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ENVIRONMENTAL SUSTAINABILITY AND CLIMATE BENEFITS OF GREEN TECHNOLOGY FOR BIOETHANOL PRODUCTION IN THAILAND

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ABSTRACT

Biofuels are often presented as an environmentally friendly alternative to fossil fuels; however, empirical analysis that is widely reported in the literature shows that biofuel production can have negative environmental and social impacts. The potential for these negative impacts can be avoided through careful planning of biofuel feedstock production and processing. This report focuses on how green technologies and practices can be introduced into ethanol production to reduce its environmental footprint. The research site of this study is located in Khon Kaen province in north-eastern Thailand. Emissions from ethanol production were estimated using life cycle greenhouse gas emission analysis. The analysis covered land use change, cultivation of cassava and sugarcane, ethanol processing, and transportation. Farming data from the study sites in 2013 was used to estimate emissions from crop cultivation and the transportation of cassava and sugarcane to the ethanol plants. Emissions from ethanol production processing were estimated from production data from a combined sugar milling and molasses ethanol factory and a cassava flour and ethanol factory. The estimated emissions from sugarcane farming (32 g CO_2eq/MJ ethanol) were much higher than for cassava farming (5 g CO_2eq/MJ ethanol) due to greater application of chemical fertilizer and burning during harvesting. The research estimated that the application of green agricultural technologies for sugarcane farming –non-burning, drainage management in irrigated areas, reduced use of chemical fertilizer, and increased use of green compost – would reduce emissions per year by 17 g CO_2eq/MJ ethanol. The ethanol production from cassava generated high emissions from the burning of coal in the internal boilers of the ethanol production processing plant (56 g CO_2eq/MJ ethanol). Utilisation of the waste to generate electricity and biogas would reduce emissions by 14 -26 g CO_2eq/MJ ethanol per year by reducing dependence on coal and conventional sources of electricity. The research concluded that the green technologies and practices studied could contribute to both lower GHG emissions and better environmental outcomes from biofuel production.

Key words: GHG emissions, climate change mitigation

INTRODUCTION

Biofuel production is widely promoted to enhance energy security and reduce greenhouse gas (GHG) emissions in Thailand. However, biofuel production can have negative local environment and socio-economic impacts. Some studies found that the cultivation of biofuel crops such as cassava and sugarcane required heavy application of fertilizer and pesticide, with negative environmental impacts (Suksiri et al., 2008). Another problem is that the burning of sugarcane leaves before harvesting, which is a common practice, increases carbon dioxide (CO_2) emissions and air pollution (Chomyong and Higano, 2008).

Past and on-going ethanol production in Thailand is associated with land use change. Agricultural areas under rice and other food crop cultivation have been converted to sugarcane and cassava for biofuel production due to the higher returns from the latter, and because the fertility of the soils in some areas is too low to sustain rice cultivation (Pannangpetch et al., 2009; Kawasaki and Herath, 2011). The Government of Thailand has encouraged the use of gasohol, with a 10% blend of bioethanol and 90% gasoline to achieve its target of reducing reliance on crude oil imports. Under Thailand's 15 year Renewable Development Plan (2008-2022), the Government set a target of increasing bioethanol production from 6.2 M litre/day in 2016 to 9.0 M litre/day in 2022), for both reducing fossil fuel dependency and reducing GHG emissions (Department of Alternative Energy Development and Efficiency, 2008). As a follow on from these policies, the following targets were set for the cultivation of energy crops: Sugarcane, 690,000 hectares, with 88,000 hectares (13% of total area target) for biofuel production and the remainder for food; Cassava, 1,184,000 hectares (7% (86,400 hectares) biofuels); Oil palm, 880,000 hectares (up from 480,000 hectares) (30% (264,000 hectares) biofuels) (Ministry of Agriculture and Cooperatives, 2014). These policies led to a rapid increase in bioethanol production, from 0.3 million litres/day in 2006 to 1.3 million litres/day in 2011 (Department of Alternative Energy Development and Efficiency, 2012).

The main areas with the most potential for cassava and sugarcane production are in the northeast of Thailand. These are located in the upland plateaus, where temperature ranges from 19 to 30 °C, with an average annual rainfall of about 1,300 millimetres (Office of Agricultural Economics, 2011). Over 65% of these areas is covered by clayey and poorly drained paleaquults (soils) that are suitable for cassava and sugarcane cultivation (Ekasingh et al., 2007).

Biofuel production in northeast Thailand has involved land use change and is associated with environmental harm because of heavy fertilizer and pesticide use in cultivation. Agricultural areas under rice cultivation have been converted to biofuel feedstocks, specifically sugarcane and cassava. This is associated with the policies mentioned above and the suitability of the soils for these crops.

In Thailand, biofuel crop cultivation has negative externalities, but there are ways to reduce these. For example, making better use of the waste from ethanol plants by employing green technologies would reduce environmental impacts and contribute to the sustainable development of the bioethanol industry (Food and Agriculture Organization, 2012). Total agricultural residues in Thailand in 1997 amounted to about 61 million tons; hence this could be a huge source of materials for producing biogas and green manure (Chaiprasert, 2011). Twenty million tons of bagasse, as residues from sugar mills, or nearly 29% of the total weight of sugarcane, were used to produce steam and electricity for the mills in 2004 (Papong et al., 2004).

One study on biomass utilization found that electricity generation from cane trash could reduce GHG emissions at 288 kg CO_2eq/1000 litres (Silalertruksa and Gheewala, 2009). Another study found that using bagasse in sugar mills to generate electricity could reduce emissions at 500,000 ton CO_2eq per year by substituting for electricity from conventional sources (Siemers, 2010). Another study found that avoiding the burning of cane trash could reduce emissions by over 5,000 ktons CO_2eq (Jenjariyakosoln et al., 2013). Yet another study concluded that the biogas produced from waste water treatment associated with ethanol production could reduce emissions from coal at 734 g CO_2 per FU (Papong and Malakul, 2010).

While the literature suggests that there is potential to introduce green technologies and practices into biofuels production in Thailand, there are also a number of challenges that need to be faced. First, ways need to be found to effectively use all the bagasse from the mills. Second, most farmers still burn sugarcane during harvesting and persuading them to adopt other practices need to be found (Luanmanee and Lertna, 2014). Third, technology options for waste utilization remain quite limited and expensive (Wood, 2006; Bara and Delivand, 2011).

