Life Cycle Impact Modeling of Global Warming on Net Primary Production : A Case Study of Biodiesel in Thailand

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Abstract

Life Cycle Assessment (LCA) is an effective tool for evaluating the potential environmental impact associated with all stages of a product's life cycle. Currently, a number of Life Cycle Impact Assessment (LCIA) methodologies have been developed. These methods are based on an ad hoc approach adopted by different countries and regional conditions, which make the results difficult to compare. In Thailand, the methodological choices and framework to assess environmental impacts in LCA are still under development. Because the actual amount of environmental damage differs depending on environmental variables such as climate and population density, there is a need to develop the LCIA method for use in Thailand. The aim of this research is therefore to develop LCIA method that is suitable for Thailand, within the context of global warming. The results show that the midpoint approach have been similar with any LCIA method, while the endpoint approach considered two factors are for the world and in Thailand. Based on endpoint approach, the net primary productivity (NPP) damage factor the World and Thailand from all 63 greenhouse gas emissions are 8.78×10^5 and 2.72×10^{-2} kg/kg, respectively. Further development will be developed other the effects of global warming on human health and social assets with the sensitivity analysis and other impact categories which the important environmental problems in Thailand.

Key words: Life cycle impact assessment (LCIA)/ LIME/ Life cycle assessment (LCA)/ Net primary productivity (NPP)/ Global warming

1. Introduction

In the present day, there are many environmental problems that affect our World. Some government agencies try to manage these problems by employing various tools to help inform them in the decision-making process. Life Cycle Assessment (LCA) is one such tool that can be used to assess environmental performance. It does so by accounting for all energy and material flows through a product system over its entire life cycle. According to the international standard as set out in the forthcoming ISO 14040,

LCA method generally contains four main phases: (1) Goal & scope definition, (2) Life Cycle Inventory (LCI), (3) Life Cycle Impact Assessment (LCIA) and (4) Interpretation.

In Thailand, there are many LCI databases such as for energy and agriculture. However, there is no common method that can be used to analyze the LCIA phase. Instead foreign methods are often employed for such a purpose. For example, Malakul et al. (2011) and Sampattagul et al. (2011) used different LCA methods for analyzing life-cycle environmental impacts of biodiesel

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production from palm oil. When comparing its Global Warming Potential (GWP), Malakul et al. (2011) used CML baseline 2000, while Sampattagul et al. (2011) used EDIP 2003. Accordingly, their results were vastly different. For example, Malakul et al. (2011) showed the GWP of 1.42 kg CO_2 eq./liter, while Sampattagul et al. (2011) showed that it is 22.45 kg CO_2 eq./liter. This is despite the fact that both methods might not be appropriate for Thailand. Taking this into account, this research aims to develop an LCIA method by adapting the existing models so that it is suitable for Thailand.

Currently, there are many LCIA methods developed for European and American countries. For example, EDIP2003 (Environmental Design of Industrial Products 2003) is developed for Denmark, IMPACT 2002+ for Netherland, LUCAS (LCIA method Used for a Canadian – Specific) for Canada and TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) for United States. There is only one method developed for Asian country, that is, for Japan. This method is called LIME (Life–cycle Impact assessment Method based on Endpoint modeling) and it is limited to a Japanese-language version only. Similar to other Asian countries, Thailand could also develop its own environmental impact model based on the LIME method. Global warming, which is an important environment problem, is one of the impact categories included in the LCIA method, particularly the LIME model. An increase in CO_2 concentration can have an effect on human health, social assets and primary production (Itsubo et al., 2004). This research focused on net primary productivity with priority among various endpoints regarding global warming, because Thailand is located in a tropical region, which high ability of plant production. The carbon cycle is considered a good indicator of NPP plant function (Jiang et al., 1999) and only the LIME method focuses on terrestrial plant function on the primary production.

The objective of this research is to develop a global warming impact on net primary productivity model in Thailand based on the LIME method.

