energy efficiency of biofuel production and utilization

Chapter 2 analyses the energy balances of biofuel production and utilization as substitutes for fossil fuels. Cassava-based ethanol substitutes for gasoline in form of E5 and E10, and jatropha-based biodiesel substitutes for diesel in form of B5 and B10. The analysis of energy balance follows the LCA and comparative analysis suggested by Gnansounou et al. [1]. Accordingly, the energy balance is the difference between the energy for production and utilization of a biofuel and that of its alternative fossil fuel for the same functional unit of traveling 1 km using either biofuel or fossil fuel as mechanical energy for road vehicles. For a general assessment, we conducted a sensitivity analysis for three fuel consumption levels of ethanol blends: 5% higher, the same, and 5% lower levels compared to that of gasoline, and two fuel consumption levels of biodiesel blends: the same, and 5% higher levels compared to that of diesel.

The results show that the energy inputs are 0.94 MJ MJ^{-1} for ethanol and 0.45 MJ MJ^{-1} for biodiesel, showing the feasibility compared to fossil fuels with reference to energy input efficiency. For ethanol, the energy balances are negative except for the scenarios with 5% higher fuel consumption level of ethanol blend compared to that of gasoline, meaning that the ethanol substitution for gasoline would save energy input with the fuel consumption levels of ethanol blends being the same or 5% lower than that of gasoline. Seeking for breakeven points, we find a zero energy balance if the fuel consumption levels of E5 and E10 are respectively 2.4% and 4.5% higher than that of gasoline per kilometer. This means that the use of E5 and E10 as a substitute for gasoline achieves energy savings, provided that their fuel consumption in terms of liter per kilometer of transportation is not exceeding that of gasoline by more than 2.4% and 4.5% respectively. For biodiesel, the energy balances are negative except for the scenario with 5% higher fuel consumption level of B5 compared to that of diesel. This means that the biodiesel substitution for diesel would save energy input with the fuel consumption level of B5 being the same and with that of B10 being the same or 5% higher than that of diesel. The breakeven points with a zero energy balance are found at 3.3% and 6.9% higher fuel consumption levels of B5 and B10 compared to diesel respectively. This means that the use of B5 and B10 as substitutes for diesel achieves energy savings, provided that their fuel consumption in terms of liter per kilometer of transportation is not exceeding that of diesel by more than 3.3% and 6.9% respectively.

With the target volumes of 600 kt of ethanol in 2025, the savings would reach from 13 to 42 PJ of primary energy input depending on the efficiency of blends, equivalent to 2.6 to 8.6% of fuel consumption in the transport sector in 2009 for ethanol production and use. The biodiesel target of 250 kt would achieve from 1.8 to 7.1 PJ, equivalent to 0.4 to 1.4% of fuel consumption in the transport sector in 2009. Further energy savings can be obtained through the more sustainable cultivation, an improvement of feedstock yield, improvement of energy input efficiency by using a more energy-efficient substitute for coal in ethanol processing and the mechanical husking in biodiesel processing, and further adaptation of vehicle engines to reduce fuel consumption levels of biofuel blends compared to fossil fuels.

6.1.2 GHG emission savings of biofuel production and utilization

In Chapter 2, the GHG balances of biofuel production and utilization are analysed with the same methodology approach of the LCA and a comparative analysis. The GHG emission balance is the difference between the GHG emissions from production and utilization of a biofuel and that of its alternative fossil fuel for the same functional unit. Similar to the energy analysis, we conducted a sensitivity analysis with the same scenarios in the analysis of GHG balance. The analysis shows that biofuel production results in a GHG emission of 35 g CO_2e MJ^{-1} for ethanol and a GHG emission saving of 65.7 g CO_2e MJ^{-1} for biodiesel.

For ethanol, all scenarios achieve an emission saving except for the scenario with 5% higher fuel consumption level of E5 compared to that of gasoline. This means that the ethanol substitution for gasoline would reduce emissions with the fuel consumption levels of E5 being the same or 5% lower than that of gasoline and with all scenarios for E10. Seeking for the breakeven points, we find a zero balance if the fuel consumption of E5 and E10 is respectively 3.8% and 7.8% higher than that of gasoline. This means that the use of E5 and E10 as substitutes for gasoline would achieve an emission saving, provided that their fuel consumption is not exceeding that of gasoline by more than 3.8% and 7.8% respectively. For biodiesel, since the production and utilization of biodiesel produce a GHG emission saving, the biodiesel substitution for diesel achieves a GHG emission saving in all scenarios.

As for the ethanol target of 600 kt in 2025, the emission saving would reach from 512 to 3643 thousand tonnes of CO_2e depending on the efficiency of blends, equivalent to 1.4 to 10.1% of the emissions from fuel consumption in the transport sector in 2009. The biodiesel target of 250 kt would achieve from 617 to 1391 thousand tonnes of CO_2e, equivalent to 1.7 to 3.9% of the emissions from fuel consumption in the transport sector in 2009. The opportunities for further emission savings lie in the improvement of agricultural practices, particularly a reduction of burning residue, a lower nitrogen application, and more sustainable cultivation to minimize the effects of LUC and soil management. As for the consumption of biodiesel, while emission savings is achieved, other aspects of positive contribution of energy efficiency and cost effectiveness should be considered.

6.1.3 Cost-effectiveness of biofuels in comparison with fossil fuels

In Chapter 3, the cost-effectiveness analysis is utilized to compare the social cost of a biofuel and its alternative fossil fuel: ethanol and gasoline, and biodiesel and diesel for a functional unit of 1 km of vehicle transportation. The social cost of fuel for a functional unit equals the social cost of 1 GJ of fuel (\$ GJ^{-1}) multiplied by the amount of GJ needed for a functional unit (GJ km^{-1}). The social costs of fuels (i.e. the sum of private and external costs) are calculated as the break-even prices, which are identified by setting the net present values of fuel projects equal to zero at given discount rates of 4%, 8%, or 10%. Accordingly, these break-even prices are the average costs for every GJ of fuels produced and utilised.

In terms of per GJ, the social costs of biofuels are higher than those of their alternative fossil fuels due to higher private cost components. The social cost of ethanol is 20.2 to 22.7 \$ GJ^{-1}, which is 1.6% to 13.9% higher than that of gasoline. With the consideration of fuel efficiency in transportation, different results are obtained in terms of a functional unit. The ethanol substitution for gasoline is cost–effective except for the scenarios with 5% higher fuel consumption level of ethanol blend compared to that of gasoline. The ethanol substitution for gasoline would save 0.01 to 0.03 \$ km^{-1}, equivalent to 25.3% to 67.6% of the social cost per functional unit compared to gasoline at the three discount rates. The lower fuel consumption of E5 and E10 compared to gasoline, the higher achievement of this saving. The social cost of biodiesel is 27.0 to 29.1 \$ GJ^{-1}, which is 41.3% to 52.0% higher than that of diesel at the three discount rates. The biodiesel substitution for diesel is not cost–effective for all scenarios with an increase in social cost from 0.01 to 1.04 \$ km^{-1}, equivalent to 28.6% to 2804.4% of the social cost per functional unit compared to diesel if the fuel consumption of B5 and B10 remains the same or 5% higher compared to that of diesel.