One way forward is through a better understanding of the benefits of introducing green technologies and practices into biofuels production for GHG emissions and environmental impacts. While studies have been conducted on reducing GHG emissions through management of the waste generated in the ethanol production process and avoiding the burning of cane trash during harvesting, these studies did not assess the potential for other green agricultural practices to contribute to GHG emission reductions, because of their limited data. Important questions that need to be addressed regarding the sustainability of biofuels production in Thailand include: How can green technologies and practices contribute to GHG emissions reductions? How effective are green technologies in reducing emissions? What are the challenges of introducing green technologies into bioethanol production?

This study aims to (1) examine the potential of green technologies and practices to reduce GHG emissions by using data from biofuel feedstock growers and ethanol producers in Khon Kaen province, and (2) estimate the amount of emissions reduction associated with green technologies.

METHODOLOGY

Study Sites

Khon Kaen province is located in the central part of northeast Thailand and has an elevation of 100-200 metres above sea level. It comprises 26 districts, with a total area of 10,886 square kilometres, and has approximately 1.76 million inhabitants, 24% of whom are engaged in farming.

Three districts in Khon Kaen were selected for this study: Nam Phong (E16°42′10″ N102°51′17″), Kranuan (E16° 42′ 22″ N103° 4′ 44″) and Mueang Khon Kaen (E16°26′18″ N102°50′20) (Figure 1). Nam Phong and Kranuan are the main fuel crop planting areas, while Mueang Khon Kaen was chosen as an area where conversion from paddy to fuel crops has taken place. There are currently two sugar mills and two ethanol plants using molasses and cassava in Khon Kaen.

The total rainfed area in Khon Kaen was nearly 82% or 539,913 hectares of the total farmland in 2010 (Khon Kaen Meteorological Station, 2012). The fertility of 65% of the total farming area is naturally low. Rice and vegetables are usually planted in lowland areas, while cassava and sugarcane occupy the upland areas. Changes in market prices have played an important role in determining the kind of upland crops. Rice is grown for household consumption, but cash crops (e.g. cassava and sugarcane) seem to be preferred by farmers for generating quick financial returns.

Because water supply has become increasingly scarce and because a constraint in labor supply is being experienced during the peak season, some farmers have shown interest in converting rice lands for sugarcane and cassava cultivation (Khon Kaen Provincial Statistical Office, 2012). The area under rice cultivation decreased from 413,000 hectares to 393,000 hectares within a 15 year period – 1993-2009.

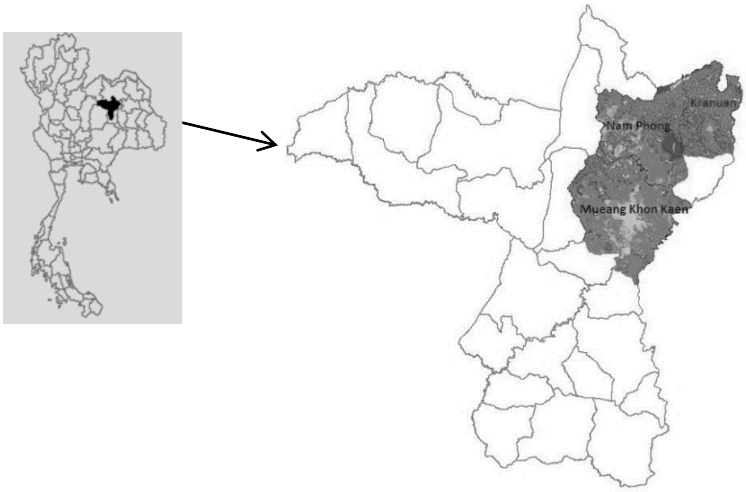


Fig. 1. Location of study sites in Khon Kaen province, Thailand

Life Cycle Greenhouse Gas Emissions Calculation

The GHG emissions of ethanol production were calculated applying the life cycle assessment (LCA) methodology that is widely used by the International Sustainability and Carbon Certification (International Sustainability Carbon Certification, 2010). GHG removals and emissions during cultivation and harvesting of feedstocks, transportation of raw materials to the mills, ethanol processing and transportation of the ethanol to the point of sale are incorporated in the calculations. The emissions sources are: emissions from the extraction or cultivation of input materials (E_{ec}), emissions from carbon stock changes caused by land-use change and management (E_l), emissions from the process for producing the biofuel (E_p), emissions from transport and distribution (E_{td}), and emissions from the use of biofuel (E_u). The emissions credits are: emissions saving from soil carbon accumulation via improvement of agricultural practices by adopting green agricultural technologies and management of field drainage, e.g. through the building of levees and drains (E_{sca}), and emission savings from the biofuel production system, such as savings associated with organic fertilizers from waste utilization, biogas recovery and excess electricity from co-generation (E_{crd}). The net GHG emissions formula (mega joule-MJ) is thus:

$$E = E_{ec} + E_l + E_p + E_{td} + E_u - E_{sca} - E_{crd} \quad (1)$$

Various materials and inputs including diesel, fertilizers, pesticides and electricity were used in the feedstock cultivation. There were no differences in types of input used for cassava farming and sugarcane farming at the study sites. The emissions from input materials (E_{ec}) were estimated from the amount of materials and inputs used in farming and their emission factors. Nitrous oxide (N_2O) emissions from the application of nitrogen fertilizer to the soil and soil disturbance are assessed. The emissions from crop residues and biomass waste were estimated from the volume of biomass burnt multiplied by the combustion and emission factors. The amount of crop residues available for burning was estimated from average yield multiplied by residue to product ratios (RPR) (Department of Energy Development and Promotion, 2012).

The equation used in the estimation of emissions from extraction of input materials (E_{ec}) is:

$$E_{ec} = \sum_i (M_i \times EF_i) \quad (2)$$

Where: M_i is amount of materials and inputs used (kg/ha or litre/ha); EF_i is emission factors of inputs used (kg CO_2-eq/ha); and i is materials and inputs type.