2. LIME model

Life Cycle Assessment (LCA) is a technique conventionally used to assess the environmental performance by accounting for all energy and material flows through a product system over its entire life cycle and a forthcoming international standard in the ISO 14044 series (The European Standard EN ISO 14044, 2006). LCA method generally contains four main phases: (1) Goal & scope definition, (2) Life Cycle Inventory (LCI), (3) Life Cycle Impact Assessment (LCIA) and (4) Interpretation.

In the third phase, LCIA according to ISO 14044 is aimed to evaluate the significance of potential environmental impact on the indicator based on the LCI results (The European Standard EN ISO 14044, 2006). Most of the LCIA methods are based on the European model, but only the LIME (Life–cycle Impact assessment Methodology based on the Endpoint modeling) method is taken from the Asian (Japanese) model. The LIME method follows all the steps according to ISO 14044, as shown in Figure1. First, we need to determine which impact category that should be considered, LIME is capable of considering eleven impact categories, which includes urban air pollution, hazardous chemicals, eutophication, ozone layer depletion, global warming, ecotoxicity, acidification, photochemical oxidant, land use, waste and resource consumption. The inventory is then classified into the related impact categories. During the classification,

several substances are allocated in impact categories that share a common characteristic. This step is thus called characterization. For LCIA, the method described so far should satisfy the goal of LCA. However, for the analysis to be useful for decision making purposes, further steps are needed, including normalization, grouping, weighting and data quality. The indicators obtained from LCIA generally cannot be compared because they are of different magnitudes. By using the normalization step, the indicator results are normalized against the reference value. The normalized indicators do not have a unit and therefore different impact categories can be compared. Once normalized, the indicators are then grouped into relevant impact categories. The model consists of

four groups. These are human health, social assets, primary productivity and biodiversity, with units express in Disability–Adjusted Life Years (DALY), Japanese Yen, Net Primary Productivity (NPP) and Expected Increase in Number of Extinct Species (EINES), respectively. In the weighting step, the indicator results of different impact categories are weighted with the numerical factors based on value choice (The European Standard EN ISO 14044, 2006). LIME method is based on conjoint analysis to provide weighing across the four safeguard subjects. Finally, data quality within an LCA includes not only the data's uncertainty and parameter variability of the LCI and LCIA phases, but also model uncertainty of the LCIA (Bare, 2010).
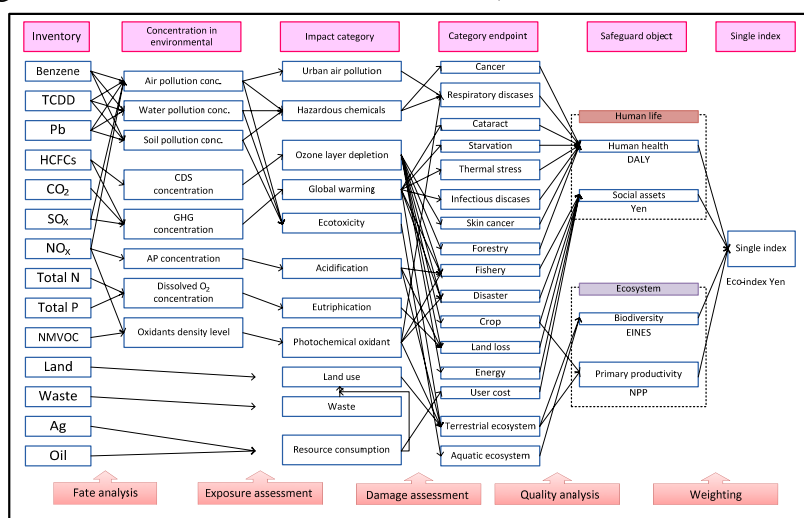

Figure 1 LCIA framework of LIME (Andrae, 2010)