Examining the cost-effectiveness of biofuels under different fuel consumption levels of blends, we identify the required fuel consumption levels of blends to make biofuels cost-effective compared to fossil fuels. For the ethanol to be cost-effective, the fuel consumption of E5 and E10, in terms of L km^{-1} compared to that of gasoline, is not increased by more than 1.7% for E5 and 3.5% for E10 at the discount rate of 4%. For the cost-effectiveness of biodiesel, the fuel consumption of B5 and B10 compared to that of diesel should be decreased by more than 1.4% for B5 and 2.8% for B10 at the discount rate of 4%. The higher discount rate requires the lower fuel consumption of blends in terms of L km^{-1} to achieve the cost-effectiveness in comparison with their alternative fossil fuel. We can conclude that the cost-effectiveness of using biofuels in comparison to fossil fuels depends on the efficiency of biofuel production and blended fuel combustion. For a sustainable biofuel market in Vietnam, further investments will be needed for both, improving the efficiency of biofuel production and blended fuel combustion.

6.1.4 Socioeconomic impacts of biofuel production policy

An applied general equilibrium model is utilized in Chapter 4 to investigate the impacts of biofuel production policy in Vietnam on the welfare, production, consumption, and international trade for Vietnam and its main trading partners. We have also studied the direct emission savings for Vietnam under the implementation of biofuel production policy. The cassava sector shifts its output from export to the domestic intermediate use for ethanol production. With an insignificant decline in food production and consumption, the competition of land use for food and feedstock production seems to be relatively small under the biofuel production policy in Vietnam, but evidently the production output of cassava for export is substantially reduced. The production of the industrial sector in Vietnam decreases while consumption of industrial products remains unchanged and imports of these products increase. The biofuel production policy results in an enhancement of energy security in Vietnam by increasing domestic production of fossil fuel by 0.9% and decreasing its import by 3.2% and its domestic use by 0.5%.

As an integrated effect on the economy, the welfare in Vietnam increases by 0.4%, under the implementation of the biofuel production policy in Vietnam. Vietnam better allocates its resources and shifts its international trade towards utilizing its comparative advantages. This results in a decrease in the shadow price of capital and an increase in the shadow price of land. These effects increase the income, which is reflected in an increase in consumption and utility in Vietnam. For MTP, the implementation of the biofuel production policy in Vietnam induces changes in international trade between MTP and Vietnam, particularly reducing the export of fossil fuel and services and import of cassava, and increasing the export of industrial goods. At the same time, the import of certified emission reductions increases. Overall, there is a negligible change in the welfare of MTP as an integrated effect. The slight increase in the utility of Vietnam and the negligible change of the utility in MTP has almost no impact on the total welfare of the two regions because of the small share of Vietnam. The biofuel production policy leads to a direct increase in emission savings of 19% as compared to the reference scenario.

6.1.5 Impacts of biofuel incentive policy on welfare in Vietnam

Chapter 5 extended the applied general equilibrium in Chapter 4 to address the implications of biofuel incentive policies in Vietnam on welfare, the production, and consumption for Vietnam and its trading partners under adoption of the biofuel mandate in Vietnam. The imposition of a tax on fossil fuels causes the outputs of industrial goods, fossil fuel, and services to decrease due to an increase in the price of intermediate input of fossil fuel in the production as compared to the reference scenario. The redistribution of tax revenue to consumers results in increases in consumption by 0.4% of all goods except for biofuels. The tax policy mostly affects the international trade with MTP with the decreases in its net exports by 0.4% for agricultural goods, by 0.3% for processed food, and by 0.2% for cassava, and with the increases in net imports by 1.1% for industrial goods, by 0.3% for fossil fuel, and by 3.1% for services.

An additional introduction of a subsidy on biofuels enhances the production and decreases the import of services because biofuels are used as intermediate inputs for the service production. An increase in the clearing prices of biofuels as substitutes for fossil fuel increases the import of fossil fuel under the scenario with both tax and subsidy. That a portion of tax proceeds is used to finance the biofuel subsidy before redistributing to consumers leads to a decrease in consumption of all goods. Under the biofuel incentive policies, the trade of Vietnam with MTP seems to be slightly disadvantaged, reducing the exports of agricultural goods, processed food, and cassava and increasing the imports of industrial goods, fossil fuel, and services.

The welfare increases by 0.42% under the implementation of a 10% tax on fossil fuel and by 0.41% under the implementation of both 10% tax on fossil fuel and 10% subsidy on biofuel incentive policies in Vietnam. That the subsidy for biofuel use is deducted from tax proceeds before the redistribution to consumers reduces the welfare by 0.01%, as the biofuel output is so small compared to the fossil fuel use in the economy. Regarding MTP, the implementation of biofuel incentive polices in Vietnam mostly affects the trade between MTP and Vietnam and have no impacts on the total welfare in the two regions.

6.2 Methodology reflections

In this thesis, the life-cycle assessment is used to access the energy and GHG balances, which are identified as the differences between energy for and the GHG emissions from the production and utilization of a biofuel and those of its alternative fossil fuel for the same functional unit of 1 km of road transportation. The key methodological issues of the application of LCA to biofuels are system boundaries, functional unit, and allocation [1-4]. For the system boundaries, the two common systems of biofuels are a well to tank and well to wheel assessments. While the former is appropriate for the assessment of the same fuels without the consideration of the fuel performance, the latter is proper for the comparison of different fuels and blends by covering the combustion of fuels in the vehicle engine. The analysis in Chapters 2 and 3 utilized the well to wheel LCA for the comparison of biofuels and fossil fuels. Relating the system boundaries, the effects of land use change in feedstock plantation are also considered in this study. Various functional units are used in LCA studies for comparing biofuels and fossil fuels; however, it is important to choose the functional unit reflecting the same services and capturing the mechanical efficiency of different types of fuels [1,2]. This study used the functional unit of traveling 1 km using biofuels or fossil fuels as mechanical energy for road vehicles, which can embody the fuel efficiency and the relevant services of motor fuels for travelling. Allocation refers to the distribution of environmental burdens between outputs in the system. The ISO standards recommended that the allocation should be avoided if possible through division of the whole process or expanding the system. While the former seems to be impossible, the latter so-called substitution method is based on the assumption that the function-equivalent production system has the same environmental impacts [1,5]. If the avoidance of allocation is impossible, it is suggested to apply the allocations based on physical relationship between environmental burdens and the outputs or the economic value [1]. Literature on allocation methods indicated the required data accuracy and details, the reality of substitution alternatives in the substitution allocation method, and the objection of energy allocation by considering if the considered co-products are really meant for the purpose of energy [1,5]. In this study, the biofuel co-products are considered including cassava stillage, dried distillers grains, biogas, and CERs for ethanol, and seedcake for biodiesel. The substitution allocation method has not been applied for the analysis of energy and GHG balances, and the private benefits of co-products are considered in the analysis of cost-effectiveness.

In Chapter 3, the cost-effectiveness analysis is used to compare alternative fuels (ethanol with gasoline, and biodiesel with diesel) in terms of their social cost of production and utilization for a functional unit of 1 km of road transportation. Cost perspective is one of key methodological issues in cost-effectiveness analysis [6]. Literature indicates two main cost perspectives of social and private costs. Robert et al. [6] reported around 60% of studies on cost-effectiveness analysis adopting the social cost perspective, 10% focusing on the private perspective, and the remaining 30% employing both perspectives. The cost-effectiveness analysis in this thesis employed the social cost perspective with the external costs and benefits of GHG emissions and non-GHG emissions from fuel production, distribution, and combustion, and security of supply of fossil fuels. Although the cost-effectiveness analysis is useful for the economic comparison of alternative policy measures with the integration of environmental and economic objectives, it is worth noting that the cost effectiveness analysis seeks the lowest-cost option among different measures for a given target. It measures technical efficiency, not allocative efficiency; that is, it does not necessarily signify an optimal resource allocation because the predetermined target may not be efficient [7,8]. Therefore the cost-effectiveness should not be the sole criterion in designing policies but be supplemented with further considerations of equity, impacts on welfare, other macroeconomic issues as well as the administrative feasibility [6-8].