Land-use change in terms of replacing one crop type with another, specifically rice to cassava and rice to sugarcane, was found in the study areas. The increase in biomass stocks of the annual crops in a single year was assumed equal to biomass losses from harvest and mortality in the same year, and thus there was no net accumulation of biomass carbon stocks. With this assumption, the emissions from carbon stock changes caused by land-use change and management (E_l) was estimated from soil organic carbon stock (SOC) of farming practices and soil conditions on site before and after biofuel crop production. To make this comparison, total emissions were divided by the IPCC's default value for 20 years. Emissions from carbon stock changes caused by land-use change and management (E_l) were estimated as follows:

$$E_l = \frac{CS_R - CS_A}{\text{Crop yield x 20}} \text{x}3.664\text{xBCF} \quad (3)$$

$$= \frac{C_{B,R} + SOC_R - C_{B,A} - SOC_A}{\text{Crop yield} \times 20} \times 3.664 \times BCF$$

$$= \frac{SOC_R - SOC_A}{\text{Crop yield} \times 20} \times 3.664 \times BCF$$

$$SOC = SOC_{Ref} \text{ x } F_{LU} \text{ x } F_{MG} \text{ x } F_l$$

Where: CS_R means total carbon stocks before conversion of other crops to biofuel crop (ton C/ha); $C_{B,R}$ is biomass and SOC_R is soil organic carbon before conversion of other crops to biofuel crop; CS_A is total carbon stocks after conversion of other crops to biofuel crop (ton C/ha); $C_{B,A}$ is biomass and SOC_A is soil organic carbon after conversion of other crops to biofuel crop; SOC_{Ref} is the reference value of SOC based on the IPCC's default values; F_{LU} is stock change factor for the land use system; F_{MG} is stock change factor for the land management; F_l is stock change factor for input of organic matter; constant "3.664" is the conversion factor for mass carbon to mass carbon dioxide (CO_2), and "BCF" means the amount of feedstocks required to produce bioethanol.

The emissions from bioethanol production processing (E_p) were measured from all inputs used in the processing stages of ethanol production, and the processing of waste to generate electricity, steam and biogas, etc. Emissions from molasses-based ethanol production were calculated from the emissions of the sugar mills and ethanol plants.

The processing of molasses-based ethanol began with the sugarcane being loaded into the crushing process in the sugar mills to extract sugarcane juice. The sugarcane juices were clarified to remove impurities and concentrated into syrup, seed with raw sugar crystals in a vacuum pan, and boiled until sugar crystals had formed and grown. The crystals were separated from the syrup by a centrifugal process to extract the raw sugar products and molasses. The molasses was used in the ethanol production. The main processes of the ethanol production processing were fermentation, distillation and dehydration. The ethanol product from molasses was 99.5% pure ethanol.

The main processes of the cassava-based ethanol processing were milling, mixing and liquefaction, fermentation and distillation and molecular sieve dehydration. The emissions of cassava ethanol production were estimated from the combustion of fuels in the industrial boilers for steam production, and the electric power used for drying cassava chips and ethanol. The cassava ethanol was purified to 99.5%.

The emissions from bioethanol production processing (E_p) were calculated from:

$$E_p = \sum_j (M_j \times EF_j) \quad (4)$$

Where: M_j is amount of materials used in the bioethanol production processing (litre or kg or kWh per year); EF_j is emission factors of materials used (kg CO_2-eq /MJ biofuel); and j is material type.

The emissions from the transportation of feedstock (E_{td}) were estimated from the amount of feedstock required for producing bioethanol, emission factors for transportation with full load and empty load, and transportation distance with/without load. The formula used to estimate emissions from the transportation of feedstock is:

$$E_{td} = (M_{full\ load} \times Distance_{full\ load} \times EF_{full\ load}) + (M_{empty\ load} \times Distance_{empty\ load} \times EF_{empty\ load}) \quad (5)$$

Where: $M_{full\ load}$ is amount of feedstock with full load (ton feedstock/MJ bioethanol); $Distance_{full\ load}$ is distance with full load (km); $EF_{full\ load}$ is emission factor for transportation with full load (kg CO_2-eq/ton-km); $M_{empty\ load}$ is amount of feedstock with empty load (ton feedstock/MJ bioethanol); $Distance_{empty\ load}$ is transportation distance with empty load (km); and $EF_{empty\ load}$ is emission factor for transportation with empty load (kg CO_2-eq/ton-km).

The emissions from the use of biofuel (E_u) was estimated from the amount of biofuel used, non-CO_2 GHG emission factor from the use of biofuel, and global warming potential factors for non-CO_2 GHGs. It is assumed that CO_2 emissions from the use of bioethanol was balanced by the CO_2 fixation during crop growth and set to zero. The formula is:

$$E_u = (M_{biofuel} \times EF_{Non\text{-}CO2} \times GWP) \quad (6)$$

Where: $M_{biofuel}$is amount of biofuel used (unit per MJ of biofuel); $EF_{Non\text{-}CO2}$ is Non-CO_2 GHG emission factor from biofuel used (kg CH_4/MJ biofuel and kg N_2O/MJ biofuel); and GWP is global warming potential factors for the non-CO_2 GHG (kg CO_2-eq/kg)

The emissions reduction from the use of green technology can be considered to be the results of adopting green agricultural technology and waste utilization, as presented in Table 1. Emission reduction from adopting green agricultural technology (E_{sca}) was estimated from reduction in the amount of synthetic chemical inputs used, an increase in the use of green compost and manure, drainage management of irrigated land, and avoided burning during harvest:

$$E_{sca} = \frac{(M_{substituted\ fuel} \times EF_{substituted\ fuel}) \times BCF}{Crop\ yield} \quad (7)$$

Where: $M_{substituted\ fuel}$ is the amount of fossil fuel derived material inputs (e.g. urea) that would be substituted by green manure or compost during the biofuel crop production (kg or MJ/ha); $EF_{substituted\ fuel}$ is emission factor of the fuels or materials that would be replaced by the by-product generated from bioethanol production system (kg CO_2-eq/kg); crop yield means annual yield of biofuel crops (ton/ha); and BCF is amount of feedstocks required to produce bioethanol (kg feedstock/MJ bioethanol).

The emission reduction from bioethanol production processing (E_{crd}) was assessed from waste utilization including producing green compost from crop residues, producing steam and electricity from bagasse as waste of ethanol plants, and producing biogas from the upflow anaerobic sludge blanket (UASB) wastewater treatment system. The green compost was distributed from the sugar mill to member sugarcane growers as organic fertilizer. The formula for emission reduction from bioethanol production processing is:

$$E_{crd} = \frac{(M_{Exc-elec} x EF_{substituted\ elec}) + (M_{substituted\ fuel/materials} x EF_{substituted\ fuel/materials})}{Yield} \quad (8)$$

Where: $M_{Exc\text{-}elec}$ is amount of the excess electricity from the bioethanol production system. It will be sold to the grid-electricity system in Thailand (kWh/year); $M_{substituted\ fuel/materials}$ is amount of fuels or materials that can be substituted by the by-products generated from the bioethanol production processes (kg or MJ/year); $EF_{substituted\ elec}$ is emission factor of the grid-electricity that can be substituted by the excess electricity of bioethanol production system (kg CO_2-eq/kWh); $EF_{substituted\ fuel/materials}$ is emission factor of the fuels or materials that can be replaced by the by-product generated from bioethanol production system (kg CO_2-eq/MJ bioethanol); and yield is annual yield of biofuel crops (MJ bioethanol).

