Journal of Cleaner Production 134 (2016) 563–573

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

# Risks of indirect land use impacts and greenhouse gas consequences: an assessment of Thailand's bioethanol policy

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A R T I C L E I N F O

*Article history:*
Received 17 November 2014
Received in revised form
14 May 2015
Accepted 23 May 2015
Available online 1 June 2015

*Keywords:*
Indirect land use change
Consequential LCA
Attributional LCA
Biofuel

A B S T R A C T

This study aimed to assess indirect land use change (iLUC) and greenhouse gas (GHG) consequences of Thailand's bioethanol policy by using consequential life cycle assessment (CLCA) and a systematic iLUC model based on global land market. The results indicated the risk that life cycle GHG emissions of cassava- and molasses-based bioethanol systems may outweigh those from their fossil fuel counterparts both with and without the iLUC effects. The iLUC emissions from bioethanol were around 39%–76% (±8–15%) of the gasoline GHG emission baseline. Inclusion of relevant suppliers for the use of fully utilised by-products which are renewable energy sources (i.e. molasses and bagasse) highly affected the GHG consequences. Various controlled conditions such as non-fully utilised molasses and bagasse potentially lead to significant GHG reductions. The additional molasses and bagasse production dedicated specifically for bioethanol production potentially contribute to substantial GHG reductions. Further studies are required to determine other environmental impacts from bioethanol and to consider other iLUC modelling choices and emerging research development.



## 1. Introduction

As a step towards the development of a low carbon and sustainable society in Thailand, the 10-Year Alternative Energy Development Plan (AEDP): 2012–2021 (DEDE, 2012a) was established by the Royal Thai Government aiming at a target on using renewable energy at 25% of total energy consumption by 2021. The plan has aimed to reduce emissions of 76 million tonnes $CO_{2\text{-eq.}}$/year by 2021 with expected revenue of 23,000 million baht gained from selling carbon credits. As a part of the AEDP, bioethanol is the most important biofuel for which the production technologies are currently and commercially available.

Many policies in developing countries may consider greenhouse gas (GHG) emissions from biomass as zero due to their ability to equally uptake and release the carbon dioxide from/to the air during the production and use phases. When GHG emissions from the whole life cycle from raw material extraction to end-of-life treatment are included, the emissions are not negligible and may exceed the benefits gained from fossil fuel replacement. There are plenty of existing studies assessing GHG emissions of biofuels (Börjessen and Tufvesson, 2011; Gnansounou et al., 2009; Searchinger et al., 2008). It was found that the methodological choices (i.e. the method used for handling co-products, the type of reference systems, the type of land use changes, etc.) significantly affect GHG and energy balances of biofuels. To capture potential GHG consequences of biofuels demand, consequential life cycle assessment (CLCA) handling co-products by system expansion and incorporating actually affected suppliers (Weidema et al., 2009) can be used as a tool. Regarding the type of land use changes, Börjessen and Tufvesson (2011), Searchinger et al. (2008) and Marelli et al. (2011) addressed possibilities that GHG emissions of bioenergy from direct and indirect land use changes (dLUC and iLUC) might equal or outweigh emissions from fossil fuels. The dLUC and iLUC are defined as "*change in human use or management of land within the product system being assessed*" and "*change in the use or management of land which is a consequence of direct land use change, but which occurs outside the product system being assessed*", respectively (ISO, 2013). Since CLCA aims at modelling the consequence of a change in demand using cause–effect relationships to identify the upstream impacts of the decision, land use changes are not necessary to occur within the specific product

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http://dx.doi.org/10.1016/j.jclepro.2015.05.091
0959-6526/

system being assessed and considered as iLUC. For example, bioethanol feedstocks being cultivated in a specific country may have upstream impacts from land occupation somewhere else in the world. Therefore, only iLUC is taken into an account in this study. To emphasise on the importance of the iLUC impacts on GHG emissions, international and well-known iLUC experts concluded about biofuel/bioliquids policy in EU in Marelli et al. (2011, p.56) that "*including iLUC effects, there will be little or no GHG reduction compared to (fossil fuels)*". One of proposals is to apply a single world market model instead of individual models to find emissions for every crop resulting in varied modelling choices (Marelli et al., 2011, p.57). Although there are high uncertainties and no consensus iLUC modelling methods, the iLUC effects should be taken into account in Thailand's bioethanol policy as potential risks so as to ensure that the targeted carbon reduction can actually be met.