In this thesis, an applied general equilibrium model is used to investigate the economy-wide impacts of biofuel production and incentive policies in Vietnam on welfare in Vietnam and its main trading partners. Following the step-wise approach, we conducted the model simulations with the biofuel production targets in Chapter 4 and biofuel incentive policies of a tax on fossil fuels and biofuel subsidies in Chapter 5 to investigate the impacts on welfare and other socioeconomicimpacts. This step-wise approach is useful to obtain the insights of different aspects of biofuel issues in Vietnam, particularly the impacts of biofuel production targets of ethanol, biodiesel, and both biofuels in Chapter 4 and those of biofuel incentive policies in the context of adopting the biofuel mandate in Chapter 5. We focused on the difference between the reference scenario and simulated scenarios to identify these impacts.

The general equilibrium modeling can provide a comprehensive analysis of the whole economy and the economy-wide impacts of biofuel policies by capturing the linkages between all economic agents in the economy and the international trade effects; however, it is too aggregated to address the microeconomic issues on biofuels. The analysis in Chapters 2 and 3 with a focus on the biofuel industry performance in three aspects of energy efficiency, GHG emissions, and economic viability is to fill out this shortcoming of the general equilibrium modeling and provide the whole picture of biofuel issues in Vietnam. Another shortcoming of modeling is that the applied general equilibrium models are a simplification of reality. The models are calibrated using the best data available and chosen parameter values to produce the numerical results from the simulations. Therefore, the results should be interpreted with care, and the sensitivity analyses should be supplemented to verify the robustness of results against parameter values. In Chapters 4 and 5, a sensitivity analysis of the elasticity of substitution between biofuel and fossil fuel is conducted to evaluate the effects of the elasticity of substitution on the model results, and a sensitivity analysis of the tax rate is conducted to address the implication of the optimal tax. As significance of modeling biofuels, we have accounted for the by-products of biofuels and modelled land use in value terms in the applied general equilibrium model in this thesis.

As mentioned in Chapter 1, modeling biofuels has three main approaches. The implicit modeling approach does not require data on biofuel sectors and commodities but the adjustment of data on biofuel crops. The approach of modeling biofuel as a latent technology used data on inputs and cost structures of biofuels. The approach of disaggregating biofuel sectors from the Social Accounting Matrix requires the available data on biofuel sectors mostly based on the GTAP-BIO database [11]. In this thesis, I adopted the modeling biofuel sectors for Vietnam as latent technologies with the assumption that biofuels are consumed for local transportation in Vietnam without any international trade and that biofuels sectors in the main trading partners of Vietnam are not considered. This is an acceptable assumption in the context that the biofuel production in Vietnam has been focused on domestic consumption under the government's policies.

6.3 Policy relevance

The biofuel mandate in Vietnam has come into effective since 2015; it is crucial to understand energy efficiency, GHG emission performance, economic viability of biofuels, and their impacts on welfare and the whole economy in Vietnam. The insights of findings from this research on these aspects have the following policy implications.

Opportunities for further achievement: technology, infrastructure, and flexible-fuel vehicles

The results show with the targets of 600 thousand tonnes of ethanol and 250 thousand tonnes of biodiesel in 2025, the emission saving would reach from 1,129 to 5,034 thousand tonnes of CO_2e, and the energy saving would achieve from 14.6 to 49.2 PJ. Cost-effectiveness of ethanol is feasible with the break-even points of fuel consumption of blends compared to that of gasoline not more than 1.7% for E5 and 3.5% for E10 at 4% discount rate. Cost-effectiveness of biodiesel seems to be unfeasible at the current fuel consumption levels of biodiesel blends with break-even points of fuel consumption of B5 and B10 lower than 1.4% and 2.8% compared to that of diesel respectively. The achievement of biofuel production and use is contingent upon the feedstock yields, sustainability in agriculture, conversion technology, the fuel efficiency of blends, and cost of infrastructure of the supply chain. This implies some measures for further achievement. Firstly, the investment in research and development in biofuels will help to increase the feedstock yields and to enhance the efficiencies of conversion and oil extraction. Due to problems associated with knowledge spillovers and uncertainty, such an investment often calls for government's support. Secondly, the government should give the preferences for the use flexible-fuel vehicles to improve the fuel efficiency of blends by some incentives to both manufacturers and users, e.g. investment incentives, reducing registration fees, providing road tax credits. Thirdly, blend stations need to be set up adequately to minimize the distance from fossil fuel refineries or stations and biofuel processing plants. This helps the suppliers to reduce the transportation cost and the consumers to be convenient for their daily usage.

Challenges for sustainable biofuels

To meet the targets of 600 thousand tonnes of ethanol and 250 thousand tonnes of biodiesel in 2025, a total land area of 339,945 ha is required for feedstock production, which corresponds to 7.4% of Vietnam's arable land in 2009. Of this, it is thought that 14% of the necessary land would come forestland, 66% from grassland and 20% from other cropland. The land use change from the biofuel production system could bring about direct effects associated with losses of biodiversity and ecosystem functions and decreased carbon stocks and indirect effects, which are involved to not one specific actor, but a wide range of actors in a spatial and temporal manner. For this reason, the government's policies should link the actions of biofuel producers to relevant stakeholders in a global commodity market with biofuel sustainability frameworks. The policies, e.g. trading mechanisms, biofuel certification systems, sustainability standards, payments for environmental services need to be established to ensure a sustainable biofuel development.

Public acceptance and political feasibility

The development of biofuels requires a shift from food crop to non-edible feedstock. This shift needs to be performed technically and institutionally not only to safeguard biodiversity and soil fertility but also to protect the property and land use rights of households and to maintain labor standards, living conditions, and safety of biofuel use. In addition, the results suggest that Vietnam improves its welfare by a combined policy of a tax on fossil fuel and subsidies on biofuels in the context of adopting the biofuel mandate from an economic point of view. However, it may be difficult to gain sufficient political supports for these incentives. Policies are outcomes of the weight given to macro-economic factors, e.g. balance of trade, government budget deficit, economic growth, energy security and climate change, as well as the interests of specific groups, e.g. consumers, farmers, biofuel producers, and oil companies. A more governance-oriented approach for biofuel policies, which attempts to cover social impacts, environmental quality, and economic and political feasibility, should be based on setting specific targets to make the policies more feasible and effective. Public acceptance for biofuels will be the last challenge to be addressed once the infrastructures, flex-fuel vehicles and biofuel supply system are all in the market. Many citizens may have low environmental awareness and are worried about the safety and the cost-effectiveness of biofuel use. While the mandatory biofuel blends has forced the public to make the switch to biofuels, it is important to ensure that they are provided with sufficient information pertaining to the changes.