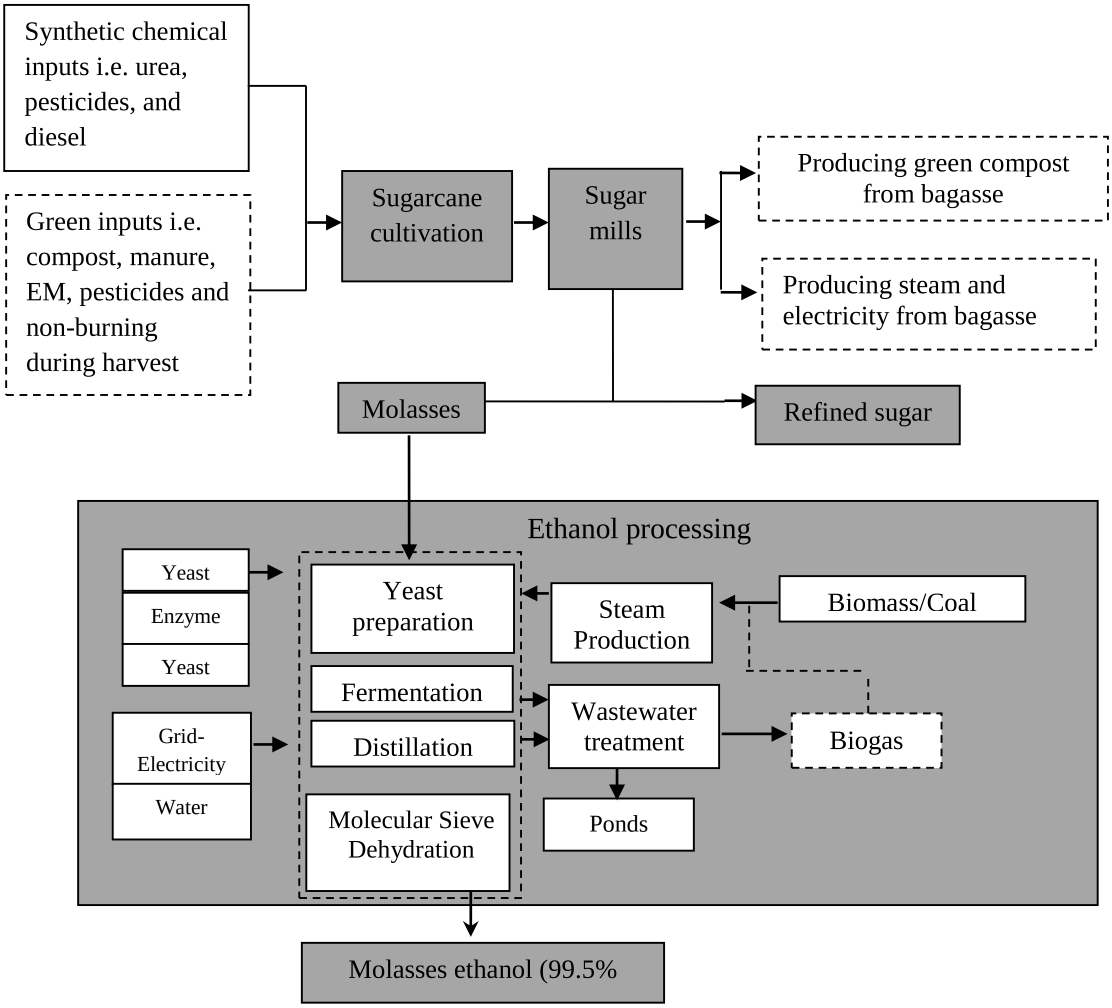
Table 1. Green technology for the ethanol production assessed in this study

Green Technology	
1) Green agricultural technology	
1.1 Using green compost from crop residues and manure from raising cows and chickens	/
1.2 Simple practices to reduce use of chemical pesticides	/
1.3 Reduction of open field burning	/
1.4 Management of field drainage to reduce N_2O emissions	/
2) Waste utilization	
2.1 Producing green compost from field crop residues and waste from biofuel production processing such as bagasse	/
2.2 Producing steam and electricity from bagasse	/
2.3 Producing biogas from treatment of wastewater by the upflow anaerobic sludge blanket (UASB) system of the ethanol production processing from cassava	/

The green technologies for ethanol production from molasses and cassava are shown in Figures 2 and 3.

Data Sources

The data for biofuel crop cultivation and transportation were obtained from interviews with 91 biofuel crop growers in the study sites in Khon Kaen province in 2013. The data for the ethanol processing are production data from the sugar mills and bioethanol plants in Khon Kaen province. The formulas and emission factors used are from the published literature and statistical records (Intergovernmental Panel on Climate Change, 2006; Ecoinvent Centre, 2010; International Sustainability Carbon Certification, 2010; Office of Agricultural Economics, 2012; Thailand Greenhouse Gas Management Organization, 2013).