Various assessment studies in Thailand have shown potential risks that iLUC induced by feedstock cultivation may contribute to net GHG emissions increase as compared to fossil fuels rather than mitigation when transforming forest into agricultural land (Silalertruksa et al., 2009; Silalertruksa and Gheewala, 2009). The previous studies in Thailand only considered iLUC effects based on a specific amount of a given crop being produced in a specific country and its specific potential impacts. For example, increased demand for 1 tonne cassava in Thailand led to increased cassava production in the country or in a future supply country (i.e., Vietnam) followed by land expansion, intensification or crop displacement of 1 tonne cassava (Silalertruksa et al., 2009). By using the crop-country specific approach, the iLUC impact from cultivating a specific crop in different regions will not be the same although the crop with the same yield is cultivated on land with similar productivity (Schmidt et al., 2015). Due to the fact that many crops are substitutable and sold in a global market, the assumption of crop-specific markets may not always hold. Under the present circumstances on globalisation and continuous growth in global markets of land-using products, the markets for land are more global rather than local. Furthermore, land use modelling by taking land occupation in terms of the land's potential productivity into account (not the specific amount of a given crop) will be able to systematically capture the iLUC effects globally. With the main aim to encourage sustainable replacement of fossil fuels towards low carbon society, there is a need to further investigation of the actual life cycle GHG consequences including land use impacts on the global scale from implementing measures to reach the bioethanol target of Thailand. Not only are land use impacts taken into account at global level under CLCA modelling, other specific product systems are to be considered based upon their global market if they have been traded internationally. The main purposes of this study are to quantify iLUC impacts and GHG emissions from Thailand's bioethanol policy and to recommend how to set up the policy more sustainably in the future based on the potential consequences.

In order to demonstrate this research systematically, this paper is separated into four main sections. After the introduction in Section 1, Section 2 transparently defines goal and scope of the study, demonstrates important selected modelling choices and scenarios, and documents how the data were gathered. The results and discussion in Section 3 cover the effects on GHG consequences from iLUC, co-product handling approach, CLCA and ALCA modelling choices, unconstrained molasses and bagasse, technology and yield improvement, and implications for sustainable bioenergy in Thailand. The last section concludes the important findings and recommends how to promote sustainable bioenergy in Thailand.

## 2. Methodology

### 2.1. Goal and scope definition

The main goal of this study is to identify the potential indirect land use change impacts on the global scale and GHG consequences of Thailand's bioethanol in 2021 based on AEDP: 2012–2021 (DEDE, 2012a). The assessment also aims at determining possible risks from uncertainties and recommendations on how to set future policies of sustainable bioenergy in Thailand. The functional unit (FU) is defined as "*Thailand's bioethanol production in 2021 according to AEDP: 2012–2021 (*DEDE, 2012a*), totalling 9 million litres per day*". In order to evaluate the overall life cycle GHG risks of Thailand's bioethanol policy, the life cycle GHG emissions from a conventional petroleum fuel (gasoline) is used as baseline for comparison. Specific feedstocks for the bioethanol production in Thailand generally include sugarcane molasses and cassava depending on several factors such as availability, production costs and prices of the feedstocks for other competitive uses. The ratios of different feedstocks in Thailand in 2021 are specifically identified in Section 2.1.3. Scope and system boundaries are further defined with respect to LCA modelling approach, iLUC modelling, and descriptive assessment scenarios as follows.

#### 2.1.1. LCA modelling approach and life cycle impact assessment method

Consequential life cycle assessment (CLCA) considering the impacts from a change in demand for bioethanol in Thailand is applied to quantify GHG emissions. The approach deals with market-based cause–effect relationship by identifying what will happen if we increase the production of the product in question. CLCA includes marginal (actually affected) suppliers and handles co-products by expanding the investigated product system to include the additional functions and their affected processes related to the co-products (or system expansion). Another system modelling approach is attributional LCA (ALCA) or a status-quo approach which includes average suppliers and links and/or partitions the unit processes of the co-product system by using mass/energy/economic allocation techniques (Sonneman and Vigon, 2011; Weidema et al., 2009). In fact, an important aspect in life cycle inventory (LCI) modelling for both CLCA and ALCA is market delimitation of the products/product systems which has been described intensively in Weidema (2003) and Weidema et al. (2009). Product inputs and outputs are linked via markets. To determine the certain markets of specific products/product systems geographically, the trading conditions are crucial. Without the imports and exports of the product across the geographical boundary, geographical segments can be delimited (Weidema et al., 2009). This implies that in case the products are imported and exported internationally, the global market is to be considered. For example, the market for electricity is delimited with national and/or regional boundary whereas most of agricultural products are traded internationally under the global market. A global market is applied for land in this study as explained previously in Section 1.

The selected system modelling approach is CLCA and the details of co-product handling and included suppliers are specifically described in the system boundaries. Furthermore, the methodologies on system expansion and identification of marginal suppliers in CLCA are described comprehensively in Weidema et al. (2009). In sensitivity analysis, ALCA using energy-based allocation, average electricity and land use supplies is also taken into account.

To calculate the GHG emissions, IPCC 2007 GWP 100a (IPCC, 2007) is chosen as the method for life cycle impact assessment carried out by using SimaPro 8.0.3 (PRé Consultants bv, Amersfoort, The Netherlands).