6.4 Limitation and recommendations for future research

In this thesis, the analysis of energy and GHG balances and cost effectiveness of biofuels follows the LCA approach. However, the results of each LCA study largely depend on the quality and reliability of data inputs and specific scopes of biofuel chains in technical, geographical, and agronomical aspects. This study focuses on cassava-based ethanol and jatropha-based biodiesel produced and utilized in Vietnam with the specific parameters and conditions for the period from 2010 to 2025. These parameters include the average projected yields of cassava and jatropha, the application levels of fertilizer and pesticide in feedstock production, the management of agricultural residue, the truck capacity, transportation distances in the biofuel supply chain, the conversion ratio of dried chips to ethanol, the oil content of jatropha seed, the extraction and transesterification efficiencies, and processing technologies with the anaerobic digester installation and biogas utilization for ethanol conversion, and mechanical extraction for biodiesel processing. We applied a fixed price of the global external cost of GHG emissions, the adjustment results from the estimation for EU countries for the external cost of non-GHG emissions, and the lowest estimation of external cost of energy security of supply from the literature for the calculation of cost-effectiveness. Since these parameter inputs are specific for the case of Vietnam, the research results may capture some uncertainty and discrepancies with other studies. A sensitivity analyses for these parameters will provide a comprehensive understanding of the whole picture on biofuel performance.

The environmental impact of biofuels in this study focuses on GHG emissions from feedstock production with the assumption that biofuel feedstock comes wholly from newly domestic cultivation as a result of LUC. For the modeling analysis, I focus on the direct impact of the production and utilization of biofuels as substitutes for fossil fuels in transportation. I do not explicitly model the emissions in other sectors, and in this respect, the analysis is restricted to a partial analysis. This analysis can be extended in further research by integrating changes in fuel use and emissions of all sectors in the economy.

In the analysis of the general equilibrium models presented in Chapters 4 and 5, I assumed that all biofuels produced in Vietnam are for domestic use, and I did not explicitly model biofuels in MTP countries due to insufficient data on production, consumption, and trade flows of biofuels in these countries. These assumptions were made because our study focuses on the direct impact of the production and utilization of biofuels as substitutes for fossil fuels in transportation in Vietnam and the biofuels are not meant to be used for export purposes. For the introduction of tax and subsidy, the international trade remains in a competitive setting with free trade between Vietnam and its main trading partners for all tradable goods including fossil fuels before and after biofuel incentive policies. The tax proceed after covering the subsidies (if any) is redistributed to the consumers in Vietnam as a lump-sum transfer without any administration cost of tax and subsidy performance. If the data was sufficient, the study could be further developed by releasing these assumptions and considering the welfare impacts on different household groups stratified by income levels.

6.5 Closing remarks

Biofuel production has continued to develop and driven by the government support around the world. A comprehensive analysis of biofuel production and the policy implementation is crucial for the biofuel sustainability development. This thesis has shown for the energy efficiency, GHG emission savings, and the economic viability of biofuels as energy for transportation and the impacts of biofuel policies on welfare, the economy, and emission in the context of adopting biofuel mandate in Vietnam. The study has found that the substitution of ethanol for gasoline and biodiesel for diesel could achieve energy and emission saving, but the cost-effectiveness is only shown to be valid for the case of ethanol. Welfare of Vietnam in 2025 increases under the implementation of the biofuel production and incentive policies in Vietnam because of better allocation of resources, more local production of energy and a reduction of energy imports, and the redistribution of tax proceed to households. The research methodology in this thesis provides the basis for empirical studies for other developing countries

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Appendices

Appendix 1. Checklist for focus group discussion

1. Introduction of the purpose of focus group discussion

2. Land use change, for feedstock production, and opportunity cost of land use

- Which land is used for feedstock production? If crop shifting, which crops were cultivated before feestock production?
- How is the opportunity cost of land? How is the cost of hiring agricultural land?
- What are the GoV's policies on land use?

3. Farming practice of biofuel feedstock of cassava, jatropha

- How do farmers cultivate feedstock crop concerning mono-(or inter-) cropping, intensive cultivation?
- How is the usage of fertilizer and pesticide in cultivation?

4. Supply chains of biofuel feedstock

- How are production inputs provided for farmers?
- What are the supply chains of feedstock from farming site to the processing plant?

5. Government's policies

- What are the government's policies regarding land use, feedstock production, biofuel processing and supply, and environment?

6. The impacts of feedstock production and biofuel processing on households' livelihood, food market, energy market, and environment

- Impacts on income: revenues from feedstock supply, profits, or returns to labor
- Impacts on employment generation: new employment creation opportunities, especially local area

  Opportunities for linkages and value added: forward/backward linkages between large/small or farm/off-farm enterprises, other sectors; potential to add value to raw materials and gain higher earnings including post-harvest, storage, processing, transport and marketing, to diversify agricultural market, and to increase competitiveness, to met market demand and growth potential for domestic use and exportation of feedstock

  Increases in productivity: technologies or management systems to increase the productivity and earnings of on-farm and off-farm activities in the subsector
- Benefits to key target groups: Viable for those with little land or capital available; employment, income and food security to the poor, the landless and ethnic minority
- Government's policies: Government's interest and programs that can translate into positive linkages with government services in the markets
- Adverse impact on environment, market, production and other risks
- Comparative advantages of locally produced feedstock
- Market assessment of existing local agricultural products, and energy input

7. Constraints, difficulties, and recommendations

- What are your difficulties or constraints in farming, market accessibility, or policy implementation?
- For further market development, would you please suggest solutions and supports needed to all stakeholders in the markets?

Thank you very much for your time.

Appendix 2. Questionnaire for households for cassava/jatropha

1.Date: ..../12/2010 2. Interviewer: ....

3.District:..Commune:..

....

Introduction

Good morning, we are from Nong Lam University and doing a research on cassava/jatropha production and sales to produce biofuel in Vietnam. Can we speak to household head or person who manages farming activities in your family?

Section 1. General information

4. a. Name of interviewee: ....

b. Relationship with household head (see Code 1) ....

[Code 1. Relationship with household head**]**

1=Household head	2=Husband/wife	3=Parents
4=Siblings	5=Children	6= Nephew /niece
7=Others (specify.........)		

5. Information of household head

a. Name of household head:..b. Age:...................

c. Sex: 1. Male 2. Female

6. Number of household members?...(persons)

7. Number of family labors?... (labors)

8. Phone number:...

Section 2. Information of household's agricultural system

9. Apart from cassava, do your family have any other income sources in 2010?

a. Income source	b. Area (ha)	c. Sale (000đ)	d. Cost (000đ)	e. Time of occuring income	f. Note
Agricultural product 1………………					
Agricultural product 2………………					
Agricultural product 3………………					
Husbandry..					
Trading					
Worker					
Official					
Hired labor					
Other:………………………………					
Total					

Section 3. Information of cassava/jatropha cultivation

10. How long have you cultivated cassava? …………….. .... years.

Section 3.1 Soil

From question 11 to question 14, the interviewer fill in the Table 1

Code 2 Ownership	**Code 3** Type of soil and land	**Code 4** Intercropping/monocropping	**Code 5** Use before growing cassava
1. Owner 2. Hired land 3. Not identification (specify) .... 4. Other (specify).........	**Terrain** 1.Sloping 2.Plain 3.Hollow 4.Other (specify)............ **Soil** 5. Bazan 6. Red soil 7. Grey soil 8. Other (specify)...........	1. Monocropping 2. Intercropping (specify ....) **Code 4b. Crop interrope with cassava** 3. .... 4.	

Information of cassava/jatropha cultivation

Farm	Area (m^2)	Ownership (Code 2)	Type of soil and land (Code 3)	Intercropping/monocropping (Code 4)	Use before growing cassava	Note
1						
2						
3						

11. How many cassava farms do you have? .... (farm)

12. Area of each farm? (Table Q1)

13. Opportunity cost of land
    a. Ownership of the farm? (Code 2)..
    ....
    b. If it is hired land, how much is the cost of hiring? ('000 VND/ha/year)...
    c. Other case, specify: ....

