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Attributional and Consequential Life Cycle Assessment for Biomass Energy Production from Maize Cob in Chiang Dao district

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ABSTRACT

Maize is one of the most typical crops cultivated in Chiang Mai, Thailand. According to Office of Agricultural Economics, maize production in Chiang Mai in 2016 was about 121,665 tonne while the maize residues (cobs, leaves, and stalks) was around 253,063 tonne. In Chiang Dao, one of district in Chiang Mai, the production of maize and maize residues were 17,905 and 37,242 tonne, respectively. Maize farming in Northern of Thailand is growing tremendously. However, the current maize farming practices have also caused several problems to local communities as well as urban dwellers. Therefore, improper agricultural practices have contributed to negative environmental impacts. This study evaluates the life cycle environmental impacts of biomass energy production from maize cob in Chiang Dao district by using Attributional Life Cycle Assessment (ALCA) and Consequential (CLCA) approaches. The system boundary of this study includes land preparation, planting, weeding, farming, harvesting, maize cob pellet production and heat production from maize cob pellet. The functional unit of this study is 1 MJ of biomass energy production from maize cob. The data were obtained from field survey supplemented with Thai National Life Cycle Inventory Database and scientific publication. The product systems being effected under global and national markets depend on the market delimitation of each product. The additional maize cob production dedicating specifically for biomass energy production from maize cob potentially contributes to substantial environmental impacts reductions and biomass fully utilization. Furthermore, this research presents how modelling choices affect the environmental impacts of biomass energy production from maize cob.

Keywords : Attributional LCA; Consequential LCA; Maize cob; Biomass energy; Chiang Dao

INTRODUCTION

Most of the area in Chiang Mai province are upland area and various crop cultivated in this area. Maize is one of the most typical crops cultivated in this area. According to Office of Agricultural Economics [1], maize production in Chiang Mai in 2016 was about 121,665 tonne or 689 kg/rai while the maize residues (cobs, leaves, and stalks) was about 253,063 tonne. While maize production in Chiang Dao district was about 17,905 tonne or 652 kg/rai and the maize residues was about 37,242 tonne. Maize farming in northern Thailand is growing tremendously. However, after harvesting processes, open burning is widely used in order to get rid of maize cobs and husks in land preparation for next period. The current maize farming practices have also caused several problems to local communities as well as urban dwellers. Therefore, improper ways of agriculture, have contributed to environmental impacts.

When performing an LCA, there are two different LCA approaches, attributional LCA (ALCA) and consequential LCA (CLCA) were identified and described. In previous LCA studies of maize production performed in different countries, mostly ALCA was used and some kind of allocation (mass, energy-based or economic; [2] estimated the environmental impacts for corn cultivation of corn grain and corn stover grown under the current tillage practices for various corn growing locations in the US Corn Belt. The environmental performance of this study due to crop management, soil properties, and climate conditions. [3] compared the LCA results from the application of different allocation methods of gasoline and ethanol as fuels and with two types of blends of gasoline with ethanol in USA. [4] assessed the life cycle of a bio-refinery system which converts crop residues (corn stover and wheat straw) into bioethanol, bioenergy, and bio-chemicals (phenols). Moreover, [5] determined the reduction in the (GHG) emissions for corn ethanol compared to gasoline by integrating biomass fuels to replace fossil fuels (natural gas and grid electricity) in a U.S. [6] analyzed the environmental performances of maize silage for biogas production in Italy. They found, the nitrogen cycle and the linked emissions are relevant for the environmental burden of crop cultivation, especially for acidification and eutrophication. Recently, [7] assessed the feasibility of mobilizing maize and wheat residues for large-scale bioenergy applications in South Africa by establishing sustainable residue removal rates and cost of supply based on different production regions.

Regarding Consequential LCA study, [8] demonstrated and compared ALCA and CLCA of an average conventional milk production system in The Netherlands. [9] defined the system boundaries in consequential agricultural LCA in the case of LCA of increased demand for wheat in Denmark. He also argued that the attributional way of defining system boundaries in agricultural LCA implies several blind spots. This study showed that there are different ways to meet increased demand for agricultural products and that the environmental impact from these different ways vary significantly. [10] investigated the environmental consequences (on climate change and land use) of an increase grass-based milk in France using a consequential life cycle assessment (CLCA) approach. [11] assessed the direct and indirect environmental impacts to be expected if the demand of biodiesel in Spain increases to meet current European obligations using a consequential approach. [12] evaluated and compared the environmental performance of five different vegetable oils, including the relevant market responses induced by the oils' by-products. Also the life cycle inventory is using a consequential approach. In 2016, [13] assessed 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. Furthermore, [14] quantified the indirect environmental impacts of global energy crop land area and the subsequent iLUC, if an additional demand of biofuel in Spain occurs, from a consequential approach. In 2017, [15] assessed climate change mitigation potentials using biomass-based fuels to replace fossil energy under consequential and attributional modelling approaches. They also determined policy implications and recommend the specific contexts suitable for each modelling choice by using specific illustrative cases on biofuels. Moreover, [16] assessed potential environmental life cycle consequences of palm-based biodiesel production in comparison with conventional diesel production under two modelling choices (Consequential and Attributional LCA). Recently, [17] investigated the relationship between social responsibility paradigms and the system modelling choices in LCA. He also identified three different social responsibility paradigms: Value chain responsibility, Supply chain responsibility and Consequential responsibility.