3. Modeling the effects of global warming on net primary productivity

Figure 2 shows the schematic diagram of the damage function of global warming potential (GWP). Global warming is the result of an increase in radiative forcing in the atmosphere for each unit of Global Warming Substance (GWS). This unit could be estimated from (1) greenhouse gas increase, (2) radiative forcing increase, (3) changes in temperature as a result of the relationship

between (1) and (2), and (4) potential damage caused by the interactions of (2) and (3) for each GWS. The system boundary of the damage function includes the damage of global warming on human health, social assets, and primary productivity. At present, only the damage that is related to primary production has been considered. Eq. (1) shows that the damage from global warming can be calculated in four consecutive steps (De Schryver et al., 2009):

$$CF_{x,e} = \frac{dC_x}{dE_x} \cdot \frac{dRF}{dC_x} \cdot \frac{dTEMP}{dRF} \cdot \frac{dIMPACT_{NPP}}{dTEMP} \qquad (1)$$

dE_x: the change in emission of greenhouse gas x (kg/year)
dC_x: the change in air concentration of greenhouse gas x (ppb)
dRF: the change in radiative forcing (W/m^2)
$dTEMP$: the change in global mean temperature (°C)
$dIMPACT_{NPP}$: the marginal change in damage for net primary productivity (°C/kg)

The endpoint damage for primary productivity due to temperature increased. The net primary productivity (NPP) of Thailand has been based on according to Boonpragob and Santisirisomboon, (1996) which covers six types of forest in Thailand including subtropical dry forest, subtropical moist forest, subtropical wet forest, tropical dry forest, tropical moist forest and tropical wet forest. The potential distributions of Thai forests under the future climate change are simulated by UK89 (United Kingdom), UKMO (United Kingdom Meteorological Office), and GISS (Goddard Institute for Space Studies model) models. The UK89, GISS and UKMO were simulated of current and $2 \times CO_2$ climate change scenario. Those models changed in future global mean temperature and precipitation for 0.5×0.5 grid using linear interpolation. The simulation models the different areas of forest types under current and changed climate of each scenario climate models. The NPP related to marginal changes in temperature, as a result of climate change, can be calculated as:

$$\frac{dIMPACT_{NPP}}{dTEMP} \approx \frac{\Delta NPP}{\Delta TEMP} \qquad (2)$$

ΔNPP: the average change in primary productivity due to a temperature change.

For the analysis that covers the whole world, NPP were calculated by Melillo et al. (1993) based on eq. (2), for NPP of planting including polar desert, wet/moist tundra, boreal, coniferous, grassland, temperate forest, savanna, arid shrubland, tropical forest, xeromorphic forest, desert, mediterranean shrubkand, etc.
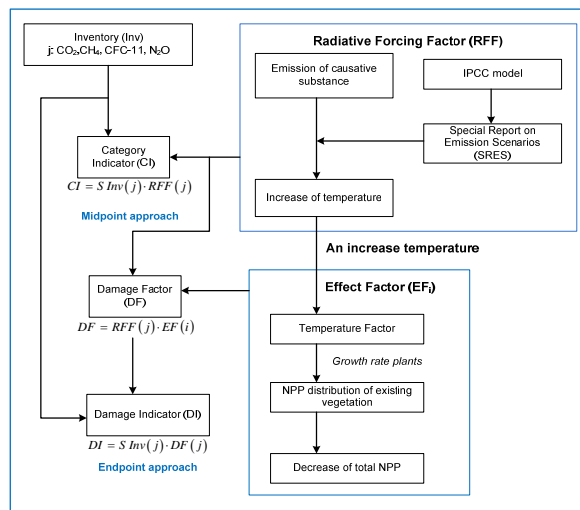

Figure 2 Damage function of global warming for primary production

4. Case study: diesel and biodiesel from palm oil

To test the reliability of the model proposed above, a case study is conducted to estimate the impact of global warming on net primary productivity of biodiesel from palm oil, compared with those of conventional diesel. The system boundary of diesel is crude oil extraction, crude oil refinery and transportation, whereas the system boundary of biodiesel from palm oil is palm oil plantation, palm oil extraction, conversion (transesterification process) and transportation. For diesel transportation, diesel from overseas is assumed to be transported 20,000 km (round trip) to refineries at Rayong (a province in Thailand) using freight ships. For biodiesel, the representative oil palm plantation and crude palm oil production are located in the southern part of Thailand, and is assumed to be located around 20 km (round trip) to the oil palm planting areas (Sampattagul et al., 2011), while biodiesel plantation is assumed to be transported 1,600 km (round trip) to Rayong by using truck with a carrying capacity of 40 tons.