14. Which kind of soil and land do you cultivate cassava? (Code 3) ....

15. a. Do you monocrop or intercrop cassava?
    b. If intercrop, with which crop?

16. Before growing cassava, which purpose did you use this area? (Code 5)
    a. Purpose? ....
    b. Year of shifting to cassava? ....

Section 3.2 Water

17. Which water source do you use in cassava cultivation?..

18. Cost of using water? ....

Information on water pumping machine

19. Do you use water pumping machine? 1. Yes 2. No

20. Type of energy for the operation of water pumping machine?

1. Diesel 2. Electricity

21. Productivity of water pumping machine?...(horsepower)

Section 4. Cost, energy and emissions of feedstocks production

Section 4.1 Cost, energy and emissions of cassava cultivation

22. Specify: area which are considered? ....

23. Growing season**:** 1. Summer – Autum .... (from .... to ....)
2. Autum – Winter .... (from .... to....................................)

Section 4.1.1 Ploughing

24. Number of working days for ploughing
   a. Number of working days in family: .... days
   b. Number of hired working days:.. days
   Cost per working day: ....VND (day)

Machine

25. a. Do you use machine for ploughing? 1. Yes 2. No
   b. Which type of energy do you spend for using ploughing machine?
   1. Diesel 2. Electricity
   c. Working day needed?...(days)

26**.** Do you use fertiliser during ploughing? 1. Yes 2. No

Fertiliser and peticide

Items	Ingredient	Amount (kg, if not, specify ....)	Unit price ('000/kg, if not, specify ....)	Total cost ('000)	Time of spraying (month?)	Note
Ploughing – Basal Fertilising						
Seed treatment						
Additional fertiliser						
Pesticides						
1. Weeding						
2. Insect						
3.Disease						

Section 4.1.2 Seed treatment and planting

27. Which kind of cassava variety did you use? ....

28. Variety source:
    1. From previous crop 2. Buying 3. Other (specify) ....

29. a. Number of seed :..
    b. Cost of seed: ....VNDcrop

30. a. Did you do any treatment before planting ? 1. Yes 2. No
    b. How do you performe treatment?
    i. Name of chemical used in treatment :.......................................
    ii. Cost:...VND/crop

31. Working days for planting
    a. Number of working days in family: .... days
    b. Number of hired working days: .... days

32. Other cost incurring?

Section 4.1.3 Caring

33. Do you reseed if the first time has not been good? 1. Yes 2. No

34. If yes, how much is the cost incurring?

35. Do your cassava plants have any disease or insect? 1. Yes 2. No
    a. Specify name of disease or insect: ....
    b. Name of pesticide used: ....
    c. Cost of pesticide used: ....
    d. Number of working days for treatment: .... days

36. Weeding

a. Time of weeding/crop:.. time/crop

b. Number of working days for each time ....

Section 4.1.4 Harvesting

37. Number of working days:... days

a. Number of working days in family: .... days

b. Number of hired working days: .... days

38. Other costs (credit and so on)...

....

SALE OF CASSAVA 2010 (2009)

Code 6 Type of product		**Code 7** Starch content level		**Code** 8 Place of transaction	
1: Fresh root 2: Cassava chip 3: Sales before harvest 4: Other (Specify).......................		Specify: - Starch content level - Estimation?		1: Farm 2: Station in commune 3: Station in district 4: Processing plant 5: Other (Specify)	
Month	Output (kg) (a)	Sale (kg) (b)	Price (000đ/kg) (c)	Type of product (**Code 6**) (d)	Starch content level (**Code 7**)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
Total					

39. Apart from root, do you utilise plant and leaves? (specify amount, revenue, or opportunity cost)

....

Cost incurring for transportation (in case not selling at farm)

40. If not selling at farm

- Cost of transportation (specify amount and calculation): ....
- Fuel consumed (specify amount and calculation):...

Cost incurring for slicing cassava (in case farmer do not sell freshroot)

41. Number of

1. Freshroot for slicing: ....(ton)
2. Number of dried chip: ....(ton)

42. How do you slice cassava ?

1. Use machine 2.Manually

43. Working days for slicing

1. Number of working days in family: .... days
2. Number of hired working days : .... days

44. Cost of buying/hiring slicing machine :.. VND/ha

45. Cost of labor for slicing cassava?

1. Number of working days in family: .... /ton
2. Number of hired working days: .... working days/crop

46. Fuel or energy used in slicing:

1. Electricity 2. Fuel 3.Other: specify…………….

47. Trends of cassava farming in the recent 3 years

Items	Unit	2008	2009	2010
Total area	ha			
Yield	ton/ha			
Output	ton			
Price of fresh root	‘000VND/kg			
Price of cassava chip	‘000VND/kg			
Price of seed	‘000VND/plant			
Sale of seed	‘000 VND			

Section 4.2 Cost, energy and emissions of jatropha cultivation

Section 4.2.1 Cost in farming construction period

48. What kind of land was used in cultivation at the beginning?

1. Forest land 2. Cultivated land 3. Hired land

Items	If yes, please, specify this cost		
	Quantity	Price	Total
1. Have you hired land for jatropha cultivation?			
2. Did you conduct clearing/weeding before growing?			
3. Did your land have tractor plough before growing?			
4. Did you hire labor for seeding?			
5. Did you hire labor for planting/caring?			
6. Did you create seed by yourself or buy it?			
7. Did you put down basic fertilizer or not?			
8. Other costs (specify……………….)			
9. Other costs (specify……………….)			

49. Which equipment did you buy for the crop cultivation?

Name of equipment 01: .... Price: .... Useful life: .... (months)
Name of equipment 02: .... Price: .... Useful life: .... (months)
Name of equipment 03: .... Price: .... Useful life: .... (months)

50. From tree planting to the first harvesting. Which costs have incurred?

Items	Unit	Price	Quantity	Total
Plough against fire				
Weeding				
Watering				
Fertilizer				
- NPK				
- Urea				
- Nitrogenous fertilizer				
- Phosphate				
- Kali fertilizer				
- Muck				
- Other costs				
Herbicide, insecticide				
Labor cost				
Total				

Section 4.2.2 Costs incurred in every season, on harvested area in this season

51. How much did you spend for planting, maintenance, harvest and selling?

Cost items	Unit	Price	Quantity	Total
Fertilizer/Pesticide				
Spray chemicals				
Weeding				
Harvest				
Preservation, storage				
Dry				
Others (specify………………...)				
Total				

52a. How have been the cassava/jatropha cultivation in recent years in your commune?

....

....

52b. Are there any advantages or disadvantages regarding cassava/jatropha cultivation in your commune?

....

....

Section 4.2.3 Feedstock supply

53. Would you please provide us information on your recent sale?

Month	Amount sold (kg)	Selling price (VND/kg)	Product Types (Code 01)	Product quality (Code 02)	Types of buyers (Code 03)
Total					

In case of selling before harvest, ask estimated output and revenue of the whole farm

....

....

Code 09. Product types	**Code 10.** Quality	**Code 11.** Types of buyers
1: Fresh 2: Dry 3: Sales on average 4: Sales before harvest time 5: Others (Specify………...............)	5: Very good 4: Good 3: Average 2: Bad 1: Very bad	1: Dealer 2: Purchasing station 3: Processing units 4: Others (Specify……………….)

54. Which factors do you think your selling prices depend on?

No.	Factors	Evaluation (1: Dependent, 2: Not dependent)
1	World price	
2	Supply and demand	
3	Quality of cassva/jatropha	
4	Types of products (Fresh, dry, others:...............................)	
6	Selling time	
7	The ability of negotiation	
8	Buyers (whom)	
9	Others:...	