Note: [dashed box] are the elements of green technology

EM is the effective microorganisms

Fig. 2. Green technology in molasses-based ethanol production

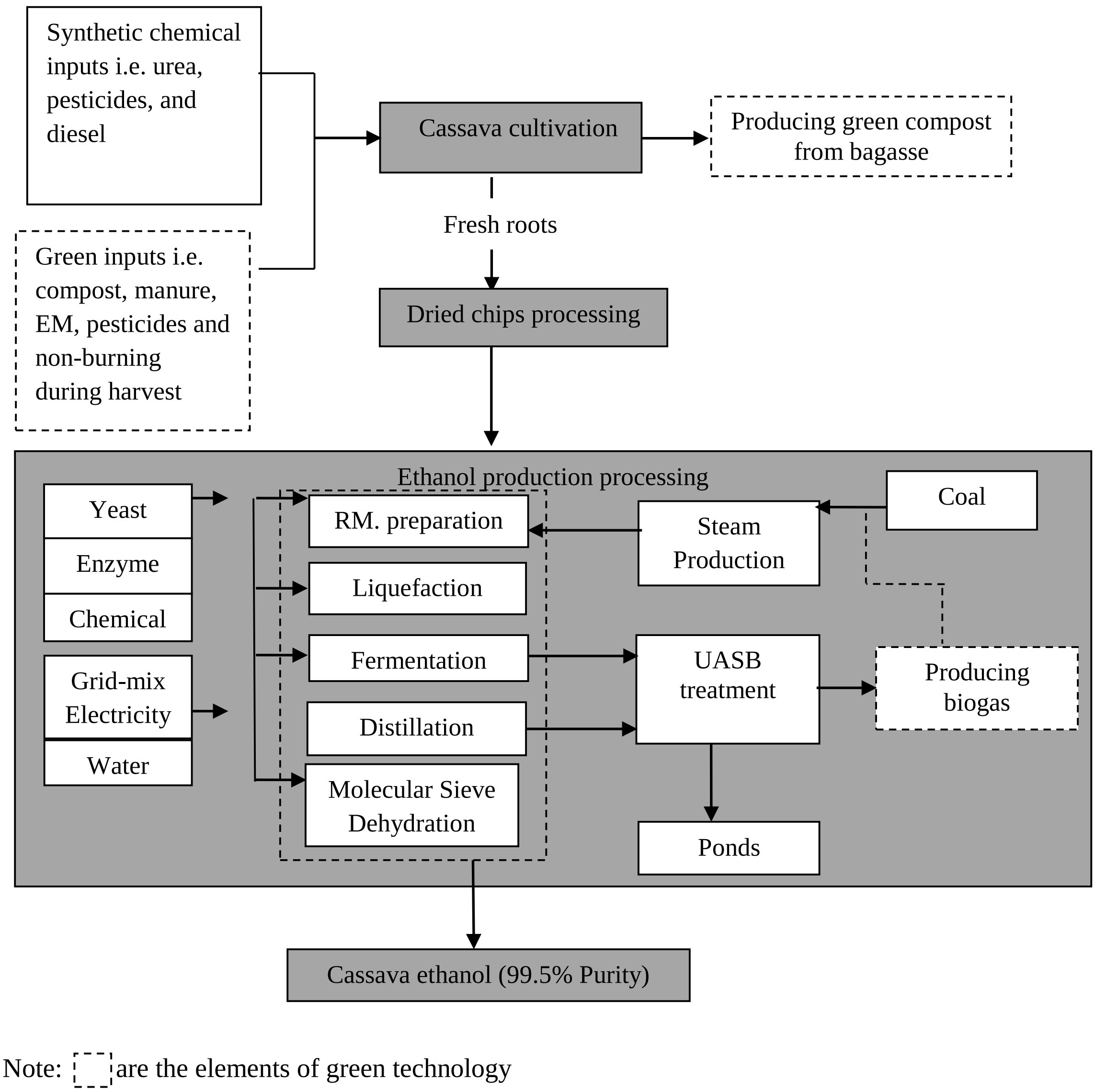


Fig. 3. Green technology in cassava-based ethanol production

RESULTS AND DISCUSSION

Life Cycle Greenhouse Gas Emissions Assessment of Ethanol Production

The emissions from sugarcane ethanol production are estimated from land use change, sugarcane cultivation and harvesting, sugar milling, molasses ethanol processing, and transportation of fresh sugarcane, molasses and ethanol. Table 2 shows the average yield of sugarcane and input values of molasses ethanol production. The average yield of sugarcane was 79 ton per hectare. Chemical fertilizers and herbicides were the major inputs for sugarcane cultivation.

At the study sites most farmers were small-scale sugarcane and cassava growers, meaning they likely used small tractors for land preparation and planting. For harvesting cassava, the farmers preferred to dig by hand, as the use of machines caused roots to break. For sugarcane harvesting, the farmers applied two approaches. First, some farmers cut the cane manually and burnt the leaves and trash before harvesting. Half of the sugarcane supplied to sugar mills in Khon Kaen province (Office of Cane and Sugar Board, 2007) was burnt before harvesting. Second, for large-scale sugarcane cultivation, farmers used harvest tractors to cut the cane. This approach separated out the sugarcane leaves. One harvest tractor could harvest 1 ton of sugarcane in 1.5-2.5 hours. The use of harvest tractors reduced emissions from the burning of the sugarcane leaves, but produced emissions from diesel combustion. Generally, at the research sites sugarcane was delivered to the sugar mills by 16 ton trucks. The distance from the study sites to sugar mills was nearly 30 km.

Land use changes associated with the production of biofuel feedstocks were observed in the research area and from historical land use data (Land Development Department, 2012). A comparison of land use and land cover of the years 2000 and 2012 in the three study districts shows that the rice cultivation areas in Mueang Khon Kaen district increased from 9,396 hectares in 2000 to 29,334 hectares in 2012, and that 5,190 hectares of rice areas were converted to sugarcane and cassava in Nam Phong district and 3,742 hectares in Kranuan district over the same period. Average soil carbon stock of land before conversion to biofuel crops was 43 ton C per hectare, and after conversion was 22 ton C per hectare.

According to data from a sugar mill in Khon Kaen province, 1 ton of sugarcane produced 109 kg of sugar and 45 kg of molasses. The sugar milling required two main inputs – lime and NaOH. The processing of molasses ethanol required four main inputs – molasses, sulfuric acid, urea and electricity. The molasses ethanol plants were attached to the sugar milling plants and the molasses were transferred from sugar mills to ethanol plants by pipelines.

Table 2. Average inputs used for the ethanol production from sugarcane in Khon Kaen, 2013

Life cycle stage	Inputs	Unit	Range	Mean
1. Cultivation and harvesting				
	Main inputs:			
	• Diesel use	litre/ha	12.1-213.5	53
	• N-fertilizer	kg/ha	26-203.4	89
	• P-fertilizer	kg/ha	26-204	90
	• K-fertilizer	kg/ha	23.4-582	229
	• Urea	kg/ha	0-412.2	71
	• Herbicides (Paraquat)	kg/ha	0-525.4	84
	Average yield of sugarcane	ton/ha	78.7-79.4	79
2.Transportation				
	• 10 wheel truck, 16 ton load	ton sugarcane/L ethanol		0.023
	• Distance from farms to sugar mills and ethanol plants	km	4-69	30
3. Sugar milling				
	Main inputs:			
	• Lime	kg/L ethanol		0.038
	• NaOH	kg/L ethanol		0.01
	Main outputs:	kg sugar/ton cane		109
	• Sugar products	kg molasses/ton cane		45

Life cycle stage	Inputs	Unit	Range	Mean
	• Molasses • Excess electricity	kWh/ton cane		37
4. Ethanol production processing				
	Main inputs:			
	• Sugarcane	kg/L ethanol		23.3
	• Sugarcane molasses	kg/L ethanol		4.6
	• Sulfuric acid	kg/L ethanol		0.024
	• Grid-electricity	kWh/L ethanol		0.223
	• Urea	kg/L ethanol		0.003
	• Steam (internal supply by sugar mill)	kg/L ethanol		3
	Main output: 1 litre of bioethanol			

Note: The energy density of bioethanol is about 21.2 mega joules (MJ) per litre
Source: Field data, 2013.