The second step of LCA involves data collection on the input and output of diesel and biodiesel systems, based on life cycle inventory (LCI). These inventory data were gathered from various research studies. For diesel, crude oil extraction and refinery stage were gathered from eco-invent database. Oil palm plantation, extraction and conversion stage used inventory data based on Thai LCI database and publicly available research studies (Malakul et al., 2011; Sampattagul et al., 2011; Papong et al., 2010; Pleanjai and Gheewala, 2009). Crude oil transport was based on freight ship with fuel oil consumption rate of 1.86 kg/km (Eco-invent, 2012). For domestic transport, a 40-ton truck use diesel oil based on consumption rate of 1.82 km/liter (Sampattagul et al., 2009). Mass allocation was applied in the extraction stage between crude palm oil and palm kernels, and in the conversion process allocated between biodiesel and glycerin. The main input–output data is shown in Figure 3. This data is then used to analyze the environmental impact based on the model employed in this research. Finally, suggestions are made for future improvement of the model.
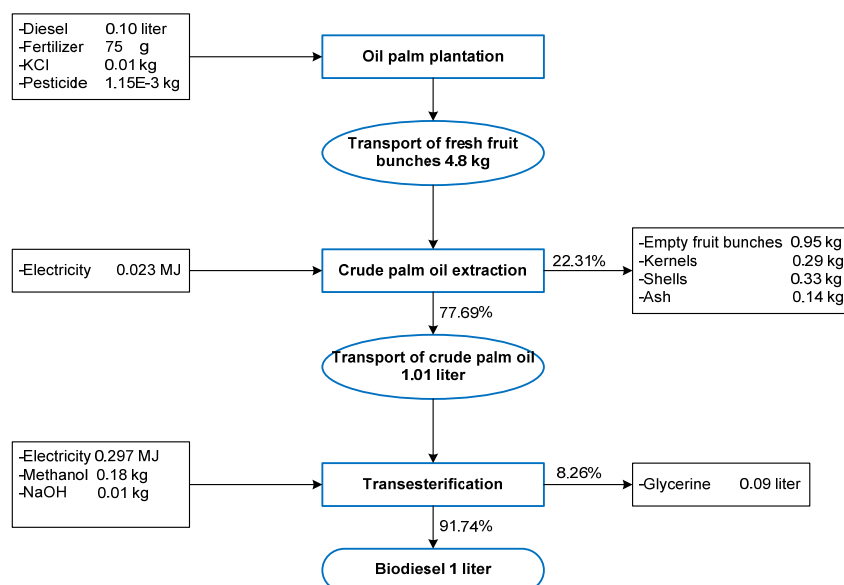

Figure 3 Life cycle inventory of biodiesel from palm oil

5. Results

The impact of midpoint and endpoint factors for selected greenhouse gases, comprise of important greenhouse gases from a total of 63 greenhouse gas emissions as shown in Table 1. The negative value substance means that it has a net cooling effect on a global temperature. Based on the midpoint approach, the global warming potential (GWP) and temperature factor (TF) are the same for any LCIA method that is based on the Intergovernmental Panel on Climate Change (IPCC) factor (Intergovernmental Panel on Climate Change, 2000). Based on an endpoint approach, the net primary productivity damage factors are 8.22×10^{12} and 2.55×10^5 kg·year/°C for the World and Thailand, respectively. The total NPP damage factor for the world and Thailand from all 63 greenhouse gas emissions are 8.78×10^5 and 2.72×10^{-2} kg/kg, respectively.