55. Through which source do you get price information and how often?

....

Post-harvest activities

56. Who performs post - harvesting? Traders or farmers? Reasons?

....

57. If you performed post – harvesting, which is the kind of job? And how did you earn?

....

Section 5. Impacts on livelihoods, agricultural market, energy market, and environment

58. What are the impacts of feedstock supply on your livelihoods? And in your community?

....

59. What are the impacts of biofuel production on agricultural markets, especially food market?

....

60. What are the impacts of biofuel production on energy markets?

....

61. What are the impacts of biofuel production on environment?

....

Section 6. Government's policies, contraints, difficulties and recommendations

62.Have you known any government policies relating to feedstock supply, environment?

....

....

63. Have you been affected by these policies? Have you received any support from the government?

....

....

64. In your feedstock production

....

....

65. In your feedstock supply

....

....

66. In other aspects

....

....

Your opinions and contributions are very useful and will all be considered and reported for further steps in the projects. Thank you very much for your time.

Appendix 3. Questionnaire for traders in the supply chain

Code: ....Date of interview:..........................Interviewee:...
Commune: ....District: ....Province: ....
Trader of cassava/jatropha: ....

General information

1. List your agricultural products and the structure of goods you are involved in?
2. How long have you traded for this crop (cassava/jatropha)? In which months?

Section 1. Linkages

Section 1.1 Purchasing

3. Please provide the information regarding to the price, quantity and sources of cassava/jatropha?

Code 1: Sellers	**Code 2**: Grading	**Code 3**: Buyers
1. Farmers in your commune 2. Farmers outside the commune 3. Middle man 4. Purchasing station (level 02) 5. Others (specify.....................)	1. Very good 2. Good 3. Ordinary 4. Bad 5. Very bad	1. Purchasing station (Level 01) 2. Processing factoty 3. Others (specify................................)

Month	Sellers (Code 1)	Quantity (kg)	Categories (Code 2)	Price (VND/kg)
Total				

4. How much is your total purchase per day?

	Maximum	Minimum	Average
Quantity (kg/day)			
Number of days (kg/day)			

5. Purchasing period: .... months

Section 1.2 Selling

6. Please provide the information regarding to the price, quantity and source of cassava/jatropha?

Month	Buyers (Code 3)	Quantity (kg)	Grade (Code 2)	Price (VND/kg)
Total				

7. How much is the total sale per day?

	Maximum	Minimum	Average
Quantity (kg/day)			
No of days (kg/day)			

8. Selling period: ....months

Section 1.3 Price and margin

9. Difference between buying and selling prices: ....VND/kg

10 a. Do you pay higher price for middle men than for farmers? 1.Yes 2. No

b. If yes, how much is the difference per kg? ....VND/kg

11. How do you determine the buying and selling price?

....

....

12. The price of cassava/jatropha compared to previous seasons?

1. Higher 2. Lower 3. Same Higher/Lower:…………..%

Section 1.4 Linkages

13. What is your solution to deal with the temporary shortage of product?

....

....

14. a. Do you receive any previous funding for you business? If yes, from whom? And how does it operate?

....

b. Do you pay in advance to your customers? If yes, who is that? And how does it operate?

....

....

15. How is your linkage with other stakeholders in the supply chain?

....

....

16. What do you know about markets of feedstock (international and domestic one)

....

....

17. How many percents of domestic production are used for biofuel production (case of cassava)? What are the other purposes?

....

....

Section 2. Transaction cost

18a. On average, the profit that you get per 01 kg cassava/jatropha is:..VND/kg

18b. Do you include these costs?

Package

- Packing cost: 1. Not included 2. Included
How much is the packing cost? (specify) ....

Communication

- Communication cost: 1. Not included 2. Included
Communication/telephone cost? ....VND/ 01 month

Labor

- Labor cost 1. Not included 2. Included

a.How many labors are there in your business?: .... people
b.How much is their monthly salary? ....VND/01month/01 labor
c.Which kind of jobs are they in charge of?

Transportation

- Transportation cost: 1. Not included 2. Included
- How much is the transportation cost? (Specify): ....
- Who pays the transportation cost? 1. Farmers 2. Dealers 3. Purchasing station

Other notes about transaction cost:

....

Section 3. Impacts on livelihoods, agricultural market, energy market, and environment

19. What are the impacts of feedstock supply on your livelihoods? And in your community?

....
....

20. What are the impacts of biofuel production on agricultural markets, especially food market?

....
....

21. What are the impacts of biofuel production on energy markets?

....
....

22. What are the impacts of biofuel production on environment?

....
....

Section 4. Income and value added

23. Have you performed any post-harvest activites/processing?

....
....

24. How is the value added of these performance?

....
....

25 a. How many labors participate in your business of cassava/jatropha? ....persons
25 b. In which how many family members are there? ....persons

26. Would you please tell us some information about your annual income?

Income sources	Amount (VND/month)	Note
Cassava		
Jatropha		
Others (specify)…………………………		
Total		

Section 5. Government's policies, constraints, difficulties and recommendations

27. Have you known any government policies relating to feedstock supply, environment?

....

....

28. Have you been affected by these policies? Have you received any support from the government?

....

....

29. In your feedstock purchasing and selling ....

30. In other aspects ....

....

Thank you very much for your time.

Appendix 4. Checklist for the interview with managers in processing plants

Name of the processing company:..
Addres: ....
Contact information: ....

1. Introduction of the purpose of the group discussion

2. General information

- Investment in technology, purchasing feedstock, biofuel delivery
- Employment: How many employees are there in your company? % of local employees in total?

3. Linkages

Inflows of biofuel feedstocks

- Volume and operation capacity: Input of feedstock (actual and capacity),
- Investment in feedstock production: yes/no, If yes, how is this investment?
- Importation of feedstock
- How can you attain a stable input volume for biofuel production
- Describe your feedstock purchasing from farming site to the processing plant: how many chains, the structure, % of each source, major suppliers
- Which policies do you apply in the feedstock purchasing? Regarding purchasing price, supporting farmers

Outflows of biofuel products

- Volume and operation capacity: output of biofuel (actual and capacity)
- Investment in retail distribution: yes/no, If yes, how is this investment?
- Exportation of biofuel
- Describe your delivery of biofuel from company to the gas station: how many chains, the structure, % of each source, major buyers
- Which policies do you apply in the delivery of biofuel? Regarding selling price

By-products

What are your by-products? How do you deal with these by-products?

4. Conversion technology

- Conversion ratio: ratio of input and output
- How do you manage the environmental issues in biofuel processing?

5. Impacts of the company's operation on households' livelihood, food market, energy market, and environment

- Opportunities for linkages and value added: forward/backward linkages between large/small or farm/off-farm enterprises, other sectors; potential to add value to raw materials and gain higher earnings including post-harvest, storage, processing, transport and marketing, to diversify agricultural market, and to increase competitiveness, to met market demand and growth potential for domestic use and exportation of feedstock
- Increases in productivity: technologies or management systems to increase the productivity and earnings of farm and off-farm enterprises in the subsector
- Benefits to key target groups: Viable for those with little land or capital available; employment, income and food security to the poor, landless poor, rural women and ethnic minority
- Adverse impact: Adverse impact on environment, market, production and other risks
- Existing local agricultural products, and energy input

6. Government's policies and strategy

- What are the government's policies regarding land use, feedstock production, biofuel processing and supply, and environment?
- Have you been affected by these policies? Have you received any support from the government?