This research aims to evaluate the environmental impacts related to emissions within a set system boundary through the life cycle of biomass energy production from maize cob in Chiang Dao district, northern Thailand using an attributional LCA (system allocation) and a consequential LCA (system expansion) approach to present the consequences of important approach in LCA studies.

METHODOLOGY

Goal and scope

An attributional LCA (system allocation) and consequential LCA (system expansion) approach are applied in this study. The system boundary of this study is starting from land preparation process and continues through farming process, following which is the harvesting process; the last process is heat production from maize cob pellet. The system boundary is presented in Figure 1. The functional unit of this study is 1 MJ of biomass energy production from maize cob. An economic allocation was applied to the production of maize grain and maize cob, which is being sold on the market for livestock and energy applications. Maize grain and maize cob impacts were allocated using economic allocation factors according to the average market prices referring to [1], resulting in the following values: 92% for maize grain and 8% for maize cob.

Study area

The maize cultivation under assessment is carried out in Chiang Dao area, district of Chiang Mai, Thailand. Most of the terrain in Chiang Dao district is covered by upland areas. The agricultural land use map of Chiang Dao district was shown in Figure 2. Field operations can be divided into: (1) land preparation, (2) planting, (3) weeding, (4) farming, (5) harvesting and milling, (6) post harvesting (open burning) and transport and (7) heat production from maize cob pellet.

The first crop of maize usually starts in April-May with land preparation and sowing and ends in November or December for maize yield harvesting. In 2016, the maize production in Chiang Dao district was about 17,905 tonne and the maize residues was about 37,242 tonne.

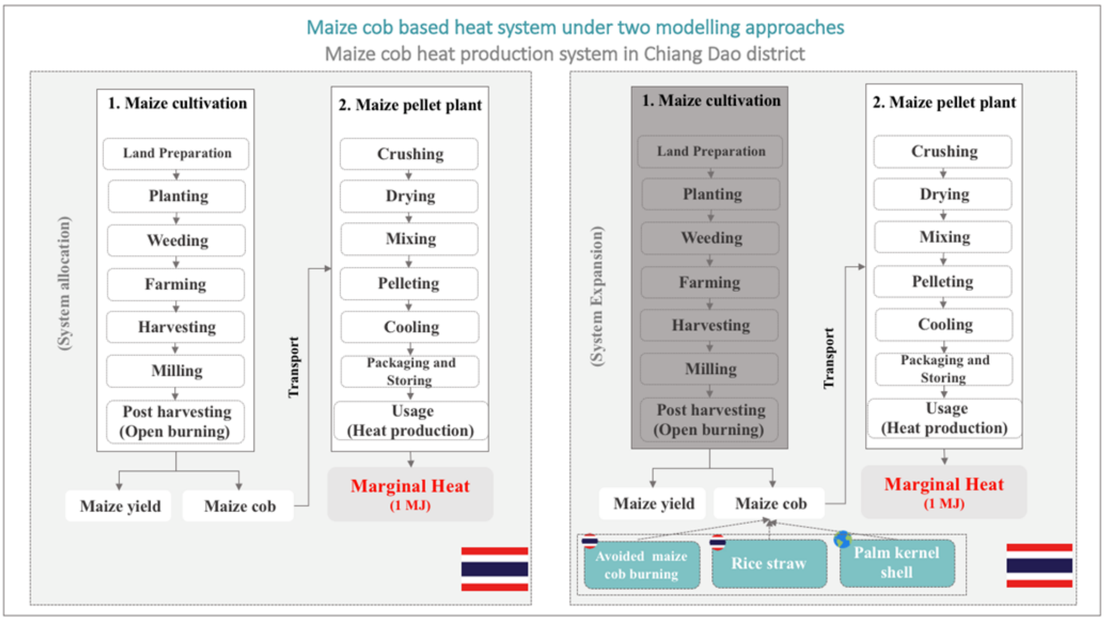

Figure 1 Overall system boundaries of Chiang Dao district's maize cob heat production system under a consequential modelling approach. The grey boxes represent the excluded processes, because they are not affected by the additional maize cob heat production system