Fresh cassava was the main raw material for the cassava ethanol production. Dry cassava chips were used when there was a shortage of fresh cassava. The average yield of cassava was about 30 ton per hectare (Table 3). The production of 1 litre of cassava ethanol required 6.1 kg of fresh cassava. The use of chemical fertilizers and chemical pesticides were greatly lower in cassava farms than inputs values in sugarcane farms. The main inputs for the cassava ethanol processing were fossil fuel, electricity and steam. The steam used in the ethanol processing was produced in the internal boilers by burning coal. The electricity bought from the national grid system used about 0.31 kWh for 1 litre of ethanol.

Table 3. Average inputs used for the ethanol production from cassava in Khon Kaen, 2013

Life cycle stage	Inputs/outputs	Unit	Range	Mean
1. Cultivation and harvesting				
	Main inputs:			
	Diesel use	litre/ha	0.4-10.6	3.1
	N-fertilizer	kg/ha	23.4-188.5	50
	P-fertilizer	kg/ha	23.4-188.5	50
	K-fertilizer	kg/ha	23.4-266.1	87.5
	Urea	kg/ha	0-208.3	28.8
	Herbicides (paraquat)	kg/ha	0-5	0.6
Average yields of cassava		ton/ha	15.6-45.8	30
2.Transportation				
	• 4 wheel truck, 7 ton load	ton cassava/ L ethanol	10-52	0.0061 25
	• Distance from farm to ethanol plant	km		
3. Ethanol production processing				
	Main inputs:			
	• Cassava	kg/L ethanol		6.1
	• Coal	kg/L ethanol		0.33
	• Grid-electricity	kWh/L ethanol		0.31
	• Water	L/L ethanol		16.02
	Main output: 1 litre of bioethanol			

Source: Field data, 2013

Emissions Reductions from Green Technology

Based on data obtained from interviews with farmers and the ethanol factory in Khon Kaen province, the emissions of ethanol production consisted of five factors: conventional fuel crop production, carbon stock changes caused by conversion of rice land to fuel crops, feedstock processing and biofuel production, transportation of feedstock, and use of bioethanol. It is assumed that there was limited technology for waste utilization.

An example of how the life cycle GHG emissions of molasses ethanol production were calculated is:

$E = E_{ec} + E_l + E_p + E_{td} + E_u$

(1) $E_{ec} = EM_{fertilizers} + EM_{diesel} + EM_{paraquat} + EM_{field\ burning} + EM_{N2O\ of\ land\ management} + EM_{CO2\ of\ urea\ application}$

$EM_{fertilizers} = (M_{N\ fert} \times EF_{N\ fert}) + (M_{P\ fert} \times EF_{P\ fert}) + (M_{K\ fert} \times EF_{K\ fert}) + (M_{urea} \times EF_{urea})$
= (88.75x2.6) + (90x0.252) + (228.75x0.16) + (70.63x5.53)
= 681 kg CO_2eq/ha
= 681/79 = 8.57 kg CO_2eq/ ton sugarcane
= (8.57 x 23.3)/1,000 = 0.2 kg CO_2eq/L ethanol

$EM_{diesel} = (M_{diesel} \times EF_{diesel})$
= (53.13x0.33)/79 = 0.22kg CO_2eq/ton sugarcane
= (0.22 x 23.3)/1,000 = 0.0051 kg CO_2eq/L ethanol

$EM_{paraquat} = (M_{paraquat} \times EF_{paraquat})$
= (84.38x3.23)/79 = 3.43kg CO_2eq/ton sugarcane
= (3.43 x 23.3)/1,000 = 0.08 kg CO_2eq/L ethanol

$EM_{field\ burning} = M_{field\ burning} \times$ confusion factor $\times (EF_{N2O} \times GWP_{N2O} + EF_{CH4} \times GWP_{CH4})$
= 19.84 x 0.5x (0.00007x298+0.0027x25) x 1,000 = 876.70 kg CO_2eq/ha
= 876.70/79 = 11.05 kg CO_2eq/ton sugarcane
= (11.05 x 23.3)/1,000 = 0.26 kg CO_2eq/L ethanol

$EM_{N2O\ of\ land\ management} = (F_{ON} + F_{SN}) \times GWP_{N2O} \times EF_{N2O-N}$
= (0+88.75) x 298x0.0157 = 416 kg CO_2eq/ha
= 416/79 = 5.24 kg CO_2eq/ton sugarcane
= (5.24 x 23.3)/1,000 = 0.12 kg CO_2eq/L ethanol

$EM_{CO2\ of\ urea\ application} = (M_{urea} \times EF_{CO2urea})$
= 70.625 x 0.2 = 14.13 kg CO_2eq/ha
= 14.13/79 = 0.18 kg CO_2eq/ton sugarcane
= (0.18 x 23.3)/1,000 = 0.004 kg CO_2eq/L ethanol

Therefore,

E_{ec} = 0.2 + 0.0051+ 0.08+ 0.26+0.12+0.004 = 0.67 kg CO_2eq/L ethanol
= 668.42 g CO_2eq/L ethanol
= 668.42 /21.2 = 31.53 g CO_2eq/MJ ethanol

(2) $E_l = \frac{CS_R - CS_A}{\text{Crop yield x 20}} x3.664xBCF = \frac{C_{B,R} + SOC_R - C_{B,A} - SOC_A}{\text{Crop yield} \times 20} \times 3.664 \times BCF = \frac{SOC_R - SOC_A}{\text{Crop yield} \times 20} \times 3.664 \times BCF$

SOC rice field = $SOC_{Reference} \times F_{LU} \times F_{MG} \times F_I$
= 39 x 1.1 x 1.0 x 1.0
= 42.90