7. Constraints, difficulties, and recommendation

- What are your difficulties or constraints?
- For further market development, would you please suggest solutions and supports needed to stakeholders in the markets?

Thank you very much for your time.

Summary

Biofuel production has continued to develop and is driven by government support around the world. A comprehensive analysis of biofuel production and the policy implementation is crucial for the biofuel sustainability development. The objective of this thesis is to study the energy efficiency, GHG emission savings and the economic viability of biofuels and to examine the impacts of biofuel policies on food production, welfare, and emissions in Vietnam.

Chapters 2 and 3 study the performance of biofuel industry in Vietnam following the life-cycle assessment and comparative analysis and focus on three aspects of energy efficiency, emissions, and economic viability. The results show with the targets of 600 thousand tonnes of ethanol and 250 thousand tonnes of biodiesel in 2025, the emission saving would reach from 1129 to 5034 thousand tonnes of CO_2e, and the energy saving would achieve 14.6 to 49.2 PJ. For the ethanol to be cost-effective, the fuel consumption of E5 and E10, in terms of L km^{-1} compared to that of gasoline, is not increased by more than 1.7% for E5 and 3.5% for E10 at the discount rate of 4%. For the cost-effectiveness of biodiesel, the fuel consumption of B5 and B10 compared to that of diesel should be decreased by more than 1.4% for B5 and 2.8% for B10 at the discount rate of 4%. The cost-effectiveness of using biofuels in comparison to fossil fuels depends on the efficiency of biofuel production and blended fuel combustion. For a sustainable biofuel market in Vietnam, further investments will be needed for both, improving the efficiency of biofuel production and blended fuel combustion. To meet the government's target of biofuels in 2025, a total land area of 339,945 ha is required for feedstock production, which corresponds to 7.4% of Vietnam's arable land in 2009. Of this, it is thought that 14% of the necessary land would come forestland, 66% from grassland and 20% from other cropland. Further achievement of energy savings and emission savings can be obtained through further investment in technologies for sustainability in agriculture, an improvement of feedstock yield, improvement of energy input efficiency, use of flexible-fuel vehicles to reduce fuel consumption levels of biofuel blends compared to fossil fuel.

Chapters 4 and 5 investigate the economy-wide impacts of biofuel production and incentive policies in Vietnam on welfare, the economy and emissions of greenhouse gases in Vietnam. Under the biofuel production policy there is a decline in food production and consumption in Vietnam; however, the energy security is enhanced by an increase in domestic production of biofuel in Vietnam and a reduction in the import of fossil fuel. Under the biofuel production policy, the annual greenhouse gases emission saving in Vietnam in the year 2025 will be increased from 6% under business as usual to 25% percent. In Chapter 5, we find that an imposition of a 10% tax on fossil fuels causes the outputs of industrial goods, fossil fuel, and services to decrease as compared to the reference scenario. These biofuel incentive policies mostly affect the international trade between Vietnam and its main trading partners with a decrease in net exports by 0.4% for agricultural goods, by 0.3% for processed

food, and by 0.2% for cassava and an increase in net imports by 1.1% for industrial goods, by 0.3% for fossil fuel, and by 3.1% for services. An additional introduction of a subsidy on biofuel increases the domestic production of services and slightly shifts the fossil fuel sector towards less production and more imports. Welfare of Vietnam in 2025 increases under the implementation of the biofuel production and incentive policies in Vietnam because of better allocation of resources, more local production of energy and a reduction of energy imports and redistributing tax revenues to consumers in Vietnam. For its main trading partners, the biofuel implementation in Vietnam induces changes in international trade with Vietnam, particularly reducing the export of fossil fuel and increasing import of certified emission reductions from Vietnam. Overall, there is a negligible change in the welfare in MTP.

The research methodology in this thesis provides the basis for empirical studies for other developing countries. The insights of findings indicated opportunities for further achievement by investigating in advanced technology in agriculture and biofuel processing, infrastructure in the supply chain, and flexible-fuel vehicles. Though Vietnam can improve its welfare by implementing the biofuel blend mandate or a combined policy of a tax on fossil fuel and subsidies on biofuels in the context of adopting the biofuel mandate from an economic point of view; however, the political feasibility of these policies should be further considered in reality. A more governance-oriented approach for biofuel policies, which attempts to cover social impacts, environmental quality, and economic and political feasibility, should be based on setting specific targets to make the policies more feasible and effective. Public acceptance for biofuels will be the last challenge to be addressed once the infrastructures, flex-fuel vehicles and biofuel supply systems are all in the market.

Samenvatting

De productie van biobrandstoffen vertoont een stijgende trend en deze ontwikkeling wordt gestuurd door overheidsmaatregelen wereldwijd. Een diepgaande analyse van de productie van biobrandstoffen en beleidsimplementatie is essentieel voor de duurzame ontwikkeling van deze brandstoffen. Het doel van dit proefschrift is om de energie-efficiëntie, de vermindering van broeikasgassen en de economische levensvatbaarheid van biobrandstoffen te bestuderen en om de effecten te analyseren van biobrandstof-beleid op de voedselproductie, maatschappelijke welvaart en broeikasgasemissies in Vietnam.

In Hoofdstuk 2 en 3 wordt de performance van de biobrandstofindustrie in Vietnam bestudeerd met levenscyclusanalyse en in een vergelijkende studie. De focus ligt op drie aspecten: energie-efficiëntie, emissies en economische levensvatbaarheid. De resultaten laten zien dat bij de doelen van 600 duizend ton ethanol en 250 duizend ton biodiesel in 2025, de vermindering van emissies oploopt tot tussen de 1129 en 5034 duizend ton CO_2-eq. De energiebesparing zou 14,6 tot 49,2PJ bedragen. Om de bijmenging van bio-ethanol kosteneffectief te laten zijn, wordt de brandstofconsumptie van E5 en E10 (in termen van liter per kilometer in vergelijking tot die van benzine) niet verder verhoogd dan 1,7% voor E5 en 3,5% voor E10 bij een discontovoet van 4%. Voor de kosteneffectiviteit van biodiesel, moet de brandstofconsumptie van B5 en B10 in vergelijking tot diesel worden verlaagd met tenminste 1,4% voor B5 en 2,8% voor B10 bij een discontovoet van 4%. De kosten-effectiviteit van het gebruik van biobrandstoffen met fossiele brandstoffen hangt af van de efficiëntie van de productie van biobrandstoffen en de efficiëntie van gemengde brandstofverbranding. Voor een duurzame biobrandstof markt in Vietnam, zullen aanvullende investeringen nodig zijn voor het verbeteren van zowel de efficiëntie van brandstofproductie als van gemengde brandstofverbranding. Om het overheidsdoel van biobrandstoffen in 2025 te halen, is een totaal landoppervlak van 339,945 ha nodig voor grondstofproductie, wat overeenkomt met 7,4% van Vietnam's landbouwgrond in 2009. Hiervan wordt vermoed dat 14% van het benodigde land van bosareaal zal komen, 66% van grasland en 20% areaal van andere gewassen. Verdere energie- en emissiebesparingen kunnen worden bereikt door investeringen in technologieën die duurzaamheid in de landbouw bevorderen, de verbetering van grondstofopbrengsten, de verbetering van energie-input efficiëntie en het gebruik van 'flexible fuel'-voertuigen om de brandstof consumptieniveau's bij biobrandstofbijmenging ten opzichte van fossiele brandstoffen te verminderen.