Table 1 Global warming factor of the midpoint and endpoint approach

Substance	Midpoint approach		Endpoint approach	
	GWP (kg CO_2 eq.)*	TF (°C·yr·kton^{-1})**	Net primary productivity (kg/kg)	
			World	Thailand
CO_2	1	4.17E-08	3.43E-01	1.06E-08
CH_4	25	1.21E-06	9.97E+00	3.09E-07
N_2O	298	1.36E-05	1.12E+02	3.46E-06
CFC-11	4750	-5.20E-05	-4.27E+02	-1.32E-05
CFC-12	10890	1.05E-04	8.63E+02	2.67E-05
CFC-13	14420	6.58E-04	5.41E+03	1.67E-04
CFC-113	6130	1.39E-04	1.14E+03	3.54E-05
CFC-114	10040	4.38E-04	3.60E+03	1.11E-04
CFC-115	7370	3.29E-04	2.70E+03	8.38E-05
HCFC-22	1810	6.67E-05	5.48E+02	1.70E-05
HFC-23	14760	6.74E-04	5.54E+03	1.72E-04
HFC-134a	1430	6.52E-05	5.36E+02	1.66E-05
HFC-152a	124	5.67E-06	4.66E+01	1.44E-06
Halon-1211	1890	-7.88E-04	-6.47E+03	-2.01E-04
Halon-1301	7140	-2.77E-03	-2.28E+04	-7.06E-04
SF_6	22810	9.65E-03	7.93E+04	2.46E-03

* Intergovernmental Panel on Climate Change, 2000
**De Schryver et al., 2009

The midpoint and endpoint indicators can be interpreted as the potential damage of primary production. Figure 4 shows the result that compared the global warming potential between diesel and biodiesel at each stage, based on the midpoint approach. Biodiesel has a higher GWP impact than that of diesel. The highest impact occurs during oil palm plantation because this stage uses intensive fertilization in the planting, which releases large amounts of CO_2 and N_2O substances. The total GWP emission of diesel and biodiesel are 0.58 and 1.61 kg CO_2 eq./liter, respectively. This result is consistent with other studies that used CML 2000 in SimaPro 7.1 program (Malakul et al., 2011), where the GWP from palm oil-based biodiesel is 1.42 kg CO_2 eq./liter.
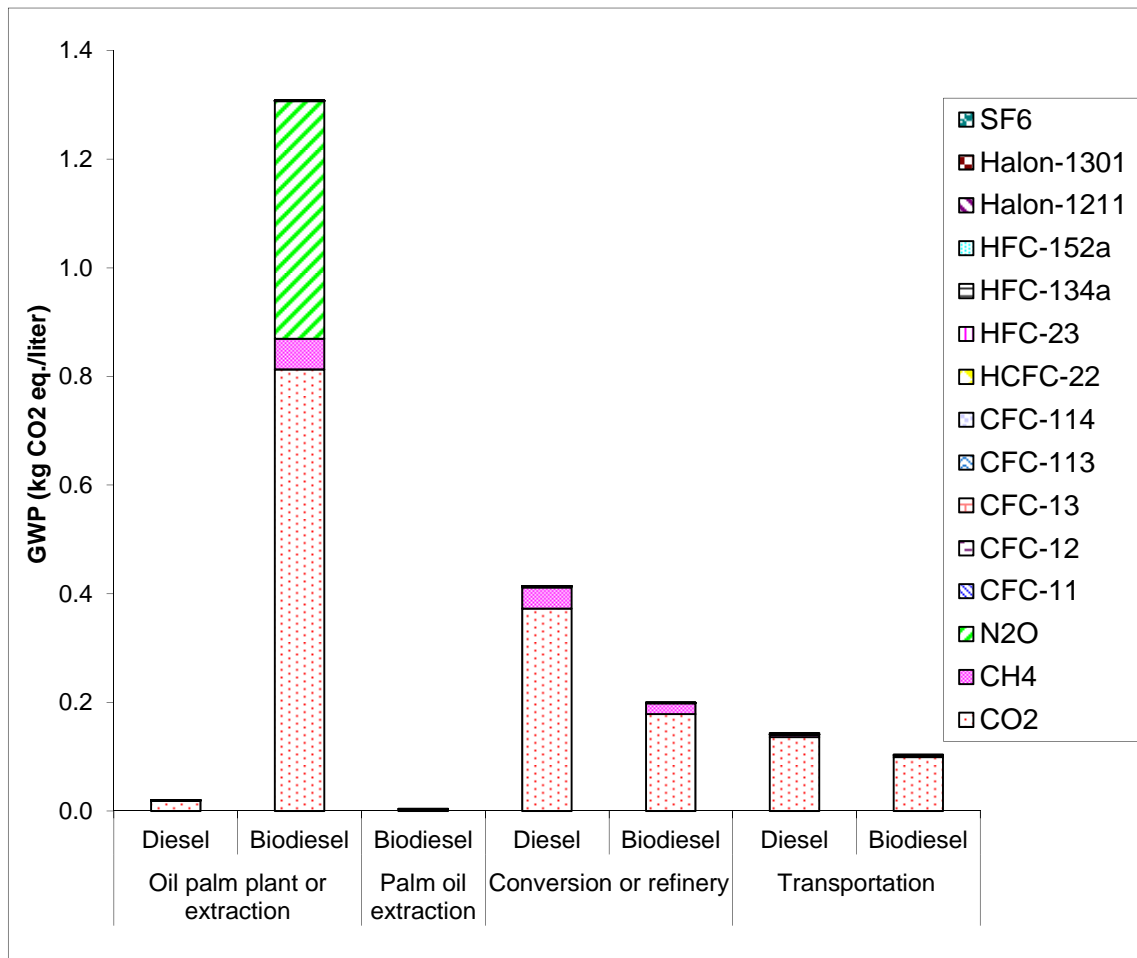
Figure 4 Comparison of global warming potential between diesel and biodiesel