SOC sugarcane = $SOC_{Current} \times F_{LU} \times F_{MG} \times F_I$
= 39 x 0.48 x 1.15 x 1.0
= 21.528

$$E_l = \frac{42.90-21.53}{79\times20}\times3.664\times1,000$$

= 49.36 kg CO_2eq/ ton sugarcane
= (49.36 x 23.3)/1,000 = 1.15 kg CO_2eq/L ethanol
= 1,150 g CO_2eq/L ethanol
= 1,150 / 21.2 = 54.25 g CO_2eq/MJ ethanol

(3) $E_p = \sum_j (M_j \times EF_j)$

EM $_{sugar\ milling}$ = $(M_{lime} x EF_{lime}) + (M_{NaOH} x EF_{NaOH})$
= (0.038 x 1.0154) + (0.01 x 1.1148)
= 0.0497 kg CO_2eq/L ethanol

EM $_{ethanol\ processing}$ = $(M_{sulfuric} x EF_{sulfuric}) + (M_{urea} x EF_{urea}) + (M_{electricity} x EF_{electricity})$
= (0.024 x 0.1219) + (0.003 x 3.2826) + (0.223 x 0.61)
= 0.1488 kg CO_2eq/L ethanol

E_p = EM $_{sugar\ milling}$ +EM $_{ethanol\ processing}$
= (0.0497 + 0.1488) x 1,000 = 198.54 g CO_2eq/L ethanol
= 198.54 / 21.2 = 9.36 g CO_2eq/MJ ethanol

(4) $E_{td} = E_{full\ load} + E_{empty\ load}$
= $(M_{full\ load}$ x $Distance_{full\ load}$ x $EF_{full\ load})$ + $(M_{empty\ load}$ x $Distance_{empty\ load}$ x $EF_{empty\ load})$
= (0.0233 x 30 x 0.0451) + (0.0233 x 30 x 0.0357)
= 0.05647 kg CO_2eq/L ethanol
= 56.47 g CO_2eq/L ethanol
= 56.47 / 21.2 = 2.66 g CO_2eq/MJ ethanol

(5) $E_u = (M_{biofuel} \times EF_{Non-CO2} \times GWP)$
= $(M_{biofuel}$ x EF_{CH4} x $GWP_{CH4})$
= (1 x 0.000018 x 25) = 0.00045 kg CO_2eq/L ethanol
= 0.00045x21.2x1,000 = 9.54 g CO_2eq/L ethanol
= 0.00045x1,000 = 0.45 g CO_2eq/MJ ethanol

The net GHG emissions of molasses ethanol production (as shown in Table 4) was calculated from (1) +(2)+(3)+(4)+(5) = 31.53 +54.25 +9.36+ 2.66+0.45 = 98.26 g CO_2eq/MJ ethanol.

The life cycle GHG emissions of ethanol production from molasses and cassava are shown in Table 4. The emissions of molasses ethanol production (98 g CO_2eq/MJ ethanol) was not so different to that of cassava ethanol production (100 g CO_2eq/MJ ethanol). The large amount of chemical inputs and burning during harvesting caused high emissions from sugarcane cultivation (32 g CO_2eq/MJ ethanol). In the cassava ethanol production, the highest source of emissions was the cassava ethanol processing (56 g CO_2eq/MJ ethanol) due to coal combustion in the internal boilers. These findings indicate that the GHG emissions of ethanol production from sugarcane and cassava could be reduced by introducing green agricultural technology and waste utilization.

Table 4. Net GHG emissions per year of ethanol production from molasses and cassava in 2013

Type of emissions	**Mean (g CO_2 eq/MJ ethanol)**	
	Molasses	**Cassava**
E_{ec}: Extraction or cultivation of raw materials	31.53	5.36
E_l: Carbon stock changes caused by conversion of rice land to feedstock crops	54.25	37.58
E_p: Feedstock processing and biofuel production	9.36	55.53
E_{td}: Transportation of feedstocks	2.66	1.33
E_u: Use of bioethanol	0.45	0.45
Net GHG emissions	98.26	100.25

The emissions reductions from green agricultural technology were evaluated from the amount of chemical inputs reduced by increasing the amount of organic fertilizers used in the study sites in Khon Kaen province. There were five farmers in the study sites producing green compost from crop residues in their farms. After harvest, crop residues were stored, chopped, and ploughed in farms. Before planting cassava or sugarcane, cowpea was planted and ploughed after 50 days to increase nitrogen fixation and improve soil structure. Some farmers in irrigated areas applied drainage management in their farms during the rainy season. Drainage practices reduced N_2O emissions by nearly 0.33 kg N_2O/ha.

The amounts of farm residues in the study sites were nearly 23 tons per ha of top and leaves on the sugarcane farms, and 3 tons per ha of stalk on the cassava farms. Open field burning emits greenhouse gas emissions as CO_2, N_2O and methane (CH_4). In this study, emissions from field burning were estimated using the amount of farm residues available for combustion (M_{FB}), the combustion factor (C_f), N_2O and CH_4 emissions factors for field burning (EF), and global warming potential (GWP). The N_2O and CH_4 equivalence factors for 100 years were used for this assessment. The burning of weeds and crop residues in cassava fields in the study sites was rare, so in this case the emissions reduction from non-burning was assumed to be zero. Most farmers burned sugarcane before harvest due to labor constraints with the high wage rate. Recently, some farmers had avoided burning because the price of sugarcane from non-burning farming was 50-70 THB per ton higher than from burning farming due to the Government and Thai Sugar Cooperation promotion of non-burning.

The sugar mills were encouraged by the Government of Thailand to produce electricity from bagasse. However, the number of sugar mills that generated electricity was small due to the high costs of electricity generation. One small sugar mill in the study sites produced about 30 megawatts of electricity and 450,000 tons of steam per year. The biomass residues of the ethanol processing were used to produce about 6,000 tons of organic fertilizer per year. Biogas was produced from the treatment of wastewater. The sugar mill distributed organic fertilizers with lower prices to member sugarcane growers. The emissions reductions from excess electricity, steam, organic fertilizer and biogas as by-product of the ethanol production were included in net emission calculation.

The average amount of emissions reduced by applying green technology in ethanol production in Khon Kaen province in 2013 was 43 g CO_2eq/MJ ethanol for molasses ethanol production and 16 g CO_2eq/MJ ethanol for cassava ethanol production (Table 5). If there was non-burning of sugarcane in the fields, the emission would be reduced by another 12 g CO_2eq/MJ ethanol. Waste utilization was found to have high potential to reduce emissions for molasses ethanol (26 g CO_2eq/MJ ethanol) and cassava ethanol (14 g CO_2eq/MJ ethanol).