Hoofdstukken 4 en 5 bestuderen de economie-brede effecten van biobrandstofproductie en het stimuleringsbeleid in Vietnam op de maatschappelijke welvaart, de economie en broeikasgasemissies in Vietnam. Onder het biobrandstof-productiebeleid is er een afname in voedselproductie en consumptie in Vietnam; daarentegen wordt de energie-zekerheid vergroot door een toename van de binnenlandse productie van biobrandstoffen in Vietnam en een vermindering van de import van fossiele brandstoffen. Onder het biobrandstof-productiebeleid, loopt de jaarlijkse broeikasgasbesparing in Vietnam in het jaar 2025 op tot een besparing van 25% tegen 6% onder de baseline. In hoofdstuk 5 vinden we dat het instellen van een belasting van 10% op fossiele brandstoffen een output-daling veroorzaakt van industriële goederen, fossiele brandstoffen en diensten ten opzichte van het referentiescenario. Dit stimuleringsbeleid van biobrandstoffen heeft hoofdzakelijk effecten op de internationale handel tussen Vietnam en haar voornaamste handelspartners door afnames van de netto exporten van 0,4% voor landbouwproducten, 0,3% voor bewerkt voedsel en 0,2% voor cassave; daarnaast zijn er toenames van de netto imports van 1,1% van industriële goederen, 0,3% van fossiele brandstoffen, en 3,1% voor diensten. Een additionele introductie van een subsidie op biobrandstof leidt tot een toename van de binnenlandse productie van diensten en een kleine verschuiving van de fossiele brandstofsector naar minder binnenlandse productie en meer import. De maatschappelijke welvaart van Vietnam neemt in 2025 toe onder de implementatie van biobrandstofproductie- en stimuleringsbeleid in Vietnam, door betere allocatie van resources, meer lokale productie van energie en een vermindering van energie-importen, en herverdeling van belastingopbrengsten aan consumenten in Vietnam. Voor haar voornaamste handelspartners resulteert de implementatie van biobrandstofbeleid in Vietnam in veranderingen in internationale handel met Vietnam: vooral de export van fossiele brandstoffen vermindert en de import van gecertificeerde emissiereducties uit Vietnam neemt toe. Over het geheel genomen zijn de welvaarteffecten bij de belangrijkste handelspartners verwaarloosbaar.

De onderzoeksmethodologie in dit proefschrift kan de basis vormen voor empirische studies voor andere ontwikkelingslanden. De inzichten uit de resultaten wijzen op verdere mogelijkheden voor verbeteringen door onderzoek naar geavanceerde technologie in de landbouw en biobrandstofprocessing, infrastructuur in de aanbodketen en flexible-fuel voertuigen. Hoewel Vietnam haar welvaart vanuit een economisch perspectief kan verhogen door het biobrandstof mandaat te implementeren, of door gecombineerd beleid van een belasting op fossiele brandstoffen en subsidies voor biobrandstoffen in de context van adoptie van het biobrandstof mandaat, moet ook de politieke haalbaarheid van deze beleidsmaatregelen in de praktijk worden beschouwd. Een meer bestuurlijk-georiënteerde benadering voor biobrandstofbeleid, gericht op sociale effecten, milieu-kwaliteit, en economische en politieke haalbaarheid, moet worden gebaseerd op het nastreven van specifieke doelen om de maatregelen haalbaarder en effectiever te maken. Publieke acceptatie van biobrandstoffen zal de laatste barrière zijn die moet worden geslecht als de benodigde infrastructuur, de flexible-fuel voertuigen en de biobrandstof aanbodsystemen allen in de markt aanwezig zijn.

About the author

Le Thanh Loan was born on January 24th 1976 in Ho Chi Minh city, Vietnam. She obtained her bachelor degree in Business Administration in 1999 at University of Economics in Ho Chi Minh city, Vietnam and her master degree in Development Economics from the Vietnam – Institute for Social Studies, the Netherlands Progamme in 2001.

From 2002 to 2003 she worked at the Vietnam Chamber of Commerce and Industry (VCCI) in Ho Chi Minh city as a training consultant. Since 2003 she has worked at Faculty of Economics, University of Agriculture and Forestry in Ho Chi Minh City, Vietnam. Her teaching subjects are Accounting Information System, Environmental Accounting Management, Valuation of Environmental Resources. She was a local trainer on Environmental Accounting Management in the EMA-SEA project in 2007. She did researches on Markets for Agroforestry Tree Products in the SEANAFE's Marketing Project, on Market Value Chain in the ADB project of Making Markets Work Better for the Poor, and on Sustainable Agriculture and Natural Resource Management in the SANREM CRSP project during 2005-2008.

She attended the Beahrs Environmental Leadership Program at the University of California, Berkeley in 2007 and received a research grant from the Economy and Environment Program for Southeast Asia (EEPSEA) in 2011 and the Global Research Alliance (GRA) Fellowship at the Kansas State University on the topic of climate change, land use change, and emission in agriculture in 2013.

In 2009 she started her PhD study on Environmental Economic and Natural Resources in Wageningen University, the Netherlands through the Erasmus Mundus Boku project. Her PhD thesis titled *Biofuel production in Vietnam: greenhouse gas emissions and socioeconomic impacts* was supervised by Prof. dr. E.C. van Ierland and Associate Prof. Xueqin Zhu. The most important results of her PhD research are presented in this thesis.

Le Thanh Loan

Wageningen School of Social Sciences (WASS)

Completed Training and Supervision Plan

Name of the activity	Department/Institute	Year	ECTS*
A. Project related competences			
Proposal writing	WASS	2010	6
Advanced Econometrics (AEP 60306)	WUR	2009	6
Advanced Microeconomics (ECH 32306)	WUR	2009	6
Advanced Macroeconomics (ENR 30806)	WUR	2009	6
Economics and Management of Natural Resources (ENR 31306)	WUR	2010	6
Theories and Models in Environmental Economics (ENR 30306)	WUR	2010	6
Introduction to Bio-economic Modelling	WASS	2009	1.5
Advanced Bio-economic Modelling	WASS	2009	1.5
Panel Data Analysis in Micro-economics	WASS	2009	1.5
B. General research related competences			
Mansholt introduction course	WASS	2009	1.5
Information literacy	WGS	2009	1.5
Techniques for writing and presenting a scientific paper	WGS	2009	1.5
Scientific writing skills	WGS	2009	1.5
Reviewing a scientific paper	WGS	2011	0.1
C. Presentation at Conferences			
Comparing social costs of biofuels and fossil fuels: A case study of Vietnam	EEPSEA, Ho Chi Minh City, Vietnam	2015	1
An applied general equilibrium analysis for biofuel production policy in Vietnam: welfare, food production and emissions	Food in the Bio-based Economy: Sustainable Provision and Access, WUR	2015	1
Impacts of biofuel incentive policy on welfare: an applied equilibrium model for Vietnam	International Energy Conference, Los Banos, Philippines	2015	1
Total			**49.6**

*One ECTS on average is equivalent to 28 hours of course work

Colophon

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Photo captions

- Cover and invitation card: Jatropha seedling in Ninh Thuan province, Vietnam designed by Le Thanh Minh
- Before Chapter 1: Meeting of the roadmap for compulsory use of E5 and selling E5 at the gas station
- Page 22: Land use change due to cassava expansion in Daknong province, Vietnam
- Page 62: Sliced and dried cassava in the sun before delivery to ethanol plants in the form of dried chips
- Page 90: Changing life in rural area owning to the expansion of feedstock production
- Page 132: Biofuels policy implementation in Vietnam
  Page 160: Meeting, workshops, and conferences on bioenergy attended by the author
- Page 196: Author in Wageningen