Figure 5 and Figure 6 compare the global warming effect on net primary productivity (NPP) for the World and n Thailand, respectively. From both figures, the calculation based on the world's data revealed 7–8 times higher than Thai values.

This main reason for this difference is due to the forest area considering category endpoint. For Thailand, the impact occurs locally, the focus area that is considered to be smaller than the world.
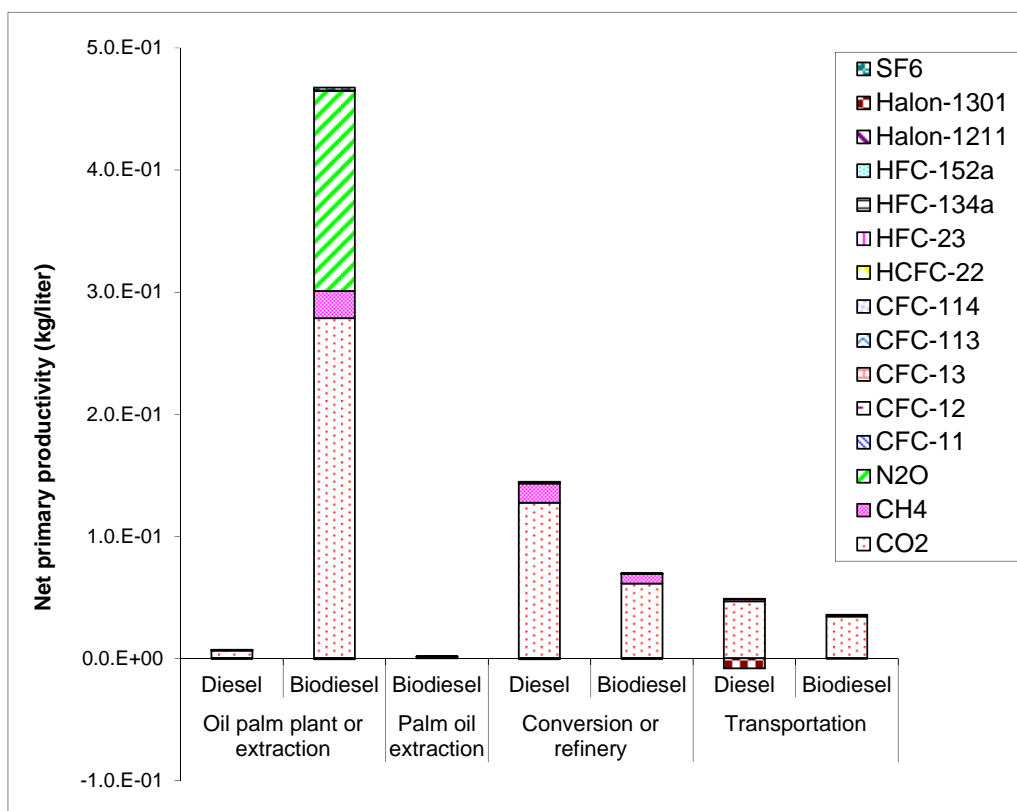
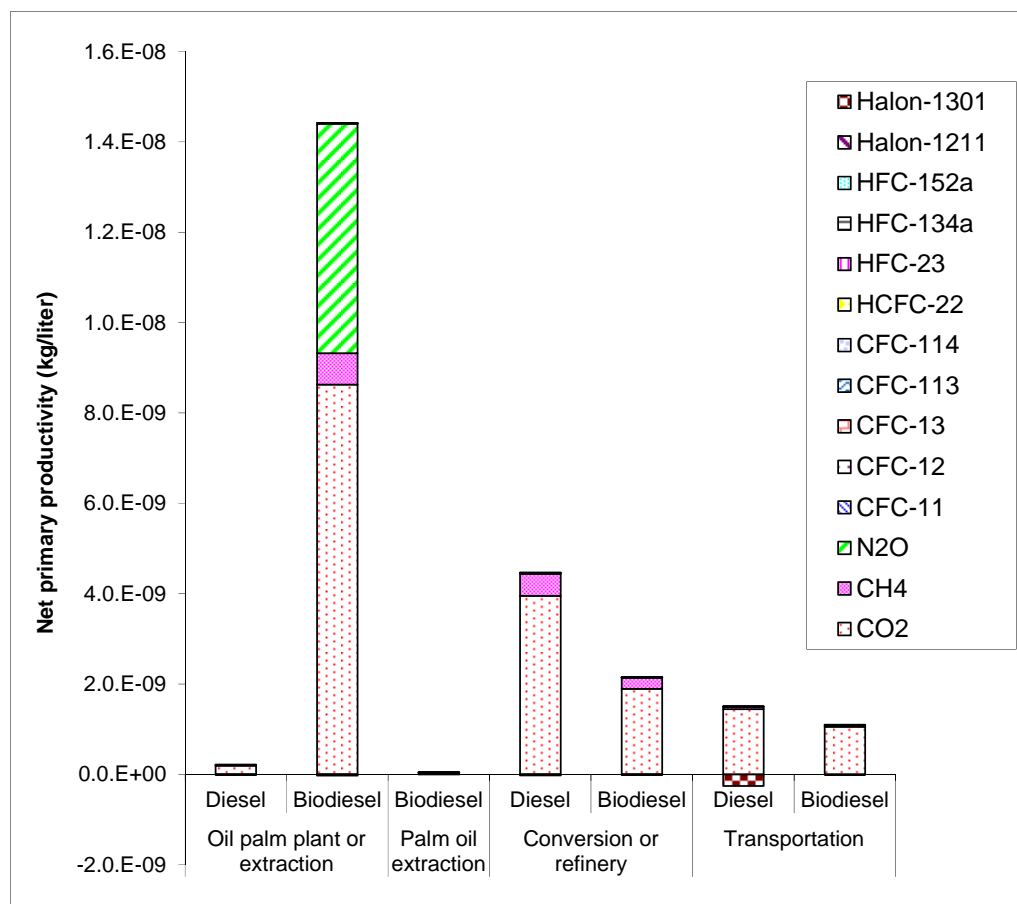**Figure 5** Comparison of the world's net primary productivity results between diesel and biodiesel

Figure 6 Comparison of Thailand net primary productivity results between diesel and biodiesel

6. Conclusion and recommendation

This study aims to analyze the effect of global warming which midpoint and endpoint damage factors. By using the endpoint factor, it was estimated that the global warming effect on net primary productivity (NPP) divided factors for the World and Thailand. When comparing the results, it was found that there were difference factors due to global warming is the global criteria but we tried to local criteria effect. Thus, in Thailand factors are smaller than the World factors. Other LCIA methods tried to evaluate the ozone layer depletion into regional areas, effects on human health that found the results were difference indicator by using refrigerator in case study (Itsubo and Inaba, 2001).