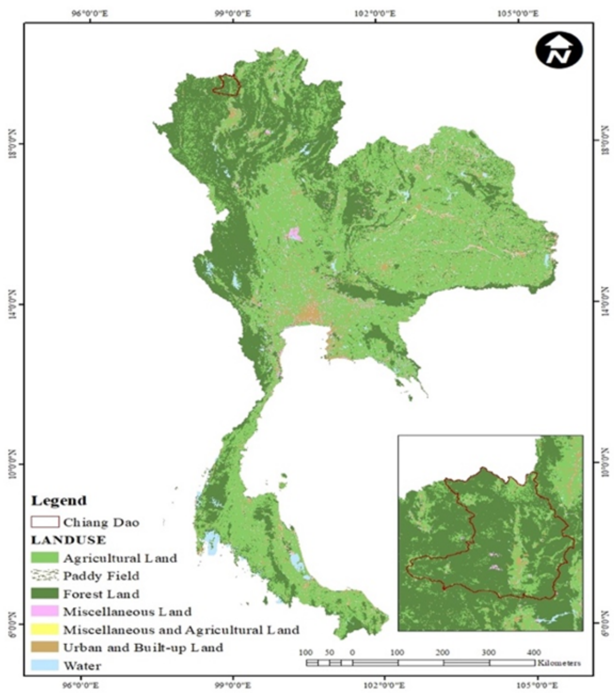

Figure 2 Agricultural land use map of Chiang Dao district, Chiang Mai Thailand

Data collection and life cycle inventory analysis

The primary data in this study were obtained directly from the 20-30 farmers in totally 100 rais of maize production area in Chiang Dao district such as, raw materials for maize production as fertilizers, herbicides, including diesel fuel which is used in agricultural machinery and transportation. The calculations and assumptions are identifiable based on secondary data, such as the existing databases in SimaPro, such as Ecoinvent data v3.0, Thai national database, and IPCC. The substituted and substituting product systems are modelled under the global and national markets depending on the market delimitation of each product.

Table 1 The conventional system and the three scenarios assessed in the LCA study

Scenarios	Description
ALCA: Conventional system	The attributional modelling approach is applied by using average suppliers and economic allocation factors for existing maize cultivation and heat energy production from maize cob under average condition in Thailand (% by economic).
CLCA: Scenario 1 Avoided open burning	The consequential modelling approach is applied under the fully utilized condition of maize cob (by-product).
CLCA: Scenario 2 Rice straw pelletizing	The consequential modelling approach is applied under the situation that substituted by rice straw.
CLCA: Scenario 3 Palm kernel shell pelletizing	The consequential modelling approach is applied under the situation that substituted by palm kernel shell.

Life Cycle Impact Assessment

This study was conducted using Life Cycle Assessment (LCA) methodology. The guiding principles of LCA follow the International Organization for Standardization (ISO) standards ISO 14040 [18] and ISO 14044 [19]. An attributional LCA (system allocation) and consequential LCA (system expansion) approach are applied in this study. A life cycle impact assessment (LCIA) was performed using SimaPro software was chosen as a method with which to assess the environmental impacts. This study focused on the endpoint of environmental impact as human health damage addressed in terms of a marginal change in DALYs unit.

The two modelling approaches have been defined in the glossary of the [20] database guidelines as:

- Attributional approach: System modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule.
- Consequential approach: System modelling approach in which activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit.

RESULTS AND DISCUSSIONS

The results of this study obtained for the environmental impacts of biomass energy production from maize cob in Chiang Dao district by using an attributional and consequential LCA approach. The additional maize cob production dedicates specifically for biomass energy production from maize cob potentially contribute to substantial environmental impacts reductions and biomass fully utilization.

Regarding an ALCA modelling approach, the significant impact on human health damage which from biomass burning in post harvesting process is about 2.40.E-06 DALYs. The second damage is farming which related to fertilizer used in the maize field. Total human health damage of existing maize cultivation and heat energy production from maize cob under ALCA approach is about 4.02.E-06 DALYs. In contrast with the ALCA results, CLCA result showed the damage under the situation to avoided biomass burning with fully utilized condition of maize cob (by-product), substituted by rice straw and palm kernel shell can reduced the environmental impact and the amount of them quite less than ALCA scenario. Figure 3 presented the environmental impacts (endpoint) of biomass energy production from maize cob based on the attributional LCA approach and the consequential LCA approach.

According to Alternative Energy Development Plan: (AEDP: 2015), The goal is to promote the use of biomass to produce renewable energy in the form of heat at approximately 22,100 ktoe at 2036 [21]. This study presented the total of human health damage as target planned at 2036 was shown in Table 2.