The results demonstrate that green technologies and waste utilization can make an important contribution to GHG emissions reductions. Figures 4 and 5 present the estimated GHG emissions of ethanol production with and without green technology. In these figures, minus (-) means positive impacts of surplus electricity.

Table 5. Net GHG emissions reduction per year of ethanol production applying green technology in 2013

Type of emissions	**Mean (g CO_2eq/MJ ethanol)**	
	Molasses	**Cassava**
E_{sca}: Good agricultural practice		
• Increasing use of green compost and manure	3.35	0.93
• Non-burning during harvest	12.14	none
• Drainage manage in the irrigated areas	1.36	0.94
E_{crd}: Waste utilization		
• Producing organic fertilizers, steam, and electricity from biomass waste and bagasse, and producing biogas from waste water treatment system	26.47	13.92
Total GHG emissions reduction	43.32	15.79

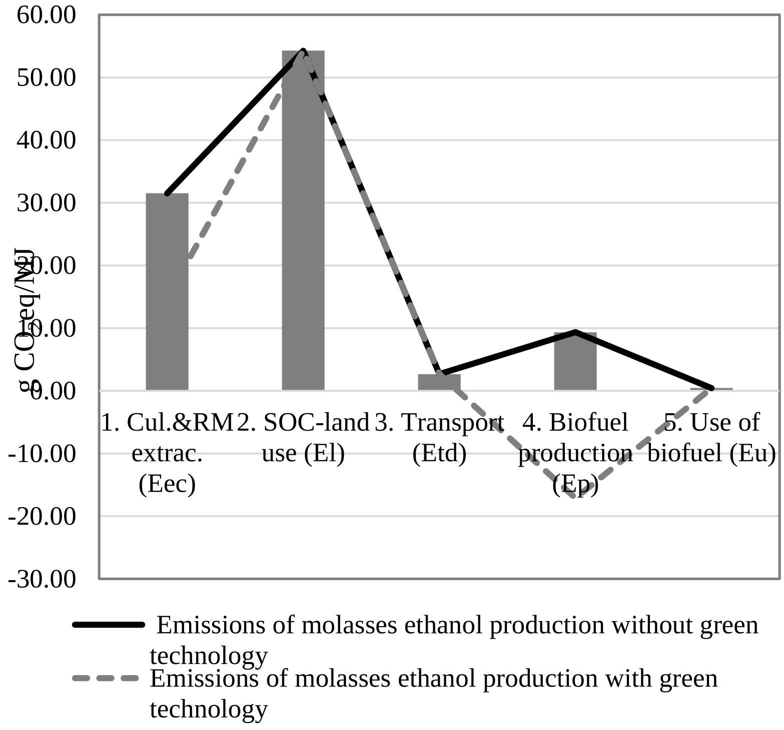


Fig. 4. Life cycle emissions reduction per year of molasses ethanol production applying green technology

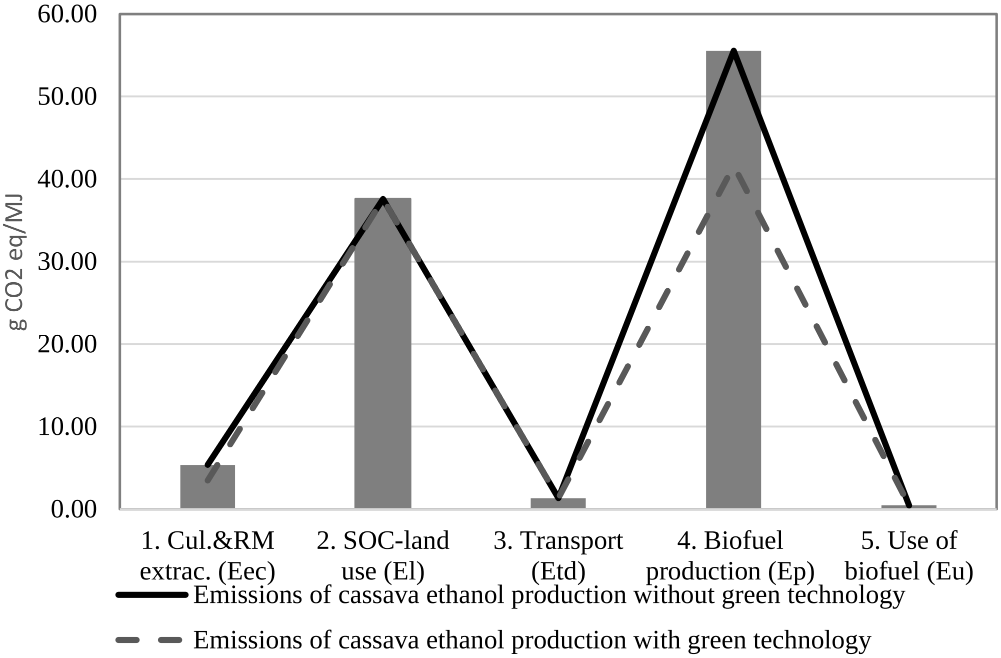


Fig. 5. Life cycle emissions reduction per year of cassava ethanol production applying green technology

CONCLUSIONS AND RECOMMENDATIONS

This study quantified the potential of selected green technologies in the form of green agricultural practices and waste utilization to reduce GHG emissions from ethanol production. The results demonstrate that green technologies and waste utilization can make an important contribution to GHG emissions reductions. Of the various technologies found at the study sites in Khon Kaen province, Thailand, the generation of excess electricity from molasses ethanol processing was found to have the highest emissions mitigation potential. Although sugarcane farming still depended on chemical fertilizers, some sugarcane farmers reduced emissions by increasing the amount of organic fertilizers used (3.35 g CO_2eq/MJ ethanol).

The study uncovered a number of challenges to applying green agricultural technologies in biofuel feedstock cultivation, namely insufficient supplies of organic fertilizers to replace synthetic fertilizers, as well as a shortage of labor and high wage rates during sugarcane harvesting, which makes the burning of agricultural residues attractive from a purely financial perspective. High costs are also a problem for waste utilization in the ethanol processing plants, and this applies to both electricity generated from bagasse and biogas produced from wastewater.

These results suggest a number of policy recommendations that would facilitate the uptake of green technology in ethanol production in Thailand. First, the Government should examine ways to encourage the production of organic fertilizer and biogas from biomass residues. Second, investments in the development of more efficient sugarcane harvest machinery that can harvest large volumes of sugarcane in short periods at lower costs than existing machinery is desirable. Third, the Government / Thai Sugar Cooperation should consider providing guaranteed farm prices for sugarcane produced without the field burning of residues.

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