For a more general use of the model, first more data needs to be compared with other models and updated data caused by global warming effects. Additionally, global warming not only has an effect forest areas, but also agricultural areas where crops are gown. In future developments should be considered. On–going research for the affects of global warming on human health and social assets will allow further improvements of the models with the uncertainty analysis.

7. Acknowledgement

8. References

Andrae, A.S.G. 2010. Chapter3: Environmental Life Cycle Assessment from a LIME Perspective. In: **Global Life Cycle Impact Assessments of Material Shifts Global Life Cycle Impact Assessments of Material Shifts**. (p.23 – 58). London: Springer.

Bare, J.C. 2010. Life cycle impact assessment research developments and needs. **Clean Technologies Environmental Policy** 12: 341–351.

Boonpragob, K., and Santisirisomboon, J. 1996. Modeling potential change of forest area in Thailand under climate change. **Water Air and Soil Pollution** 92(1–2):107 – 117.

De Schryver, A.M., Brakkee, K.W., Goedkoop, M.J., and Huijbregts, M.A.J. 2009. Characterization factors for global warming in life cycle assessment based on damages to humans and ecosystems**. Environmental Science & Technology** 43 (6): 1689–1695.

Eco-invent. 2012. The Swiss Centre for Life Cycle Inventories, ecoinvent. [Online]. Available: http://www.ecoinvent.ch. [Accessed on 15 January 2012].

Intergovernmental Panel on Climate Change (IPCC). 2000. **Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories; Intergovernmental Panel on Climate Change, National Greenhouse Gas Inventories Programme** Montreal: IPCC–XVI.

Itsubo, N. and Inaba, A. 2001. Development of endpoint – type methodology of LCIA in Japan. In: **Environmentally Conscious Design and Inverse Manufacturing** (pp.826–831). Proceedings Ecodesign 2001 Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing.

Itsubo, N., Sakagami, M., Washida, T., Kokubu, K., and Inaba, A. 2004.

Weighting Across Safeguard Subjects for LCIA through the Application of Conjoint Analysis. **International Journal LCA** 9(3): 196–205.

Jiang, H., Apps, M.J., Zhang, Y., Peng, C., and Woodard, P.M., 1999. Modelling the spatial pattern of net primary productivity in Chinese forest. **Ecological Modelling** 122: 275 – 288.

Malakul, P., Papong, S., Chom-in, T., and Noksa-nga, S. 2011. Life-cycle energy and environmental analysis of biofuels production in Thailand. **Kasetsart Engineering Journal** 75 (24): 25–40.

Melillo, J.M., McGuire, A.D., Kicklighter, D.W., Moore lll, B., Vorosmarty, C.J., and Schloss, A.L. 1993. Global climate change and terrestrial net primary production. **Nature** 363: 234–240.

Papong, S., Chom-In, T., Noksa-nga, S., and Malakul, P. 2010. Life cycle energy efficiency and potentials of biodiesel production from palm oil in Thailand. **Energy Policy** 38: 226–233.

Pleanjai, S. and Gheewala S. H. 2009. Full chain energy analysis of biodiesel production from palm oil in Thailand. **Applied Energy** 86: S209–S214.

Sampattagul, S., Nutongkaew, P., and Kiatsiriroat, T. 2011. Life cycle assessment of palm oil biodiesel production in Thailand. **International Journal of Renewable Energy** 6(1): 1–13.

Sampattagul, S., et al. 2009. **Life cycle inventory database development of truck transportation.** Final report.

The European Standard EN ISO 14044. 2006. **Environmental management – Life cycle assessment – Requirements and guidelines.** ICS 13.020. 10; 13.020.60.