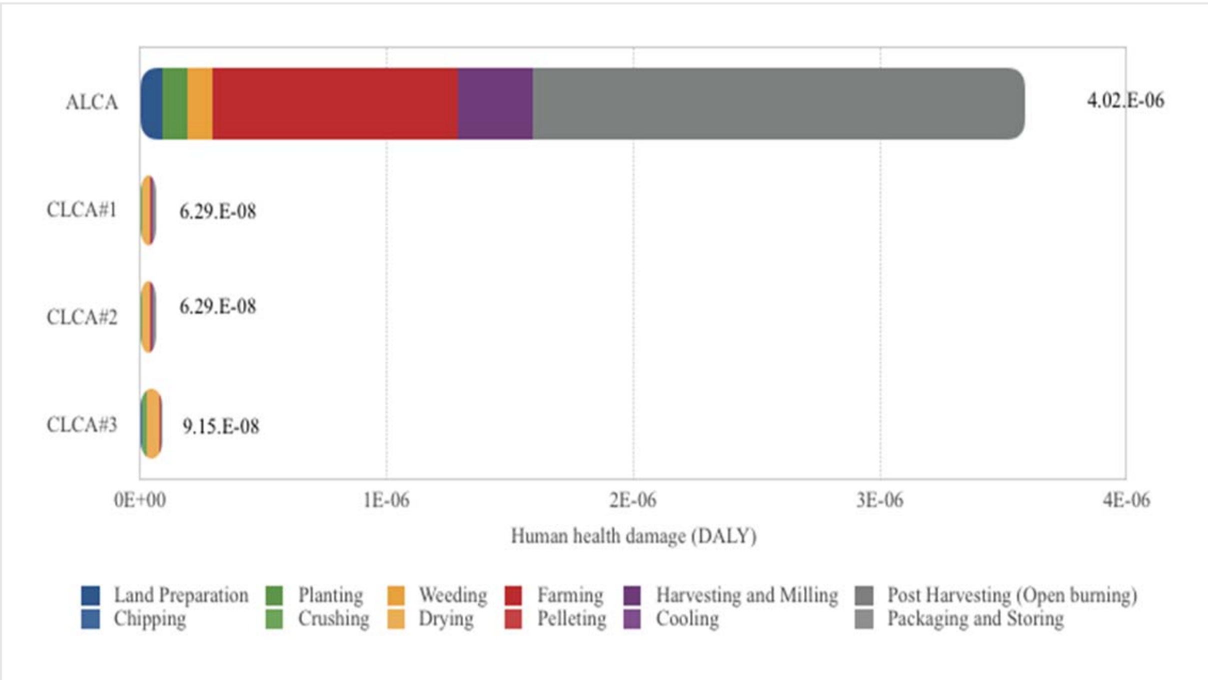

Figure 3 The environmental impacts (endpoint) of biomass energy production from maize cob based on the attributional LCA approach and the consequential LCA approach in term of DALY

Table 2 Total of human health damage as target planned at 2036

Scenario	Human health damage (DALY)
ALCA: Conventional system	3,719,742
CLCA: Scenario 1	
Avoided open burning	58,213
CLCA: Scenario 2	
Rice straw pelletizing	58,213
CLCA: Scenario 3	
Palm kernel shell pelletizing	84,673

Regarding the total results of human health damage as target planned of the use of biomass to produce renewable energy in the form of heat at 2036, this study found the large amount of damage of existing maize cultivation and heat energy production from maize cob under ALCA approach reached to 3,719,742 DALYs. In another case of CLCA, the study found the amount of human health damage of avoided open burning by fully utilized condition of maize cob, substituted by rice straw and palm kernel shell is about 58,213 and 84,673 DALYs, respectively. This results illustrated that there are different ways to meet increased demand for maize cob and that the environmental impact from these different ways vary significantly.

CONCLUSION

The study assessed the environmental performances of biomass energy production from maize cob in Chiang Dao district using an attributional LCA (system allocation) and a consequential LCA (system expansion) approach to present the consequences of important approach in LCA studies. This research present how modelling choices affect the environmental impacts of biomass energy production from maize cob.

Based on an ALCA, the result points out that the significant environmental burdens on human health damage which from biomass burning during maize field. When we considered to expanded the system boundary to substituted by another feedstock under a CLCA approach, we found its can reduced the environmental impact on human health damage significantly.

This study only illustrated the difference of two modelling choices affect the environmental impacts on pilot study. Further analysis will take into consideration on the market responses and social aspect based on the pilot study. The results of this study can also be used to further enhance policy information on biomass management in the agricultural area for maximum efficiency and sustainability biomass utilization in the future.

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